MANAGEMENT OF THE VASSE-WONNERUP WETLAND SYSTEM IN RELATION TO SUDDEN, MASS FISH DEATHS

A technical report prepared by:
J.A.K. Lane[1], K.A. Hardcastle[2], R.J. Tregonning[3] & G.J. Holtfreter[4]
on behalf of the
Vasse Estuary Technical Working Group

[1] WA Department of Conservation & Land Management
[2] Water & Rivers Commission of Western Australia
[3] Fisheries Western Australia
[4] Water Corporation of Western Australia

December 1997

CONTENTS

TABLES

FIGURES

APPENDICES

SUMMARY

The Vasse-Wonnerup wetland system extends from the centre of Busselton, 14 km north-east, parallel to the coast. The largest components are the Vasse and Wonnerup estuaries. These are 9 km and 5 km long, up to 0.6 km wide and generally less than 1 m deep even in winter. They discharge to the ocean via Wonnerup Inlet. The mouth of the Inlet is shallow and often closed by the formation of a sand bar, mainly during summer and autumn.

During the past 130 years the estuaries' catchments have been largely cleared of native vegetation to make way for agriculture, principally milk and beef production. Extensive drainage networks have been constructed and large quantities of fertilisers applied. Several of the rivers that formerly discharged into the estuaries have been diverted to the sea. In 1908 floodgates were installed on the estuaries' exit channels. These allow outflow but not inflow, thereby preventing seawater incursion and providing storage capacity for floodwaters.

These developments have greatly altered the water levels and water quality of the estuaries. Water levels now fluctuate dramatically during winter, are stabilised in spring and decline during summer. By autumn the broad expanses of both estuaries are dry. Some water is retained in the lowest reaches of the Vasse, principally in its exit channel. A very small volume is retained in the Wonnerup. During winter, spring and early summer the estuaries' waters are fresh-brackish. Remnant waters of late summer and autumn are saline due to the concentrating effects of evaporation and leakage past the gates. Both estuaries are highly enriched with nutrients, mainly of agricultural origin. These nutrients are responsible for the frequent development of algal blooms in the lowest reaches of the Vasse estuary during summer and autumn.

Vasse-Wonnerup is an outstanding habitat for waterbirds. Surveys during the 1980s revealed more than 30 000 birds of 60 species. Eighty-five species have been recorded in total. Many are migrants from other parts of Australia and from the northern hemisphere. In June 1990 Vasse-Wonnerup was listed under the Ramsar Convention as a Wetland of International Importance. As a Contracting Party to Ramsar, Australia has undertaken to conserve its listed sites and wisely manage wetlands generally.

In March 1997 community concern about sudden, mass fish deaths in the Vasse estuary exit channel, death of fringing vegetation, loss of pasture production on adjoining lands and a possible decline in use of the estuary by waterbirds, led to a meeting of government agencies. At that meeting a technical working group was formed to consider these issues.

In this report the Vasse Estuary Technical Working Group reviews the history of management of the Wonnerup Inlet sand bar and Vasse and Wonnerup estuary floodgates; documents changes that have occurred to water levels and water quality; presents a history of fish deaths and measures previously taken to prevent them, discusses management options and makes a number of recommendations aimed at reducing the incidence of fish deaths in an environmentally-acceptable manner.

The Working Group's investigations have revealed a long history of sudden, mass fish deaths in the lower reaches of Vasse-Wonnerup. Many fish were reported dead in February 1905. Further kills occurred between then and 1960, however the dates of these are not known. Since 1960 mass deaths have occurred in 1966, 1988, 1989 and 1997. All reported kills have been in the lower reaches of the system, either in the Vasse estuary exit channel or in Wonnerup Inlet or, on one occasion, in the Deadwater. Most have occurred during summer, usually in February and often following hot weather.

The principal cause of summer deaths is believed to be temporary declines in dissolved oxygen concentrations to critical levels. These declines are thought to be due primarily to night-time respiration by algal blooms, algal bloom decay and high water temperatures. Toxic products of algal blooms and (Wonnerup Inlet only) decaying seaweed might also be involved.

Three measures have been used in the past in efforts to reduce the frequency and severity of fish kills - artificial opening of the sand bar, increased harvesting of fish by netting, and partial opening of the Vasse estuary floodgates to allow fish to escape and to raise water levels.

During the early 1900s it was apparently normal practice to keep the sand bar open during summer. When this work ceased temporarily during the summer of 1904-05 thousands of fish died. Artificial openings were resumed soon afterwards. In recent years it has been difficult to keep the bar open. In February 1988, for example, several attempts were made and on each occasion it closed within a few hours. Experience suggests that summer openings of the bar are effective in preventing fish kills in Wonnerup Inlet and can also assist efforts to prevent deaths in the Vasse estuary exit channel.

The entire Vasse-Wonnerup system was opened to net fishing in 1960 in order to reduce the number of fish that might otherwise die during summer. A ban on the use of nets in Wonnerup Inlet has been reinstated, however the Vasse and Wonnerup estuaries remain open to the use of nets by commercial fishermen. While netting does not appear to prevent kills from occurring, at least in the Vasse, it has undoubtedly reduced, perhaps substantially, the number of fish that have died during such incidents.

When thousands of fish died in February 1988, the WA Water Authority opened the Vasse estuary floodgates in an attempt to improve water quality in the lowest reaches of the system and to allow free movement of fish. This was the first time that opening of the gates during summer had been agreed to since their installation. In March 1988 the Water Authority sought landholder, government agency and community views on an appropriate water level to be retained in the Vasse estuary during summer-autumn. After consideration of responses a level of -0.1 m AHD (Australian Height Datum) was adopted. This level was not to be exceeded due to the likelihood of salt damage to adjoining properties. Prior to 1988 the water level declined in autumn of most years to around -0.4 m AHD. In August 1990 a revised set of guidelines for operation of the floodgates was prepared. This formalised adoption of -0.1 m AHD as the level to be retained in Vasse estuary during late summer-autumn.

Summer-autumn openings of the floodgates have produced mixed results. On one occasion when the gates were opened for just eight hours, fish deaths were prevented. On other occasions the gates have been open for longer periods and deaths have occurred. The relationship between mass death incidents and water levels is also unclear. In February 1997 a kill occurred when the water level was +0.12 m, yet a kill did not occur in summer-autumn of 1994-95 when the level was around -0.1 m. In recent years the Vasse estuary floodgates have been opened for longer periods than originally envisaged and the water level in late summer-autumn has risen as high as +0.3 m AHD.

Melaleucas and eucalypts fringing the Vasse estuary are dying. Salt is appearing in paddocks adjacent to the estuary and hay production has apparently declined. This is not surprising given the rise of up to 0.7 m in water levels in late summer-autumn of recent years and the high salinity of these waters. Raising water levels by allowing seawater to enter also has the potential to impact adversely on at least some species of waterbirds. There have not been sufficient counts since 1988 to determine the impact of floodgate openings on bird numbers. Regular surveys are needed.

Fish kills are not a frequent occurrence in Vasse-Wonnerup. They do, however, attract considerable media and community interest when they occur. Over the years many "solutions" have been put forward. With the exception of opening of the sand bar, netting of fish and partial openings of the floodgates these ideas have not been pursued. Most would cause other, potentially greater problems or would be very costly to implement. Others would require expensive investigation before their benefits could be determined. Efforts are being made to reduce nutrient inputs to the wetland system. This work is fundamentally important and an essential part of any long term solution, however it is unlikely to reduce the incidence of kills in the short to medium term. Additional measures are needed.

During 1997 the Working Group has reviewed measures suggested or attempted in the past and has developed additional proposals. Measures proposed for implementation in 1997-98 are as follows: artificial openings of the sand bar during summer-autumn; implementation of a fish & water quality monitoring program; refinement of the 1990 guidelines for operation of the floodgates, and planting of native vegetation on the banks of the Vasse estuary exit channel to shade its waters. Several other measures are proposed for investigation in the event that measures initiated in 1997-98 prove unsuccessful. The Working Group also recommends establishment of a monitoring program to assess trends in health of fringing vegetation and counts to assess current use of Vasse estuary by waterbirds.

1. BACKGROUND

In March 1997, community and government agency concerns about the incidence of sudden, mass fish deaths in the lower reaches of the Vasse-Wonnerup wetland system, the death of vegetation fringing the Vasse estuary, loss of pasture production on adjoining land, and a possible decline in the number of waterbirds using the estuary led to a meeting of representatives of State government agencies and the Busselton Shire.

At that meeting it was agreed that the organisations represented would work together to investigate the issues that had been raised and to identify acceptable ways of attempting to resolve them. A technical working group with representatives from each agency was formed to undertake these investigations and to prepare a report for consideration prior to the 1997-98 summer.

At a subsequent meeting it was resolved that during 1997 the working group would focus its attention on the fish kill issue. The issues of death of fringing vegetation, loss of pasture production and possible declines in waterbird numbers - all of which were believed to be due to adverse effects of recent attempts to prevent fish deaths - would be addressed in this context. This would make the work load more manageable.

2. SCOPE OF THIS REPORT

This report is focussed primarily on the issue of sudden, mass deaths of fish in the lower reaches of the Vasse-Wonnerup wetland system near Busselton, Western Australia.

The report:

- describes the principal features and values of the system;
- provides a history of management of water levels and water quality of the system. In particular, the role of the floodgates and the influence of the sand bar at the mouth of the system are discussed;
- describes all of the sudden, mass fish death incidents or "kills" known to have occurred in this system and the suggested causes of each;
- describes the effectiveness or otherwise of measures previously taken to prevent fish kills, and some associated environmental impacts;
- discusses a range of options for dealing with the fish kill problem, and
- recommends various measures aimed at reducing the incidence of kills in an environmentally-acceptable and affordable manner.

Consideration of the full range of issues involved in management of the wetland system and maintenance of its values is beyond the scope of this report. This would best be achieved through preparation of a single statutory management plan. Preparation of such a plan has been proposed but will take several years to achieve. In the meantime action is needed in relation to the fish kill issue.

This report does not consider in any detail catchment management issues such as the current high level of nutrient inputs into the system. These issues are to be addressed through Land Conservation District Committees and the newly-constituted catchment coordinating body, GeoCatch.

This report has been prepared by the Vasse Estuary Technical Working Group for consideration and follow-up action by the working group's parent agencies (Agriculture WA, Busselton Shire Council, Department of Conservation & Land Management, Fisheries WA, GeoCatch, Water Corporation, Water & Rivers Commission).

3. THE WETLAND SYSTEM

3.1 Description

The Vasse-Wonnerup wetland system extends in a north-easterly direction from the centre of Busselton to Forrest Beach, a distance of 14 km. Its principal components are the Vasse and Wonnerup estuaries and their floodplains, Wonnerup Inlet, the Deadwater, "Swan Lake" and the lowest reaches of the Vasse, Sabina, Abba and Ludlow Rivers. When the estuaries are in full flood during winter they are narrowly connected by Malbup Creek (Figure 1).

3.2 *River diversions and installation of the floodgates*

Flows into and out of the Vasse-Wonnerup system have been dramatically altered since european settlement began in this district in the late 1830s.

At the time of first settlement, Vasse estuary received direct inflow from the Abba, Sabina and Vasse Rivers and indirect inflow from Iron Stone Gully, Buayanyup River, Carbanup River and other creeks further to the west. The latter group of rivers and creeks flowed into the Broadwater - New River system which emptied into the Vasse. Wonnerup estuary received inflow from the Capel and Ludlow Rivers. Of all these rivers the Capel was the most substantial.

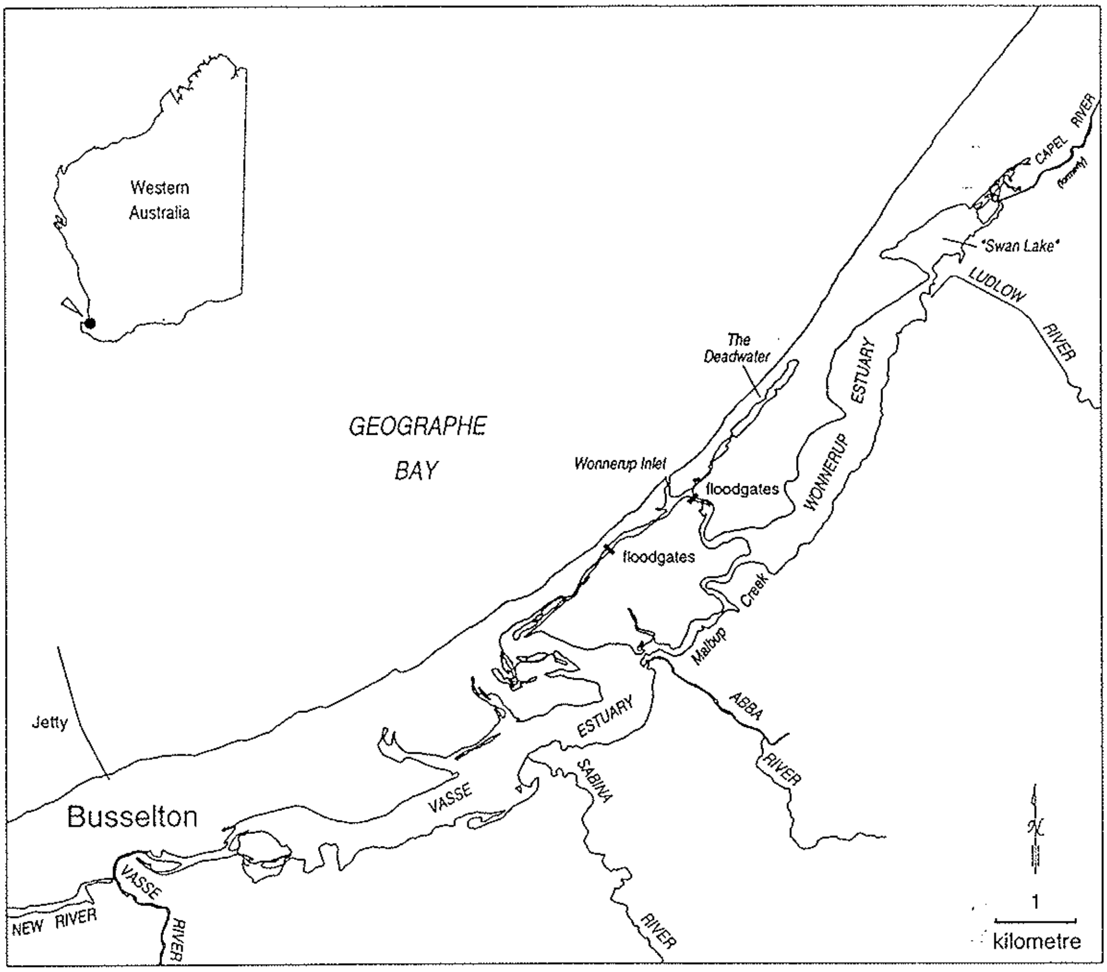


Figure 1. The Vasse-Wonnerup wetland system.

Some time during the 1880s, the Capel River was diverted to the ocean via Higgins Cut, 5 km to the north-east of Wonnerup estuary. In 1908 floodgates were installed on the exit channels of both estuaries, thereby preventing the entry of seawater. In 1915 a cut was made to drain water from New River to the ocean, thereby reducing its input to the Vasse. In previous years similar cuts had been made connecting other watercourses west of Busselton to the sea.

During the 1920s extensive drainage networks were constructed in the Ludlow, Abba, Sabina, Vasse, Iron Stone Gully, Buayanyup and Carbanup River catchments. These works increased the rate and volume of river flows. Additional works were then needed to prevent more-frequent flooding of farms and other developments, including the townsite of Busselton, located on low-lying land near the coast. In 1927 a major drain was constructed diverting the headwaters of the Sabina and virtually all of the

Vasse River's flow direct to the ocean. Soon afterwards Iron Stone Gully and the Buayanyup and Carbanup Rivers were also diverted to the sea.

3.3 Depths, salinities and nutrients

The broad expanses of the Vasse and Wonnerup estuaries fill to a maximum depth of around one metre during winter. The estuaries' exit channels are deeper, around two metres.

Floodgates (one-way flow structures) installed on the exit channels of the two estuaries in 1908 changed these waterbodies from estuarine to predominantly fresh-brackish ecosystems with most of their beds drying each summer. Since 1988 increasing amounts of seawater have been allowed back into the Vasse estuary during summer and autumn, thus inundating its broad expanses with saline to hypersaline water for up to five months of each year.

Fertilisers are used extensively in the Vasse-Wonnerup catchment. Fertiliser losses, livestock wastes and drainage from the Busselton townsite have dramatically increased nutrient inputs to the estuary during the past 160 years. The estuaries' waters are now highly nutrient-enriched.

For more detailed information concerning water levels and water quality of the Vasse and Wonnerup estuaries readers are referred to Section 5 of this report.

3.4 Nature conservation, flood mitigation and other values

The Vasse-Wonnerup wetland system is known principally for its birdlife. Surveys during the mid 1980s revealed more than 30 000 waterbirds of 60 species each year. Eighty-five species have been recorded in total. On this basis Vasse-Wonnerup was listed in June 1990 as a Wetland of International Importance under the Ramsar Convention. The system is also listed on the Register of the National Estate.

Vasse and Wonnerup estuaries were used by large numbers of waterbirds during the mid 1980s because their waters were extensive, shallow, undisturbed, nutrient-enriched, predominantly fresh-brackish and slowly dried out during summer. As waters retreated, vast food resources became available for a wide variety of species (Lane 1990).

Vasse-Wonnerup is locally significant as a habitat for fish such as mullet and bream. Commercial fishermen net the lower reaches of the estuaries during winter, spring and early summer. Significant recreational fishing activity occurs along the banks of Wonnerup Inlet, the Deadwater and the Vasse estuary exit channel.

The estuaries are fringed by saltmarshes, sedges, paperbarks and eucalypts. These plant communities have significant nature conservation, landscape and aesthetic values.

The estuaries have a vitally important role in flood protection. The floodgates on their exit channels enable water levels to be lowered during winter, thereby providing vital storage capacity for river floodwaters when high sea levels prevent their discharge to the ocean. The floodgates also prevent most[1] storm surges (large rises in sea level due to strong northerly winds and low barometric pressures) from flooding low-lying land adjacent to the estuaries and in Busselton.

3.5 Land ownership and management responsibility

Land ownership of Vasse-Wonnerup is diverse. The open waters of the Vasse and Wonnerup estuaries are mostly vacant Crown land. Some adjoining lands are within conservation reserves managed by the Department of Conservation and Land Management (CALM). Smaller areas are within recreation reserves managed by the Busselton Shire. Most of the remaining lands are privately owned. There is a grazing lease over a large portion of Wonnerup estuary.

[1] The floodgates are overtopped at +1.65 m AHD (Australian Height Datum). This has happened on several occasions. Sea level rose to +1.94 m AHD in February 1937 due to an un-named cyclone; +1.79 m in April 1978 due to Cyclone Alby and +1.70 m in April 1991 due to the influence of Cyclone Fifi. In June 1919 the original floodgates were overtopped; on this occasion during a severe winter storm.

Several State government agencies have responsibilities that are relevant to management of the system. The Water Corporation owns the estuary floodgates and is responsible for their maintenance and operation, the Water & Rivers Commission has a general responsibility for the health of waterways and Fisheries Western Australia is responsible for managing fish resources. In addition to its land management responsibilities, CALM has responsibility for implementation of the Ramsar Convention and international migratory bird agreements in Western Australia and has a general responsibility for nature conservation throughout the State.

The Busselton Shire Council has an interest arising from its general responsibility for the health and welfare of local residents. Shire land-use planning decisions can also impact on the wetlands.

Two Commonwealth Government instrumentalities, Environment Australia and the Australian Heritage Commission, have statutory responsibilities related to maintenance of the nature conservation values of the estuaries owing to their listing under the Ramsar Convention and the Register of the National Estate and their use by migratory birds.

A management plan is proposed for the Vasse and Wonnerup estuaries and adjoining nature reserves. CALM has been designated lead agency to coordinate its preparation in consultation with other agencies, landholders and the broader community. It is envisaged that this work will commence following reservation of vacant Crown land portions of the estuaries as nature reserves. This is expected to occur during 1998.

4. THE SAND BAR AND THE FLOODGATES

The sand bar at the mouth of Wonnerup Inlet and the floodgates on the exit channels of the Vasse and Wonnerup estuaries have major determining influences on the hydrology and ecology of the Vasse-Wonnerup wetland system. Attempts to resolve the fish kill issue in an environmentally-acceptable manner require an understanding of the behaviour of the bar, the purpose and operation of the floodgates and the influence of both on the system.

4.1 Sand bar at the mouth of Wonnerup Inlet

The Vasse and Wonnerup estuaries empty to the sea via Wonnerup Inlet (Figure 2). At the mouth of the Inlet is a shallow bar formed by the easterly drift of coastal sand. The bar is kept open for varying periods (days, weeks or months) each year by discharge from the estuaries during winter-spring and tidal exchange between the Inlet and the sea.

At times the bar closes, preventing flow in either direction. This may occur at any time of the year depending upon sea conditions, tide heights and the rate of discharge from the estuaries. Re-opening of the bar may occur naturally as a result of changes in sea conditions or an increase in river flows. One or more times each year the bar is opened artificially. Nowadays this is usually done by means of a backhoe or hydraulic excavator.

Occasionally a seaweed bar may be formed by heavy seas dumping large amounts of uprooted seagrass and marine macroalgae across the mouth of the Inlet. This is most likely to happen during severe winter storms. In former times if the entrance was closed by seaweed it had to be opened manually using pitch forks. Machinery was unsuitable for the task.

The mouth of Wonnerup Inlet has been narrow and shallow since at least 1829. At one time there were two entrances a few hundred metres apart (see Appendix 1). One of these (the westernmost) closed over late last century and is now vegetated. The other has migrated a little further east and is now the only opening to the sea.

The existence of a bar at the mouth of Wonnerup Inlet is not unusual. Several other estuaries in south-western Australia have sand bars that open and close each year.

4.2 Management of the sand bar

The sand bar at the mouth of Wonnerup Inlet has been opened and closed artificially on many occasions. When this practice began is unclear. The earliest reference to artificial openings found during preparation of this report is from 1905. A local resident was apparently contracted by the government "for the keeping open of a cut sufficient to allow the sea water at high tide to enter the mouth, and so flush the estuary". When this work began is not known, however it was apparently carried out "for some time". Shortly prior to February 1905 this work was discontinued, the bar soon closed and thousands of fish subsequently died in the lower reaches of the Vasse estuary (*The South-Western News, February 3, 1905;* see Appendix 6).

The next record found is from 1919. Early in December of that year the bar closed. Attempts were made to open it, but these proved unsuccessful. District Engineer A.E. Arney observed that this was the first time since the estuary floodgates were installed that the bar had "given any trouble". Repairs to the Wonnerup estuary floodgates were being undertaken at the time *(Public Works Dept file 930/18 folios 53, 54).*

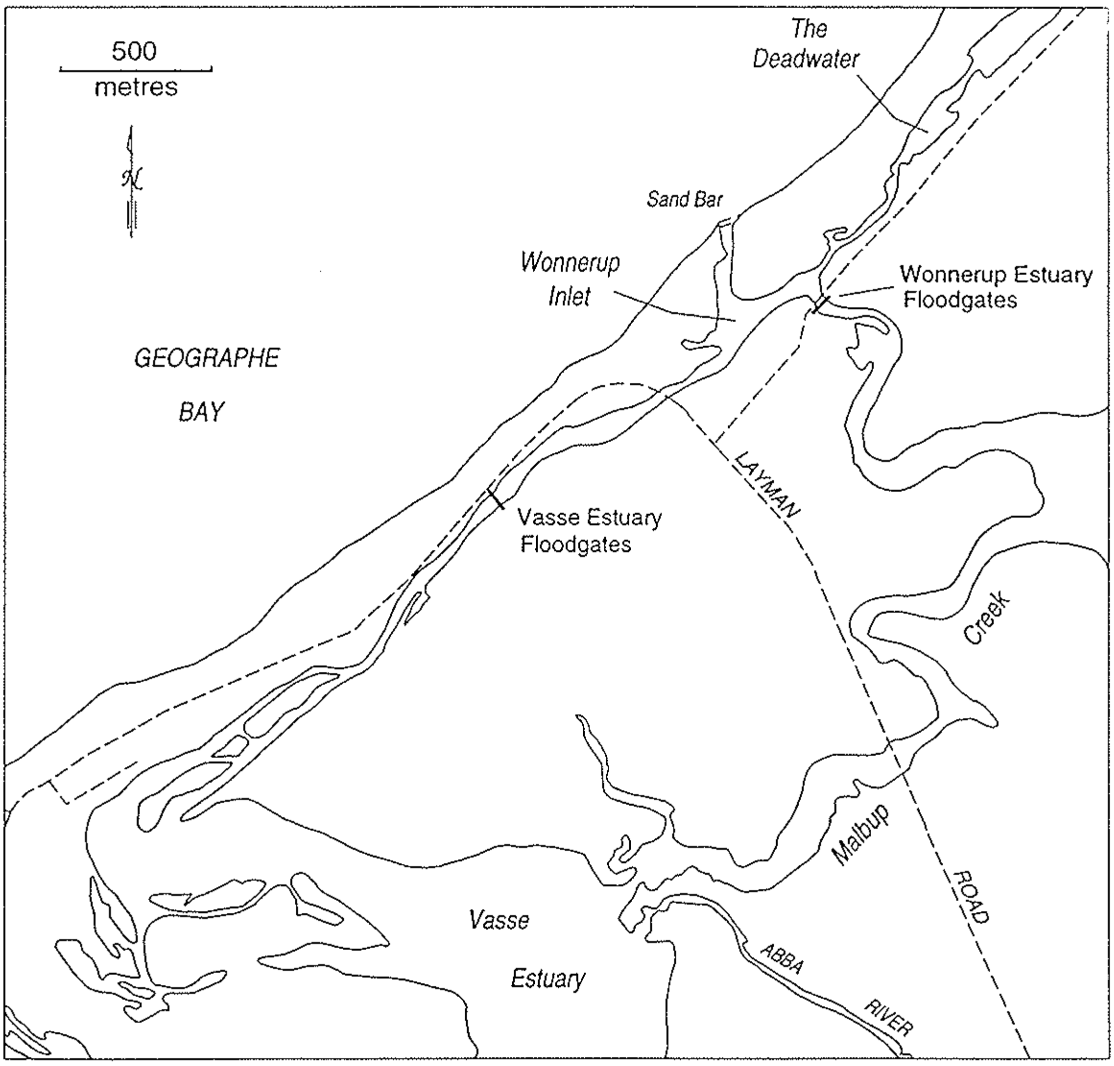


Figure 2. Lower reaches of the Vasse-Wonnerup wetland system.

Further difficulties were experienced in 1928. In mid July of that year the rivers flowed strongly and because the bar was closed the water level in the estuaries rose markedly. Low-lying lands were flooded. Attempts were made to open the bar "for the first time for the season" but were unsuccessful due to northerly winds and rough seas. On 23 July the bar was finally opened and within four days the water level was down to normal, but not before it had reached RL[2] 105.60 ft (0.80 m AHD[3]). During

[2] RL (Relative Level) was a local datum established during early settlement of the Busselton area. RL 100 ft is understood to have been 2.97 ft (0.905 m) below 0.0 m AHD (Australian Height Datum).

the next two months the bar re-formed several times but was opened on each occasion without further flooding occurring. These problems had apparently not been experienced during the previous year when "owing to the absence of northerly winds the estuary was very low and gave no trouble at all" *(PWD 930/18 f 132)*.

In 1928, it was requested by landowners that a drain be constructed to take the waters of the Abba River direct to the sea at a point between the two sets of floodgates. Discharge of river flows directly into the confined area between the floodgates and the mouth of Wonnerup Inlet would have ensured that the bar breached soon after river flow began and would have further reduced flooding of the estuaries *(PWD 930/18 f 123)*. The proposal was not agreed to by government because of the cost involved.

Commencing in the early 1930s, the sand bar was artificially closed at the end of each winter in order to raise the water level in the estuaries during spring and thereby prevent adjoining farmland from drying too early in summer *(PWD 139/40 f 18)*. This practice was presumably discontinued in 1942 when provision was made at the floodgates to achieve the same result by means of removable stop boards (see section 4.6).

How frequently the bar has had to be manually or mechanically opened since 1928 is unclear. From the references that have been found it appears likely that it was an annual event in winter and that in many years it had to be opened on more than one occasion. A Public Works Department memorandum of November 1940 indicates that it was normal policy at that time to open the bar when waters reached RL 105.00 (0.62 m AHD) in winter *(PWD 139/40 f 72)*. In July 1989 the water level in the estuary rose to +0.80 m AHD before the sand bar was successfully opened.

During the past decade or so the bar has occasionally been opened during summer. In February 1988 attempts were made to open the bar to save fish that were dying in Wonnerup Inlet, however these proved unsuccessful (see section 7.2). Within hours of the bar being opened it closed again due to the continuous movement of sand.

The "Update to Hand Book of Basic Data" prepared by the WA Water Authority in August 1990 (see Appendix 2 for full text) reads as follows with respect to management of the sand bar during winter.

> "Due to the fact that the ocean outlet ... will block easily, it may be necessary to open this bar by mechanical means on several occasions throughout the winter. Experience has shown that to attempt to open the bar without sufficient head is a waste of time, and the gauge board at the Vasse floodgate should attain a reading of at least 0.7 m AHD, or the attempt will probably fail ..."

The current winter practice is for the bar to be opened at the beginning of the season by a local contractor employed by the Water Corporation.

Concerning summer openings the 1990 Handbook reads:

> "In the event of the sand bar being closed and no water available to come back *(to maintain a level of -0.1 m AHD upstream of the Vasse estuary floodgates)*, a decision to open the sand bar must be made in conjunction with the Regional Operations Engineer as a matter of urgency".

In the context of efforts to prevent or minimise fish kills in the lower reaches of the Vasse-Wonnerup system it is important to note that the quality of water in Wonnerup Inlet is greatly affected by the state of the sand bar. When the bar is closed there is no tidal exchange with the sea and during summer-autumn the water quality in the Inlet may rapidly deteriorate (see section 8.2). At times it may be worse than the quality of water in the Vasse estuary exit channel. This has implications for prevention of fish deaths upstream of the floodgates as well as within Wonnerup Inlet itself.

---

[3] AHD (Australian Height Datum) is a national benchmark level and is roughly equivalent to mean sea level, which varies seasonally

4.3 *Installation of the Vasse and Wonnerup estuary floodgates*

Floodgates were first installed on the Vasse and Wonnerup estuaries in 1908. They were built at the same locations as the present floodgates and were attached to road bridges existing at that time.

The floodgates operated automatically, as they do now. When the water level is higher on the upstream side the gates swing open and estuary waters discharge. When the level is higher on the downstream side the gates close, preventing the entry of seawater.

The sill height of both sets of gates was RL 103 ft (+0.01 metres AHD) *(PWD 139/40 f 16)*. This was the minimum level to which the estuaries' waters could be lowered by discharge through the gates, though further lowering did occur each summer-autumn due to evaporation.

4.4 *Effects of the floodgates*

Installation of the floodgates had three major effects.

Firstly, sea water was prevented from entering the estuaries at any time of the year. Prior to installation of the gates, seawater entered the estuaries during each summer-autumn dry season and mixed with the fresh waters discharged by the rivers. Installation of the floodgates prevented this annual increase in salinity. After installation of the 1908 floodgates, estuary waters would have been fresh-brackish for much of the year. Only in late summer and autumn, when the broad expanses of the estuaries were dry, would remnant waters in their exit channels have become moderately saline, due to evapo-concentration and leakage past the gates.

Secondly, the water levels in the estuaries were lowered throughout most of the year. Water still flowed out of the system whenever the water level in Wonnerup Inlet was lower than in the estuaries, for example at low tide. However, return of water, for example at high tide, was prevented. Some winter flooding still occurred, however it was of shorter duration and usually to a lower level than previously. During summer and autumn evaporative losses caused estuary water levels to decline even further, below the +0.01 m AHD sill level of the gates.

Thirdly, most of the beds of both estuaries dried completely each year. Prior to installation of the gates this could conceivably have occurred on very rare occasions when sand bar formation at the mouth was followed by severe and prolonged drought. Following installation of the gates, drying of the beds became an annual event, with permanent water restricted to the estuaries' lowest reaches.

Installation of the floodgates was considered at the time to be very successful in achieving the following:

- reduced flooding of low-lying land in and near Busselton townsite.
- reduced inundation and waterlogging of low-lying land adjacent to the estuaries during winter and spring, thereby enabling crops and pasture to be grown in areas that would otherwise be too wet.
- prevention of inundation and waterlogging of low-lying land with seawater during summer and autumn, thereby enabling crops and pasture to be grown on land that would otherwise be too saline.

4.5 *Calls for repairs to the floodgates*

In autumn 1926, following expressions of concern by landholders about the condition of the floodgates, a detailed inspection was made by the Public Works Department. The Vasse estuary bridge-and-gate structure was reported to be nearing the end of its life and in need of complete renewal within a few years. Leakage was occurring through and around the gates and under the sill. The Wonnerup estuary structure was reported to be in very bad order. Its replacement was also recommended *(PWD 930/18 f 105)*.

In September 1927 landholders petitioned the Government to urgently repair the floodgates to prevent sea water from passing through and causing "much damage to several hundred acres of land". The petitioners also requested that the sills of the floodgates be lowered by about 15 inches (0.38 m) "which would help reclaim more land, as at present the sill is one foot seven inches (*0.48 m*) above low water which causes unnecessary flooding" *(PWD 930/18 f 107)*.

Further representations were made by landholders in February 1928. It was stated that sea water was getting through the floodgates and that "if the gates broke down altogether a very large area of land extending almost into the town of Busselton would again be flooded, as it was before the gates were constructed, so destroying a valuable area of grazing land". In May 1928, owners of land at the far western end of the Vasse estuary, "about 3.5 miles (*c. 5.8 km*) from the floodgates", made a further request for action to be taken as "the salt water was spreading over their low-lying ground and if the high tides continue it will be over their crops" *(PWD 930/18 f 119, 121)*.

In September 1928 it was requested that in addition to repairs being undertaken, the sills of the floodgates be lowered "from 20 inches to 2 ft (*0.51-0.61 m*) to enable the water to get away quicker when the sea is low" *(PWD 930/18 f 135)*.

4.6 Replacement floodgates installed

Ministerial approval was given in December 1928 for the Vasse and Wonnerup estuary floodgates to be replaced. The work was completed in 1929. The sills of both sets of gates were lowered by 1 ft 6 inches (0.46 m) to RL 101.50 ft (-0.45 m AHD) *(PWD 139/40 f 5-7)*.

For several years after construction of the new gates, landowners expressed satisfaction with the results obtained from lowering of the sills. Subsequently their views changed and at the end of each winter the sandbar at the mouth of Wonnerup Inlet was closed in order to raise the water level in the estuaries in spring. This was to prevent their land from drying too early in summer

Artificial closure of the bar proved to be an unsatisfactory method of holding back water in the estuaries however, and in 1938 it was requested by landowners that suitable provision be made at the floodgates *(PWD 139/40 f 1)*.

4.7 Seasonal installation of stop boards

In 1942, following several years of debate about an appropriate level, the floodgates were modified so that four removable stop boards could be added to each opening. This modification enabled estuary water levels to be raised up to 2 ft 6 ins (0.76 m) above sill level. This was to be done at the end of winter or in spring, when river flows began to subside. In October 1942 the boards were set 1 ft 4 ins (0.41 m) above the sills. In October of the following year they were set at 2 ft (0.61 m) above sill height. In September 1944 all four boards were put in place, raising the level 2 ft 6 ins (0.76 m) to RL 104 ft (+0.31 m AHD), as originally requested by most landowners *(PWD 139/40 f 133)*.

The practice of installing stop boards at the end of each winter or in spring in order to retain water for a longer period each summer has continued to the present day. Records have been found confirming installation each year from 1942 until 1957 *(PWD 139/40 f 134-51)*. It is also known for certain that boards have been installed each year since the late 1960s (G. Holtfreter, pers. comm.). The number of boards installed each year from 1945 until the mid 1980s and the dates of installation are not known for certain. However it seems likely that all boards were used (though perhaps in some years they were not all installed simultaneously) and that they were usually installed in September or early October[4].

In the early to mid 1980s , the Water Authority attempted to maintain a constant water level of +0.4 m AHD in the Vasse and Wonnerup estuaries for two months or so after first installation of the boards. This was done to create more favourable nesting conditions for Black Swans *Cygnus atratus*. Nests and eggs were being flooded when levels rose too high. Introduced foxes *Vulpes vulpes* were gaining access to nest mounds and their contents when levels fell too low. Stabilisation of levels was to be achieved by frequent removal and replacement of the top-most boards. This practice was discontinued after four years or so because it proved to be too time consuming (G. Holtfreter, pers. comm.).

In 1986 the Vasse estuary floodgate boards were installed on 26 September. In 1988 they were installed earlier, on 6 or 7 September.

[4] Due to time constraints, not all Water Corporation records of dates of board installation have been accessed during preparation of this report. Compilation of those records would assist future management of the wetlands and is therefore recommended.

4.8 Opening of the Vasse estuary floodgates in summer-autumn

For the first 80 years of operation the Vasse and Wonnerup estuary floodgates remained closed throughout summer and autumn of each year in order to prevent seawater incursion.

In February 1988, following a major fish kill in Wonnerup Inlet (see section 7.2), the Water Authority wedged open one of the Vasse estuary floodgates. Attempts were also made to open the sand bar at the mouth of Wonnerup Inlet, however these proved unsuccessful. The single gate remained wedged open 25 mm until some time after 15 March *(PWD file 27-01-04)*.

At the beginning of February 1989 a single gate was again wedged open in an attempt to prevent and then, when this proved unsuccessful, to minimise a fish kill incident. Eight days later the gate was closed due to landowners concerns about the potential impacts of seawater on their properties. The water level had risen to -0.095 m AHD *(PWD 27-01-04)*.

The floodgates were opened again the following summer, from 18 December 1989 until 3 March 1990, when they were closed due to the approach of a cyclone. Initially only one gate was opened, but on 15 January 1990 the number was increased to two. These openings caused the water level to rise higher than during the previous summer. At the beginning of January the level was +0.10 m AHD. More complaints were received from landholders about damage to property. Concern was also expressed about the death of native vegetation fringing the estuary *(PWD 27-01-04)*.

In August 1990 the Water Authority prepared a revised set of operational guidelines for the floodgates and sand bar. These incorporated measures aimed at preventing fish kills without causing damage to adjoining properties. These guidelines, presented in full in Appendix 2, provide for opening of the Vasse estuary floodgates if fish show signs of stress. They also provide for maintenance of a summer-autumn water level of -0.1 m AHD. The guidelines emphasise that "under no circumstances should salt water be allowed to come back behind the gates to allow the levels to become higher than -0.1 m AHD". This level was based on the previous two and a half years of experience with gate openings and was considered to be the maximum water level that could be maintained in the estuary during summer-autumn without adverse impacts on adjoining properties.

The practice of partially opening the Vasse estuary floodgates for varying periods each summer-autumn has continued since 1990. In recent years the duration of these openings has increased, with unintended consequences. These are discussed in Section 10.3 of this report.

5. WATER LEVELS AND WATER QUALITY IN THE ESTUARIES

The water level regimes and water quality of Vasse and Wonnerup estuaries have been dramatically altered by 160 years of european settlement. An understanding of the changes that have occurred is useful in attempting to resolve the fish kill issue in an environmentally-acceptable manner.

This section of the report concentrates on the Vasse estuary as few if any kills are thought to have occurred in the Wonnerup. A comparison of water levels, water quality and other characteristics of the two estuaries - particularly of their exit channels, which are quite different - would be useful. This was not possible for the present report.

The water levels and water quality of Wonnerup Inlet are not managed except by openings of the sand bar at the mouth (see section 4.2). No Wonnerup Inlet water level records have been found during preparation of this report and water quality data have only very recently been collected. For these reasons Wonnerup Inlet is given limited attention in this section.

5.1 Water level regimes

5.1.1 During early exploration and settlement

Records of early exploration of the Busselton area indicate that the Vasse and Wonnerup estuaries were shallow prior to and at the time of first european settlement in the district.

In November 1829, Mr Collie and Lieutenant Preston of the British Royal Navy explored Wonnerup Inlet and the lower reaches of the Vasse estuary in whale boats. Their description reads as follows: ".. after a narrow channel of good depth ... (*the Vasse estuary*) becomes so shallow, that our boat could with difficulty be dragged over; it then expands into a considerable sheet of water, the circuit of which we did not complete; but it appeared to be generally very shallow" (Cross 1833; see Appendix 1 of this report for full account)

When Lieutenant H.W. Bunbury of the 21st Fusiliers visited the estuaries in the mid 1830s he found "... the two estuaries ... are both very shallow in most parts, though there are places where the Natives can cross either of them by wading in the dry season". Lt. Bunbury also observed that "... instead of falling into the sea it (*the Vasse River*) discharges itself into the more western of the two estuaries (*Vasse estuary*), where it is extremely shallow and even quite dry across in the summer" (Bunbury & Morrell 1930; see Appendix 1).

No descriptions or measurements of seasonal or year-to-year changes in the water level of the Vasse estuary prior to installation of the floodgates in 1908 have been found during preparation of this report. It is probable that the level during summer and autumn varied around mean sea level. Daily tidal variation would have been very small (several cm) due to the estuary's connection to the sea being long and narrow with a shallow mouth. Larger variations (tens of cm) would have occurred over longer periods (several days) as a consequence of changes in sea level due to variations in barometric pressure (high and low pressure systems). Flooding with seawater would occasionally have occurred during summer-autumn due to storm surges. During winter and early spring the water level was probably high continuously, with some variation related to the timing and intensity of rainfall in the catchment. Winter floods would have been prolonged, rather than "flashy" as now, due to the extensive and vegetated nature of the catchment.

One of the earliest changes to the water level regime of Vasse estuary could have been a small reduction in the level and duration of winter flooding due to diversion of the Capel River to the sea in the 1880s. Prior to this diversion, Capel River would have had some influence on Vasse estuary's water levels via Wonnerup estuary, Wonnerup Inlet and Malbup Creek (see Figure 1). During the late 1800s and early 1900s several cuts were made to connect watercourses west of Busselton to the sea. These diversions may also have slightly reduced the level and duration of flooding in the Vasse.

5.1.2 Following installation of the floodgates (in 1908)

Installation of floodgates in 1908 dramatically altered the water level regimes of the Vasse and Wonnerup estuaries. Large fluctuations were introduced to winter water levels. Winter floods still occurred, but usually to a lower level and for shorter periods than before. During summer and autumn water levels declined below mean sea level, drying the broad expanses of both waterbodies.

Clearing and drainage of catchments, particularly during the early 1920s, increased the volume of river flows to the estuaries and reportedly caused an increase in flooding of adjoining lands *(PWD 289/22)*. In 1927 the problem was lessened by diversion of the Vasse River and most of the Sabina direct to the sea.

Several measurements of Vasse estuary water levels in years between installation of the original floodgates and their replacement in 1929 have been found. These records are presented in Table 1 of Appendix 3. The flood level (1.14 m AHD) measured in winter 1926 is comparable with peak flood levels of recent years (see Figure 4). No measurements of minimum (summer-autumn) water levels between 1908 and 1929 have been located. Given that most of the estuary dried each year the minimum level was probably around -0.3 to -0.4 m AHD.

During the mid to late 1920s, summer-autumn water levels increased due to substantial leakage through and around the gates, which were falling into disrepair. A May 1928 request for urgent action stated that salt water was spreading over low-lying land at the far western end of the Vasse estuary. Recent experience suggests the water level at that time was at least +0.05 m AHD, possibly higher.

5.1.3 Following replacement of the floodgates (in 1929)

The Vasse and Wonnerup estuary floodgates were replaced in 1929, thereby restoring the low summer-autumn water levels that prevailed prior to the original gates' deterioration.

The sill height of the replacement floodgates was RL 101.5 ft (-0.45 m AHD), which was 1 ft 6 ins (0.46 m) lower than that of the original gates. As a result, for the next few years estuary water levels would generally have been lower - though rarely if ever by as much as 0.46 metres - than they had been during the preceding 21 years[5]. The estuaries would also have dried earlier.

Some time during the early 1930s another change was made to water level management. At the end of winter the bar at the mouth of Wonnerup Inlet was closed to retain higher levels of water in the estuaries during spring and summer. This was done to prevent adjoining pastures from drying too early. The levels of water retained in the estuaries were presumably close to those that prevailed from 1908 to the mid 1920s when the floodgate sills were higher.

Several measurements of Vasse estuary water levels during these years of end-of-winter closure of the bar (early 1930s to 1941) have been found (Appendix 3, Table 1: 1938 & 1940 levels). With only one exception (3 Dec 1940), all of these levels are from winter-spring. No autumn levels have been found.

5.1.4 Following seasonal installation of stop-boards (1942 onwards)

_1942-78_[6]

In 1942 both sets of floodgates were modified so that stop boards could be added to each gate opening to a maximum height of RL 104 ft (+0.31 m AHD).

Several records have been found of Vasse estuary water levels from 1942-44. These are presented in Table 1 of Appendix 3. The highest levels recorded each year from 1967-78 have also been located; see Table 2 of Appendix 3. No other measurements of Vasse estuary water levels from 1945-78 have been found.

Given that there were apparently no significant changes to management of the floodgates or the sand bar from 1944-1987, it is probable that the general pattern from 1942-1978 was similar to that of 1979-1987. This pattern (see Figure 3 for winter-spring component) is for water levels to fluctuate dramatically within the range +0.8 m AHD to 0.0 m AHD during winter and for the water level to be stabilised around +0.3 m AHD (the maximum height of the stop-boards) for a short period in spring before declining to a minimum in autumn.

While no actual measurements of summer-autumn water levels prior to 1979 have been found, aerial photographs can be used to determine the minimum levels reached. Photographs taken by the Department of Land Administration (DoLA) clearly show the extent of inundation of the Vasse and Wonnerup estuaries at the time they were taken and in combination with spot heights of the estuary beds can be used to estimate levels. Photographs (1967, 1971, 1974) examined to date indicate a minimum summer-autumn water level in Vasse estuary pre-1979 of about -0.4 m AHD. At this level water extends upstream from the floodgates to a point level with (west of) the mouth of the Abba River. Further upstream the estuary is dry.

_1979-87_

The Water Corporation of WA has numerous records of winter-spring Vasse estuary water levels from 1979 to the present day. These measurements, presented graphically in Figure 3, are from a gauge board at the floodgates and were taken at approximately one week intervals from June to November each year.

---

[5] Average monthly low tide levels (predicted values for 1988) range from approx 0.0 m AHD down to -0.2 m AHD. Even with the sills lowered to -0.45 m AHD, estuary water levels probably declined little below the range of average low tide values, except during late summer and autumn due to evaporation.

[6] Section 5.1.4 has been divided into two periods because fewer water level records are available from 1942-78 than from 1979-87. No changes in water level management procedures are known to have occurred between 1942 and 1987.

In the context of the present report, *summer-autumn* water levels are particularly important. Several records from 1979-87 have been found (see Table 3 of Appendix 3), however these are a poor guide to minimum summer-autumn levels of that period. Most are from the very end of autumn when some rise in estuary water level can be expected due to the onset of winter rains, a decline in evaporation rate and a seasonal rise in sea level causing accelerated leakage past the gates.

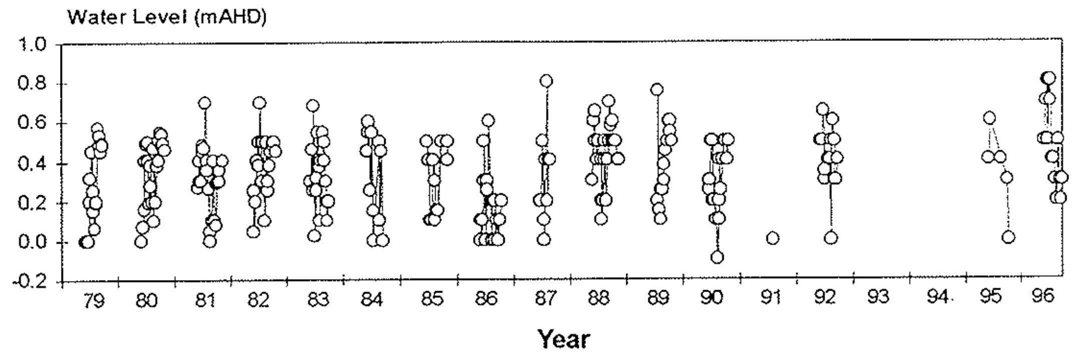


Figure 3. Winter-spring (Jun-Nov) water level records from the Vasse estuary, 1979-96.

More useful are the aerial photographs taken by DoLA. Photographs (e.g. from 1981) examined to date indicate a minimum summer-autumn level during the 1979-87 period of about -0.4 m AHD, the same as that of the pre-1979 period. As indicated above, at this level water extends upstream from the floodgates to a point level with the mouth of the Abba River. Further upstream the estuary is dry.

5.1.5 Following summer-autumn openings of the Vasse estuary floodgates (1988 onwards)

In 1988 the WA Water Authority began opening the Vasse estuary floodgates for short periods during summer-autumn of each year in an attempt to minimise the occurrence of fish kills (see section 4.8). This change to operational procedures has resulted in a rise in summer-autumn water levels.

The few data that exist for the period 1988 to mid-1992 (see Table 3 of Appendix 3) are generally insufficient to provide a clear picture of summer-autumn levels during those years. They do however indicate levels of at least +0.10, -0.09 and +0.05 m AHD in Feb-March of 1988, 1989 and 1990 respectively.

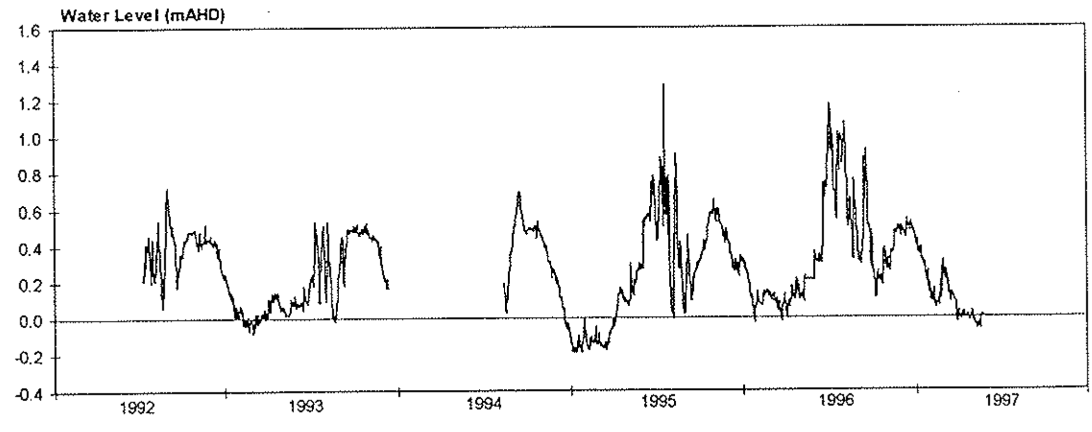


Figure 4. Continuous recordings of Vasse estuary water levels from July 1992 to May 1997.

In July 1992 the Water Authority installed continuous water level recorders on the Vasse and Wonnerup estuaries. These operated until December 1993. In August 1994 replacements were installed by CALM. Data from the Vasse estuary recorders are presented in Figure 4.

Features to note from Figure 4 are the substantial fluctuations in water level that occur in winter each year, the stabilisation at around +0.45 m AHD that is achieved by installation of stop-boards in spring and the steady decline in water level that occurs in summer, due to evaporation.

In the context of summer-autumn openings, the most significant features of Figure 4 are the high (compared with pre-1988) water levels during late summer and autumn (i.e Feb to May) of 1993, 1995, 1996 and 1997. The average minimum levels in these years were around –0.05, –0.15, +0.05 and –0.05 m AHD respectively. Pre-1988 minimum levels were around –0.4 m AHD. Note also that while the water level was generally lower during Jan-Feb of 1995 than in the other years, there was a substantial increase (to +0.15) during autumn of 1995 due to opening of the gates.

Of interest is the +0.3 m AHD peak at the end of Feb 1997. This was due to the floodgates being opened for an extended period. On 14 March 1997 the gates were closed and the water level subsequently declined to around 0.0 m AHD before winter rains commenced.

Partial opening of the Vasse estuary floodgates during summer-autumn is thought not to have impacted upon winter-spring water levels, except at the beginning of winter when the estuary can be expected to fill earlier than previously because it starts at a higher level.

5.2 *Salinity regimes*

5.2.1 During early exploration and settlement

No measurements of salinities of the waters of Vasse or Wonnerup estuaries prior to installation of the floodgates in 1908 have been found during preparation of this report.

Given the narrowness of their connections with the sea and the nature of their catchments, both estuaries would undoubtedly have been fresh during winter and spring due to the flushing effect of river flows. As river flows slackened during summer, seawater would have entered the estuaries, initially as a layer of saltwater beneath fresh, outflowing river waters. These saltwater "wedges" would have gradually made their way up the narrow channels to where the estuaries broaden and shallow. Here and further upstream wind action would have caused some mixing of salt and fresh waters, resulting in a rise in surface salinities. As summer progressed and river flows slackened further, more seawater would have entered and the salinity of estuary waters would have continued to increase. By autumn the salinity from surface to bottom in both estuaries was probably near that of seawater; whether higher or lower depending upon the balance between evaporation, river inflow, rainfall and seawater incursion. Extreme events such as storm surges would also have had an influence.

The report of Collie and Preston's visit in 1929 (Cross 1833; see Appendix 1 of this report) makes no mention of the salinity of estuary waters at that time. However, Lt. H.W. Bunbury's 1836-37 description (also in Appendix 1) of the lowest reaches of several rivers provides some insight.

Bunbury described the Ludlow River as "... but a small stream, a salt creek extending about half a mile *(0.8 km)* up *(from where it entered the Wonnerup estuary)* and then water occurring only here and there in pools". He made no mention of the salinity of the lowest reaches of the Capel River.

Of rivers entering the Vasse estuary Bunbury wrote "The Abba ... is salt about three quarters of a mile *(1.2 km)* up; there a little fresh stream constantly trickles down ...". Concerning the Sabina he wrote "The salt water extends very little way up ...". According to Bunbury the Vasse River was "... fresh during the winter and early part of the Summer at Mr Bussell's house (*Cattle Chosen; 3.6 km from the river mouth*) ..". By this he appears to imply that the river was not fresh at Cattle Chosen during late summer or autumn, at least of the year in which he visited. Bunbury also described the portion of Malbup Creek that is closest to Vasse estuary as a "salt creek".

A 1916 Public Works Department memorandum confirms that salt water extended seasonally into the lowest reaches of the Vasse River. Mr Reynolds of Wonnerup is quoted as saying that prior to the erection of floodgates the river "... was always during summer months ... salt". Following erection of the gates the river water was fresh, enabling irrigation to be undertaken at Gales farm (*Fairlawn; 3.1 km from the river mouth*) (*PWD 930/18 f 1*).

5.2.2 Following installation of the floodgates (in 1908)

Installation of floodgates in 1908 prevented the incursion of seawater and changed the estuaries from increasingly saline in summer-autumn to fresh-brackish in summer and mainly dry in autumn. The very small volumes of water remaining in the exit channels of each estuary (principally the Vasse) at the end of summer and in autumn were probably moderately saline due to the concentrating effect of high evaporation rates and slight leakage past the gates. These remnant waters were flushed from the estuary at the beginning of each winter.

During the mid to late 1920s the estuaries became saline again during summer-autumn due to lack of maintenance of the gates and, as a consequence, major leakage past them.

No measurements of salinities between 1908 and 1929 have been found.

5.2.3 Following replacement of the floodgates (in 1929)

In 1929 the predominantly fresh-brackish (since 1908) character of the estuaries was restored by construction of replacement floodgates.

In February 1937 an un-named tropical cyclone caused sea level to rise to +1.94 m AHD, overtopping the floodgates by 0.29 m. Salt water entered the estuaries. Reference to this event has been found in a June 1986 letter from B.K. Masters of Busselton to the WA Water Authority.

> "Memories *(of people interviewed)* of the 1937 cyclone which breeched the floodgates remain clear: the estuaries filled with seawater, wells became contaminated and large areas of pastured agricultural land were ruined. In some areas, there was a long period of time before pasture health and hence value to grazing stock returned to pre-1937 levels".

Although it apparently took some years for pasture health to return, the predominantly fresh-brackish hydrological regime of the estuaries would probably have been restored by the end of winter 1937 due to the flushing effect of river flows. 1937 was a year of well-above-average winter rainfall.

No measurements of salinities during the 1929-42 period have been found.

5.2.4 Following seasonal installation of stop-boards (1942 onwards)

Installation of stop-boards in September-October each year to slow the rate at which the estuaries dried out in late spring and early summer is likely to have also slowed the rate at which the salinity of estuary waters increased before drying. On average, the Vasse estuary was probably less saline during early summer from 1942-87 than during early summer of any other period, before or after. Salinities (fresh to brackish) in winter and at least early spring would have been unaffected by installation of the boards.

A few measurements of Vasse estuary salinities pre-1988 have been found (Table 1 of Appendix 4). These show considerable variation. In late January and early February 1987 the salinity of remnant waters in the lower reaches of the system ranged from 26-32 ppt. On 12 November 1987 the surface salinity of the entire estuary was only 1-2 ppt. Five weeks later, as waters began to shallow, the salinity was 3-4 ppt.

5.2.5 Following summer-autumn openings of the Vasse estuary floodgates (1988 onwards)

Partial opening of Vasse estuary floodgates during summer-autumn since 1988 to allow seawater to enter has resulted in a rise in summer-autumn water levels in the Vasse estuary. The broad expanses of the estuary no longer dry as they used to. Instead, the entire bed of the estuary is at times covered by saline water. Measurements taken during late summer and autumn of 1989, 1995, 1996 and 1997 show that the salinity of these waters approaches and occasionally exceeds that of seawater (Table 1 of Appendix 4).

The saline waters now retained in the Vasse estuary during summer-autumn appear to be fully flushed by the end of winter. Salinity ranges measured in Septembers of 1988, 1994, 1995, 1996 and 1997 were 1-2, 1-2, 1, 1 and 1-2 ppt respectively.

5.3 Nutrient levels

Nutrient concentrations in the waters and sediments of Vasse and Wonnerup estuaries have increased dramatically since first european settlement.

The primary sources of these nutrients have been identified as agricultural fertilisers and animal wastes. In the past, effluent was apparently sluiced from some milking sheds directly into drains emptying into the estuaries. Fertilisers not taken up by pastures or crops have also leached into the system. Nutrient enrichment of wetlands is a widespread problem on the Swan Coastal Plain. Investigations in the Peel-Harvey catchment have revealed several causes. These include the limited nutrient-holding capacity of sandy soils, high and strongly seasonal rainfall, shallow watertables, extensive drainage networks, over-use of fertilisers and inadequate treatment of effluent from intensive animal industries (McAlpine, Spice & Humphries 1989).

Nutrient loads transported to the Vasse estuary by the Abba, Sabina and Vasse Rivers in 1987, a year of very low rainfall, were estimated to total 3.7 tonnes of phosphorus and 29.1 tonnes of nitrogen. In 1988, a year of very high rainfall, the estimated loads were 19.6 tonnes of phosphorus and 148.4 tonnes of nitrogen. On the basis of these figures, and similar data for the Wonnerup estuary, McAlpine, Spice & Humphries concluded that the Vasse-Wonnerup system appeared to be "the most grossly enriched major wetland system known in Western Australia".

Much of the nutrient entering Vasse-Wonnerup each year flows straight through to the ocean. A substantial proportion is also taken up by aquatic plants growing in the estuaries and along their margins. A third portion is retained in the bed of the estuaries, bound to sediments. Some nutrient remains in the waters of the estuaries, either in dissolved form or in suspension. Nutrients that remain within the wetland system are cycled by biological activity and chemical and physical processes.

A complete nutrient "budget", in which all nutrient inputs and losses are quantified, has not been developed for Vasse or Wonnerup estuary. This would require substantial research over a number of years. It is known, however, that nutrient concentrations in the estuaries' waters are very high and there is good reason to believe that sediments in the estuaries are also nutrient-rich. Sampling conducted by the Water & Rivers Commission from August 1996 to August 1997 has revealed median phosphorus concentrations of 0.20 parts per million (mean 0.18 ppm; range 0.06-0.47 ppm) in the Vasse estuary exit channel. These high levels explain the occurrence of a severe algal bloom in January 1997 (0.02 ppm of phosphorus is sufficient - G.Bott pers. comm.). There can be little doubt that by causing algal blooms, high phosphorus levels are contributing to the incidence of mass fish deaths (see section 8.1).

It is not clear when the estuaries first became substantially nutrient-enriched. Some enrichment would have occurred as early as the mid 1800s due to grazing and cropping of the estuaries' floodplains and the hinterland. A butter factory established on the banks of the Vasse River in 1918 disposed of waste directly into this watercourse. The most dramatic increase in nutrient inputs to the estuaries probably occurred in the 1920s with the rapid settlement and agricultural expansion that occurred in the mid-reaches of the Ludlow, Abba, Sabina, Vasse and other rivers. Diversion of most of the flow from the Vasse and Sabina Rivers direct to the ocean in 1927 would have caused a temporary reduction in nutrient inputs to the estuary. However in subsequent years this would have been more than offset by intensification of agricultural activity in other river catchments.

In recent years efforts have been made by farmers to reduce the amounts of livestock wastes and fertilisers being lost to the rivers, estuaries and sea. It will be some years, however, before these reductions result in a significant lowering of nutrient levels in the waters and sediments of the Vasse-Wonnerup system.

6. FISHES OF VASSE-WONNERUP

The fishes found in the Vasse-Wonnerup system that are of importance to recreational and commercial fishermen are mullet, whiting, mulloway and bream. Other species of significance are listed in Appendix 5.

6.1 *Marine fishes*

Yellow-eye mullet, western sand whiting and King George whiting are marine species that reproduce in the ocean and use both estuaries and marine embayments as nursery areas. Sea mullet in contrast spawn in the ocean but the juveniles use only the waters of the estuaries as a nursery. The eggs and larvae of these ocean-spawning species are dispersed by ocean currents and each estuary shares a common genetic stock.

6.2 *Non-marine fishes*

The Black Bream is a non-marine species. The preferred habitat is brackish waters in the middle to upper sections of estuaries. In winter to spring the bream form into schools to spawn. Black Bream in the Wonnerup, and presumably in the Vasse as well, spawn from mid-July to November in the upper estuary. The number of eggs released by a female varies depending on the size of the fish. Studies have demonstrated that a small fish can produce 13 000 eggs while it is estimated that a very big female can produce in excess of one million eggs. Black Bream eggs sink to the bottom where they hatch. The juvenile fish can be found on shallow weed flats. Black Bream are carnivores opportunistically feeding on mussels, worms, small fish and crustaceans. Bream grow rapidly. One study of Swan River bream showed that the fish reached maturity at 2-3 years of age (Fisheries Department, 1993).

Because bream do not move out of their own estuarine system it is highly likely that each has its own unique genetic stock of bream. Since development of the Vasse-Wonnerup catchment for agriculture there have been a number of fish kills, probably more than occurred previously. Bream have persisted in the system however, no doubt aided by their quick rate of growth and the large number of eggs that the females produce. None-the-less it is worth noting that Vasse-Wonnerup receives high levels of nutrient input from agriculture and other sources and as a result there is a heightened risk that the system will exhibit poor water quality in summer. Should widespread fish kills occur in this system as the result of extreme water conditions then a unique stock of fish would be in danger of being lost with unknown consequences for the system's ecology. The system could be restocked but black bream stock introduced from other systems may not necessarily thrive in the unique conditions of Vasse-Wonnerup.

6.3 *Fish populations and the estuarine environment*

Estuaries represent both risk and opportunity in the life history of fishes. While fishes benefit from the productivity of estuaries they may be subject to sudden changes in water conditions resulting in localised fish kills. In the worst case fish may be trapped in an estuary in which the water conditions deteriorate markedly, particularly during dry years when estuaries such as those on the eastern south coast may become hypersaline and anoxic to the extent that fish kills occur through out the system.

The characteristics of an estuary in terms of the water flow, salinity regime and the opening of the connection to the sea are of critical importance in determining the composition of the fish population in an estuary. The positioning of floodgates across the exit channels of the Vasse and Wonnerup estuaries changed the nature of waters upstream of the gates. The gates partially restrict the migration of fish in and out of the estuaries and maintain a low salinity regime for much of the year. Although the floodgates perform a number of important functions, including the provision of protection for the Town of Busselton from flooding, it is unfortunately inevitable that a consequence of the floodgates is that the fish population will be affected. Despite this, careful management of the flood gates has the potential to reduce the negative impact on the fish populations and to reduce the incidence of kills.

Although fish kills in estuaries can result from naturally occurring conditions, human activities can strongly exacerbate the situation. Estuaries that are subject to increased nutrients, particular those that are contaminated by nutrients from farming, gardening, septic tanks or other sources are prone to algal blooms in spring and summer which result in low water quality and subsequent fish kills. In this context it is worth noting that Vasse-Wonnerup has been described as "the most grossly enriched major wetland system known in Western Australia" (McAlpine, Spice & Humphries 1989). As well, small or shallow estuaries like Vasse and Wonnerup are more likely to experience sudden changes in water quality than large or deep estuaries. For example the Swan estuary is a large estuary which can hold saline water at depth even during winter when fresh water is running strongly down river. The deep saline water provides a refuge for fishes which cannot tolerate fresh water.

6.4 Environmental tolerances of Black Bream

Direct scientific experiments have not been carried out but the following estimates are available.

Black Bream can tolerate salinities from near fresh (3 parts per thousand) to seawater (35 ppt). They can persist in hypersaline water but cannot thrive and breed. They are able to tolerate sudden decreases in salinity such as the sudden influx of fresh water to an estuary at the beginning of winter but it is not known how well they can tolerate a sudden increase in salinity. It has been reported that when the Vasse estuary floodgates were opened to relieve the situation of stressed fish (February 1997; see section 7.3) the Black Bream did not move out through the floodgates. This could be because unlike mullet which will migrate to the sea away from fresh water, black bream tend to migrate towards fresh water away from salt, or it could be that black bream cannot tolerate a sudden increase in salinity.

Black bream have been collected alive in waters from 8 to 33°C. A similar fish, the pink snapper, requires dissolved oxygen concentrations of 3.5 parts per million in order to grow and can withstand concentrations as low as 1.5 ppm for a short time. Presumably Black Bream have similar oxygen requirements and tolerances.

7. HISTORY OF MASS FISH DEATHS

Brief descriptions of all known reports of mass fish deaths in the lower reaches of the Vasse-Wonnerup system are provided below in chronological order. A summary is presented in Table 1. At the end of this section several incidents in other nearby waterbodies are described for comparison.

7.1 Prior to installation of the floodgates

1905

"Hundreds and thousands of fish of all kinds" were reported in February 1905 to be rotting upon the banks of "Wonnerup estuary" *(actually the lower reaches of the Vasse estuary and perhaps the western arm of Wonnerup Inlet)* "about the locality of Ballarat *(where the Vasse estuary floodgates are now situated)* and indeed for some considerable distance towards Busselton" *(The South-Western News, 3 Feb 1905)*. The chief cause was said to be water stagnation following closure of the mouth of the system "owing to siltage". A local resident had previously been contracted to maintain an opening to the sea, however this work had ceased. Urgent representations were made to authorities to rectify the situation. For a full description of this incident see Appendix 6. Note that this fish kill was three years prior to construction of the floodgates.

7.2 Following installation of the floodgates

1933-34

A Public Works Department memorandum of 4 May 1934 indicates that "a number of fish" died in "the Estuary" during the summer of 1933-34. Which estuary is unspecified, however the context indicates that it was the Vasse and that at least some - possibly all - of the deaths were upstream of the floodgates. How far upstream is unclear *(PWD 984/35 f 1)*.

Pre-1960

A 1960 Departmental memorandum to the Minister for Fisheries recommending opening of the Vasse-Wonnerup system to net fishing from August to October each year reads: "In recent years, the Department and the local health authority have been very concerned over the heavy mortality during the summer months among the fish inhabiting these waters *(the estuaries)*". The year or years in which the deaths actually occurred were not specified, nor the precise location of the deaths. A ban on netting in Wonnerup Inlet and the Deadwater was reinstated in 1965 following objections from line fishermen.

An article in the *Busselton-Margaret Times* of 11 Feb 1965 quotes the Busselton Shire Clerk as saying that waters near the floodgates were open to net fishing (from August to October, see above) "because there had been so many dead fish lying around one February". One Councillor is also quoted as saying "It's much better to catch those fish at a certain time of the year".

The *Busselton-Margaret Times* of 11 March 1965 quotes "a professional fisherman with years of experience in Busselton waters" as saying "it was not unusual for thousands of mullet to die when Wonnerup estuary waters subsided after winter flooding". It is clear from other comments in this article that the term "Wonnerup estuary" was being used loosely and might equally have been a reference to Wonnerup Inlet or Vasse estuary.

1966

Thousands of fish died in Wonnerup Inlet in the latter half of April 1966. One fisherman counted 300 dead fish floating at the waters' edge along 100 yards of shoreline and estimated almost 4000 dead fish "between the main bridge near Lockeville and the mouth of the river" (i.e. between the current Layman Road bridge built in 1965 and the mouth of Wonnerup Inlet). He was reported to have seen pilchard, black bream, river kingfish, yellowfin, whiting and cobbler. The cause of deaths was said to have been lack of oxygen. A temporary bar had been built across the mouth of Wonnerup Inlet to enable workmen to carry out repairs on the floodgates. This had prevented tidal exchange with the sea. Clogging of gills "when sediment built up in the murky dead water" was also said to be a contributing factor *(Busselton-Margaret Times, 28 Apr 1966).*

1984

In the second week of February 1984 thousands of fish including mullet and bream died on the upstream side of the Vasse estuary floodgates. Local Fisheries & Wildlife Department Officer, P. Lambert, was quoted as saying "a lack of oxygen suffocated the fish when a heat wave coincided with a drop in the estuary's water level" *(BMT 16 Feb 1984).* Tests were apparently conducted on some of the fish and these were said to have confirmed that lack of oxygen was the cause of death *(BMT 3 March 1988, see below).*

1988

Many fish died in Wonnerup Inlet in late February 1988. One local resident was quoted as saying "more than 1000 dead fish were strewn along the banks". The cause of death was again said to be lack of oxygen and high water temperatures. Formation of a sand bar across the mouth of the Inlet two months previously had prevented oxygenated seawater from entering *(BMT 3 March 1988).* Mr G. Holtfreter of the WA Water Authority was quoted as saying that it was the second time in his 19 years in Busselton that the problem had arisen and that tests on fish that died four years previously had revealed their deaths were also due to lack of oxygen *(BMT 3 March 1988).* Soon after the deaths began, the Vasse estuary floodgates were opened and attempts were made to open the bar however these proved unsuccessful.

7.3 Following summer-autumn openings of the Vasse floodgates

1989

On 3 February 1989 one floodgate was opened by the Water Authority because conditions were said to be the same as those just prior to the fish deaths of the previous year. Some water entered the estuary but fish were apparently unable to escape as the stop-boards had not been completely removed from the gateway or "bay". Many big fish were found dead the next day (4 February). An estimate reported in the *Busselton-Margaret Times (9 Feb 1989)* put the number at "1000 pilchards and mullet". The dead fish were removed by the Shire. On 10 February, at the request of the Fisheries Department, all boards were removed from the bay and small fish were observed moving in both directions. All boards except one were replaced at the end of the day and the gate was left wedged open. Phone calls were soon received from landowners concerned about salt water being allowed into the estuary and the floodgates were shut completely on 11 February.

1997

There was a major kill of fish on the upstream side of the Vasse estuary floodgates on 4 & 5 February 1997. The cause of the deaths was said to be a combination of high water temperatures and the suspected breakdown of an algal bloom, causing a lowering of oxygen levels in the water. The floodgates had been open several weeks prior to the event but were closed at the end of January. On 4 February, following a weekend of hot weather, fish began to appear at the surface. The gates were opened but the larger fish did not swim out, even though the mouth of Wonnerup Inlet was open to the sea. Many fish, including large numbers of Black Bream, died over the next two days. The gates remained open until 14 March when they were closed due to concerns about the impact of the rising water level on fringing vegetation, pastures and birdlife. The Water & Rivers Commission Regional Manager was reported as saying that the dissolved oxygen level was only 1.2 mg/l and this had not been sufficient for the fish to survive *(Busselton-Dunsborough Mail, 12 Feb 1997).*

Table 1. Summary of all reported mass fish deaths in the Vasse-Wonnerup system.

Year	Month	Location	Incident	Reported cause
1905	January (late)	Vasse estuary lower reaches (& west arm of Wonnerup Inlet?)	"Hundreds and thousands of fish of all kinds ... rotting upon the banks"	"Dead and stagnant water" following closure of sand bar at mouth of Wonnerup Inlet
1933-34	"summer"	Vasse estuary	"A number of fish" died	Unspecified
pre-1960	"summer"	"The estuaries"	"Heavy mortality during summer months"	Fish "landlocked" by floodgates during summer
"	February	Vasse estuary channel	"Many dead fish lying around one February"	Unspecified
"	"summer"	"Wonnerup estuary" (location doubtful, see text)	"Not unusual for thousands of mullet to die" after waters subside	Unspecified
1966	April (late)	Wonnerup Inlet - between main road bridge and mouth	Estimated that nearly 4000 fish of at least 5 species died	Lack of oxygen in water and clogging of gills after sand bar artificially closed for repairs to floodgates
1984	February (2nd week)	Vasse estuary channel	Thousands of fish died, including mullet and bream	Lack of oxygen "when a heat wave coincided with a drop in the estuary's water level"
1988	February (late)	Wonnerup Inlet	More than 1000 dead fish strewn along the banks	High water temperature and lack of oxygen after bar closed for two months
1989	February (1st week)	Vasse estuary channel	Estimated that 1000 pilchards and mullet died	Poor water quality
1997	February (2nd week)	Vasse estuary channel	Many fish died, including large numbers of black bream	Algal bloom breakdown, low oxygen, high temperatures.
"	June (mid)	The Deadwater	Many fish of at least 4 species died	Sudden drop in salinity after heavy winter rains and runoff

On 10 April 1997 a small number of struggling and dead "whitebait" *Hyperlophus vittatus* were observed within an area extending 20-30 m upstream of the Vasse estuary floodgates. There were also some mullet schooling at the gates. The gates were opened for 8 hours and the mullet swam into the Inlet. Inspections over the next few days revealed no dead, struggling or schooling fish.

Many fish died at the north-eastern end of the Deadwater between 12 & 17 June 1997. Species included trumpeter, bream, mullet and whiting. A Fisheries Department pathologist was reported to have attributed the deaths to a sudden drop in salinity following heavy rains. He was also quoted as saying "the number of different species that died shows it was an environmental problem that killed the fish and not disease". There was apparently no sign of toxic algae in water samples that were taken *(Busselton-Dunsborough Mail, 25 June 1997).* This June 1997 record is the only known instance of mass fish deaths occurring in Vasse-Wonnerup during winter.

7.4 *Fish deaths in nearby rivers and inlets*

Sudden, mass fish deaths are not confined to Vasse-Wonnerup. They occur in other waterbodies between Bunbury and Dunsborough and elsewhere in south-western Australia.

In January 1972 large numbers of "fish, shrimps and marron" died in a three mile (5 km) stretch of the Preston River downstream from Boyanup, 40 km north-east of Busselton. Two possible causes were suggested for the deaths: heat-wave conditions over New Year and alleged pollution with effluent from a butter factory in Boyanup. One farmer with a riverside property was quoted as saying "I have lived by the river since 1938 and have never seen anything like this before" *(BMT, 20 Jan 1972)*.

Thousands of fish including "trumpeter, pilchard and mullet" died in Toby's Inlet, 16 km west of Busselton, in March 1983. Their deaths were attributed to lack of oxygen and increased water temperature after the sand bar at the mouth of the Inlet closed *(BMT, 24 March 1983)*.

In November 1988 many carp (*Carassius* sp.) died in the Vasse River near Rotary Park, Busselton. The cause of death was diagnosed by a local veterinarian as being the bacterial infection "fin rot". The cause of the outbreak of this highly contagious disease was not known. It was claimed that a stormwater drain from the centre of town was polluting the river *(BMT, 24 Nov 1988)*.

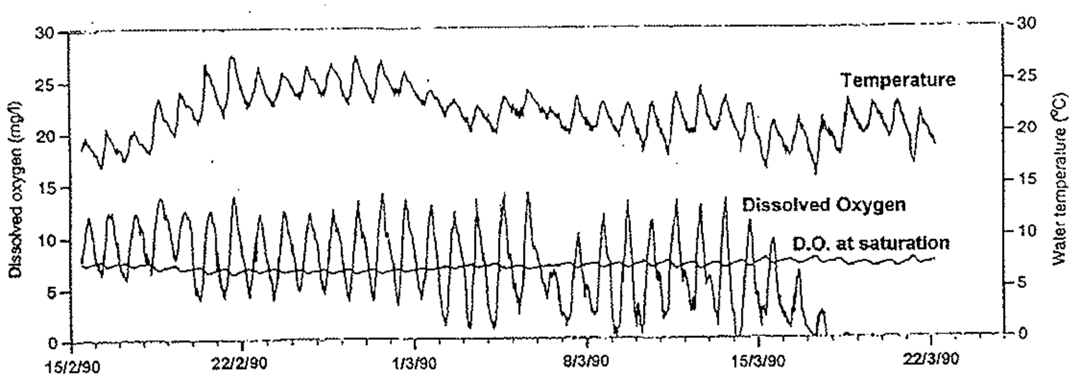


Figure 5. Temperature and dissolved oxygen concentrations in Vasse estuary channel, Feb-Mar 1990. (Based on a figure supplied by G.Bott, Department of Environmental Protection. The readings were taken approx 250m upstream of the floodgates and 10 cm from the bottom. Theoretical dissolved oxygen concentrations at saturation are provided for comparison with measured levels).

In January 1997 thousands of fish and many crabs reportedly died on the coast at Quindalup, 21 km west of Busselton, after being trapped by sand banks at low tide. High water temperatures and low oxygen after two days of hot weather were said to be the cause. Soon afterwards the Shire Council excavated two channels to the open water, thereby improving water quality and enabling fish to escape *(BMT, 9 Jan 1997)*.

8. ENVIRONMENTAL FACTORS ASSOCIATED WITH MASS FISH DEATHS

Most fish kills reported from Vasse-Wonnerup have occurred during summer, principally February, and have been confined to the Vasse estuary exit channel and Wonnerup Inlet. Most have apparently occurred immediately after several days of hot weather. Reports at the time of these deaths have suggested the probable cause to be low oxygen levels due to high water temperatures and, in at least one instance, the suspected breakdown of an algal bloom.

8.1 *Oxygen, temperature, algal blooms, nutrients and water levels*

Data collected by the Environmental Protection Authority in Feb-March 1990 show that dissolved oxygen concentrations in the Vasse estuary exit channel at times reach very low levels and on occasions (e.g. 18-22 March) may be continuously at zero for several days (Figure 5). No deaths were observed on this occasion, suggesting that the zero oxygen conditions were localised and fish were able to escape the lethal conditions. If these conditions had been more widespread and fish had been unable to escape, deaths would certainly have resulted.

The daily fluctuations in dissolved oxygen concentrations shown in Figure 5 indicate the presence of plant life, most probably micro-algae, photosynthesizing (and producing oxygen) during the day and respiring (consuming oxygen) at night. The increase in magnitude of the daily fluctuations from 20 February onwards suggests a sudden increase in abundance or "bloom" of the micro-algae. The drop in dissolved oxygen to zero mg/l from 20 to 28 February is consistent with death and decay of a bloom - no oxygen is produced and the oxygen that is already in the water is consumed by the decaying process.

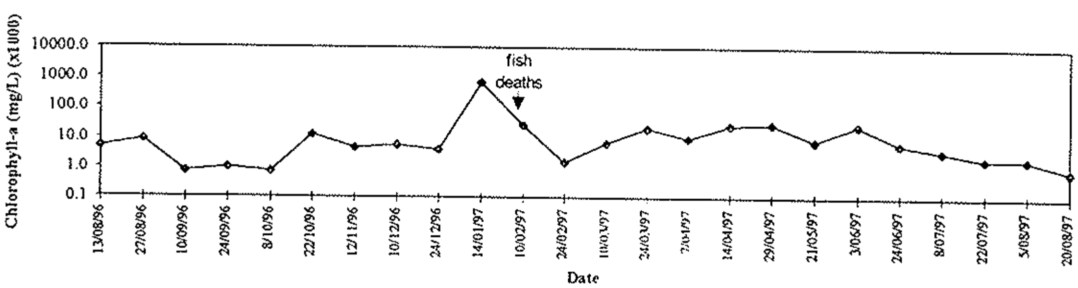


Figure 6. Chlorophyll-a concentrations in Vasse estuary exit channel, 1996-97. (Data: K.Hardcastle, W&RC). Note the logarithmic scale of the "y" axis.

Data collected by the Water & Rivers Commission in 1997 lend support for the view that at least some of the mass fish death incidents during summer are due to the death and decay of algal blooms. A water sample taken from the Vasse estuary exit channel on 14 January 1997 contained an extremely high concentration of Chlorophyll-a indicating the presence of a bloom (Figure 6). This bloom had almost entirely collapsed by 10 February, the next sampling occasion. During the intervening period (on 4-5 February) many fish died in the channel.

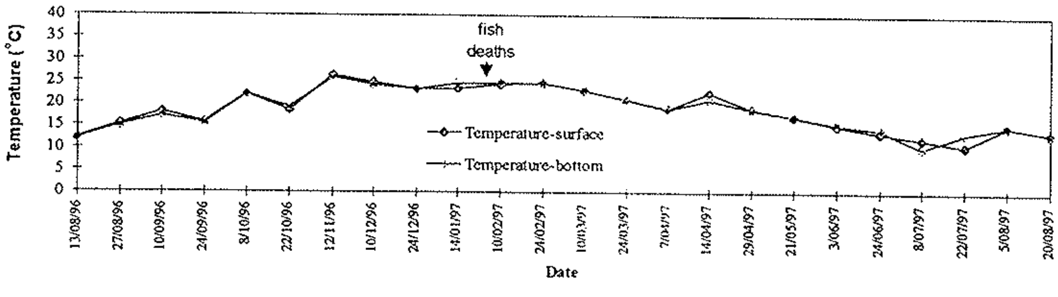


Figure 7. Water temperatures in Vasse estuary exit channel, 1996-97. (Data: K.Hardcastle, W&RC).

The water temperature and dissolved oxygen levels at the time of the February 1997 kill are not known. Water temperature was probably in excess of 25°C (see Figure 7) and may have been at a summer peak as hot weather immediately preceded the deaths. On 28 January the surface and bottom water temperatures were 25.2 and 25.3°C respectively. The dissolved oxygen levels cannot be confidently estimated from the available data[7].

Algal blooms in the Vasse estuary channel during summer are made possible by a combination of high light availability, warm water and high concentrations of available nutrients. Following their

---

[7] A figure of 1.2 mg/l reported in the *Busselton-Dunsborough Mail* (see section 7.3) is unconfirmed. The surface and bottom dissolved oxygen concentrations at 1002 hrs on 28.01.97 were 10.6 and 6.4 mg/l respectively.

two-year investigation of nutrient inputs to the Vasse-Wonnerup system, McAlpine, Spice & Humphries (1989) concluded that "Nutrient loads to the system from the surrounding agricultural catchment are the highest measured into any waterbody in the southwest of Western Australia". On the three sampling occasions prior to the February 1997 fish kill (8 Oct, 12 Nov & 10 Dec 96) the Water & Rivers Commission measured total phosphorus concentrations of 0.47, 0.28 and 0.22 mg/l in the Vasse estuary exit channel. These are more than adequate for the development of algal blooms (0.02 mg/l is sufficient - G. Bott pers. comm.).

Wind, or lack of it, may be an important factor in summer fish deaths. Wind acting on the surface of a waterbody helps to oxygenate its waters, particularly if the wind is strong enough to cause breaking waves to form. When winds are calm there is greater potential for deoxygenated conditions to develop. Light winds in late summer may be part of the reason for a high proportion of kills occurring in February. An attempt was made during preparation of this report to obtain daily wind speed and direction data corresponding with times of mass fish death incidents, however this proved unsuccessful. The Bureau of Meteorology advised that winds and temperatures were not measured, at least officially, in the Busselton area during the relevant periods. Continuous recorders were not installed until late 1997.

The precise relationship between Vasse estuary's water level and the incidence of fish deaths is uncertain. Data collected since mid 1992 do not support the theory that higher water levels in summer reduce the likelihood of fish deaths occurring. The water level in the estuary at the commencement of the February 1997 fish kill was +0.12 m AHD. This level was higher than the levels recorded on the same day in 1993 (+0.04 m) and 1995 (-0.11 m), yet no kills occurred during those years.

8.2 Sediments, seawater and seaweed

The sediments on the bed of the exit channels of the two estuaries have not been chemically tested. However, given the long history of agricultural activity in the catchment, they are certain to be nutrient-rich and thus provide an additional source of nutrients necessary for algal blooms.

Seawater either leaking into, or allowed into, the Vasse estuary exit channel during summer or autumn may, at times, contain higher levels of dissolved oxygen than water on the upstream side of the floodgates and so, in this respect, may improve conditions for fish. On the other hand this saline water, because of its higher density, may form a separate layer beneath the less-saline waters of the estuary. Under these conditions gas exchange with the atmosphere is inhibited. The lower layer has a high likelihood of becoming deoxygenated, especially if sediments on the bed have a high demand for oxygen, as is likely to be the case in the Vasse estuary channel. Deoxygenation of water overlaying nutrient-rich sediments is also likely to increase the rate of nutrient-release from those sediments, thereby facilitating the development of algal blooms, some of which are known to be toxic to fish.

Estuary waters on the upstream side of the Vasse estuary floodgates were underlain by saltier, less-oxygenated seawater shortly prior to the February 1997 fish kill. On 28 January, seven days before the deaths began, the surface salinity was 16 ppt whereas the bottom salinity was 28 ppt. The dissolved oxygen concentrations (surface & bottom) at 1002 hrs were 11 mg/l and 6 mg/l respectively.

The waters of Wonnerup Inlet may become inhospitable due to the decomposition of seaweed (seagrasses and marine macro-algae). Massive amounts of seaweed from Geographe Bay are occasionally swept into the Inlet by winter storms. This seaweed soon begins to decompose, slowly during winter when the water is cold, more rapidly in summer as temperatures rise. The decomposition process results in production of hydrogen sulphide or "rotten-egg gas", which is highly toxic to fish. The decomposition process may also lower dissolved oxygen levels. The February 1988 kill, when large numbers of fish died in Wonnerup Inlet after the bar had been closed for at least two months, may have been caused by these processes.

8.3 Other factors

In June 1997 many fish died in the Deadwater. Postmortem examination showed the cause of death to be a sudden drop in salinity and water temperature. The Deadwater is a "blind" channel connected to Wonnerup Inlet and extending 2 km north-east along the coast (see Figure 1). Fresh water discharged from the estuaries following heavy rains at the beginning of June apparently trapped many fish in the Deadwater. It appears that as this water made its way up the channel the fish retreated to its north-eastern end. Eventually they could retreat no further and were overtaken by the cooler, fresh, river water. The fish were unable to survive the sudden drop in both salinity and temperature and large numbers died. This incident was unrelated to the presence of the floodgates or the status of the bar.

Clogging of gills "when sediment built up in the murky dead water" was said to be a contributing factor when thousands of fish died in Wonnerup Inlet in April 1966. Some time prior to the deaths the sand bar at the mouth was closed artificially to allow repairs to the floodgates to be undertaken. This prevented tidal exchange with the sea. Lack of oxygen in the water of the Inlet was suggested as the principal cause of the deaths.

While the principal factors associated with most fish kills in Vasse-Wonnerup are known, the precise conditions leading to or causing fish kills are not. This information could be gained from more intensive monitoring of key parameters such as dissolved oxygen, temperature, micro-algal abundance, depth and salinity, and by monitoring the fish themselves. This information is necessary to guide efforts to minimise the occurrence of deaths. A monitoring program is recommended in section 12.1.2 of this report.

9. MEASURES TAKEN TO PREVENT MASS FISH DEATHS, AND THEIR EFFECTIVENESS

Over the years a number of measures have been attempted with the aim of preventing fish deaths from occurring and reducing the severity of kills after they have begun.

9.1 Opening of the sand bar

The first measure to be taken was artificial opening of the sand bar at the mouth of Wonnerup Inlet during summers of the early 1900s. A local resident was contracted by the government "for the keeping open of a cut sufficient to allow the seawater at high tide to enter the mouth, and so flush the Estuary". This work ceased during the summer of 1904-05 when the resident applied for cancellation of his contract. The bar closed and in February 1905 "hundreds and thousands of fish of all kinds" were reported to be rotting on the banks of the estuary (see section 7.1). Urgent requests were made to take steps "to immediately open the mouth of the Estuary, sufficient to allow a good volume of sea water to enter ...". Correspondence suggests that some time later (when is uncertain) another local resident, Mr T.H. Reynolds, was contracted to open the bar if it closed during summer.

Towards the end of December 1919 Mr Reynolds advised the Public Works Department that the bar had been closed since the beginning of the month. Attempts had been made to open it, but without success. Further attempts would be made when repairs to the Wonnerup estuary floodgates had been completed.

In February 1988 thousands of fish died in Wonnerup Inlet after the sand bar had been closed for at least two months. Attempts were made to open the bar with a backhoe to let in seawater and to allow fish to escape to the ocean but these efforts were only partially successful. A spokesperson for the Water Authority was quoted as saying "The tides were against us. They weren't high enough and there was too much moving sand at the mouth". The mouth was opened on two days in succession "but only stayed open for a few hours before closing up again". "The reason we have had the problem this time is we can't open the sand bar to the sea, not without a massive injection of funds" *(BMT, 3 March 1988).* Whether or not the brief openings of the bar significantly reduced the number of fish that died is not known. Effects on water quality are also uncertain as no measurements were taken.

9.2 Netting and removal of fish

In 1960 a second measure was adopted. On the advice of the Fisheries Department, and with the concurrence of the local authority, a five year proclamation was issued opening the entire Vasse-Wonnerup system to net fishing from August to October each year. The aim was to enable fish that might otherwise die in numbers during summer to be profitably taken. Netting in these waters had previously been prohibited.

In 1965, following representations from line fishermen and a request from the local authority *(Busselton-Margaret Times 11 Feb 1965)*, a total ban on netting was reinstated over the Deadwater and Wonnerup Inlet. At the same time the Vasse and Wonnerup estuaries were declared to be open throughout the year. In July 1992 recreational net fishing was banned in these waters. Netting in the estuaries is now limited to a small number of licensed commercial fishermen.

There were no mass fish death incidents in Wonnerup Inlet between 1960 and 1965. This may have been due to all or most of the large fish having been removed before summer or it may have been a coincidence; kills are not an annual occurrence. The extent to which continued net-fishing in the Vasse estuary has reduced the magnitude of kills in the exit channel of this waterbody - and prevented the occurrence of kills in Wonnerup estuary - is also unclear. Catch statistics are needed.

9.3 Opening of the Vasse estuary floodgates

When thousands of fish died in Wonnerup Inlet in February 1988, the Water Authority partially opened one of the Vasse estuary floodgates and removed the stop boards from that gateway. The aims of doing so were to allow fish to move from one side of the gates to the other and to improve water quality in the Inlet by hastening the flow of seawater into it. Attempts were also being made to open the mouth of the Inlet, however these proved unsuccessful (see section 9.1). Whether or not opening of the gate while the sand bar was closed had any beneficial effects on fish survival is unrecorded.

February 1988 was the first time since installation of the floodgates 80 years previously that a partial opening during summer-autumn had been agreed to by the Water Authority or its predecessors. In 1933-34 there had been a call, apparently not the first, for the floodgates to be opened "in an endeavour to preserve the fish". However the request was denied because "such action would seriously damage pasture lands" *(PWD 984/35 f 1)*. This position was maintained until some months before the 1988 incident, when it was decided that small releases of seawater into the estuary could perhaps be accommodated, subject to the agreement of potentially affected parties.

On 18 March 1988 the Water Authority wrote to landholders and government agencies seeking their views on an appropriate water level for the estuary during summer-autumn. A letter was also sent to a local newspaper seeking readers' views. After consideration of responses, the Authority adopted a practice of partial openings when conditions were such that fish deaths appeared likely, with the proviso that the water level would not be allowed to exceed -0.1 m AHD.

In February 1989 another attempt was made to prevent fish deaths in the Vasse estuary channel by partially opening the floodgates. This was, at best, only partially successful. Fish began dying one day after the gates were opened. The stop boards were subsequently removed from these bays and this may have saved some fish by allowing them to swim out of the estuary. No measurements of water quality were taken during this event.

Opening of the Vasse estuary floodgates for several weeks during January 1997 and again on 4 February 1997 when struggling fish began to appear at the water surface did not prevent a large kill in the estuary channel during the following two days (4-6 February). This was despite the mouth of Wonnerup Inlet being open to the sea at the time. It was said that the larger fish chose not to swim from the estuary channel. The water quality monitoring that was undertaken by Water & Rivers Commission during 1996-97 was not of sufficient intensity to gauge the effects of the gate openings on water quality in the channel. The monitoring program was not designed for this purpose.

Partial opening of the Vasse estuary floodgates for short periods is at times sufficient to prevent fish deaths from occurring. There were no further deaths of whitebait *Hyperlophus vittatus* after two gates were opened for 8 hours on 10 April 1997. This action also appeared to benefit at least one other species. A number of mullet were seen schooling at the gates when the whitebait were dying. These mullet swam into the Inlet as soon as the gates were opened. Note that it was not necessary to open the gates for days or weeks at a time to achieve these results. The short term opening also had no effect on the water level in the estuary because the amount of water that flowed in - while significant in terms of the small area in which the fish were dying - was insignificant in terms of total estuary water volume at the time. The effects of the opening on water quality were not measured.

10. OTHER IMPACTS OF MEASURES TAKEN TO PREVENT FISH DEATHS

As indicated in the preceding section, three measures have been employed in the past to prevent major fish kills in the lower reaches of the Vasse-Wonnerup system and to reduce the severity of kills after they have begun. These are artificial opening of the sand bar at the mouth of Wonnerup Inlet; netting and removal of fish from Wonnerup Inlet, the Deadwater and lower reaches of the estuaries; and partial openings of the Vasse estuary floodgates.

10.1 Opening of the sand bar

The sand bar at the mouth of Wonnerup Inlet has been artificially opened during summer on a number of occasions since 1904-05 (and possibly earlier) in attempts to prevent or reduce the severity of fish kills in Vasse-Wonnerup. Since 1908 the hydrological effects of these summer openings have been confined (by the floodgates) to Wonnerup Inlet and the Deadwater. The extent to which these openings have altered the ecology of these parts of Vasse-Wonnerup is unknown. Early records suggest that the mouth of Wonnerup Inlet was often open to the sea during summer in the 1800s. If that is the case, artificial openings undertaken in the 1900s have probably had little or no lasting impact on the ecological character of Wonnerup Inlet or the Deadwater.

10.2 Netting and removal of fish

From 1960 to 1965, Wonnerup Inlet, the Deadwater and the Vasse and Wonnerup estuaries were declared open to net fishing from August to October each year. The objective was to allow many of the fish that might otherwise die in numbers during summer to be caught and used profitably beforehand.

In 1965 a ban on the use of nets was reinstated over Wonnerup Inlet and the Deadwater due to a perception that netting in these waters conflicted with the interests of line fishermen. At the same time the Vasse and Wonnerup estuaries were opened to net fishing throughout the year. Recreational netting was banned from these waters in 1992 and access is now limited to a small number of licensed commercial fishermen.

Net fishing is not known to have had adverse impacts on the ecology of the Vasse-Wonnerup system. The estuaries and Inlet continue to support large numbers of waterbirds including many fish-eating species. Larger numbers (700) of Australian Pelicans *Pelecanus conspicillatus* are found on the Vasse and Wonnerup estuaries than on any other waterbody in south-western Australia except one (Peel-Harvey).

10.3 Opening of the Vasse estuary floodgates

Since 1988 the Vasse estuary floodgates have been opened for varying periods during summer-autumn in attempts to reduce the incidence and severity of fish kills. Openings for extended periods have allowed large volumes of seawater to enter what has been, for the past ninety years, a predominantly fresh-brackish ecosystem. These inflows have dramatically increased the area covered by saline to hypersaline waters during summer and autumn and have impacted upon agricultural pastures, fringing vegetation and use of the estuary by waterbirds.

10.3.1 Impacts on agricultural pastures

One of the principal reasons for installation of the floodgates in 1908 was to prevent seawater incursion during summer-autumn from destroying pastures and crops (see section 4.4). Since January 1988 the Vasse estuary floodgates have been opened for extended periods during several summers. These extended openings appear to have damaged pastures that the floodgates were designed to protect.

In March 1988 a landowner on the south side of Vasse estuary, between the mouths of the Abba and Sabina Rivers, contacted the WA Water Authority to express concern about seawater spreading across his land. The water level at the time was -0.01 m AHD. Concerns about seawater being allowed back into the estuary were also raised by adjoining landowners in February of the following year. On this occasion the water level had risen to -0.11 m AHD.

In April 1990 a farmer with land at the western end of Vasse estuary wrote to the Authority expressing serious concern about seawater having been present along the entire length of her property since the end of February of that year. The possibility of landowners suing for damage was raised. Gauge readings indicate that the water level on 3 March 1990 was +0.05 m AHD.

In August 1990 the Water Authority revised its guidelines for operation of the floodgates and control of water levels in the estuaries, taking into account the preceding two and a half years of experience with summer-autumn openings and the results of a survey of landowner and agency views conducted during 1988. The revised guidelines (see Appendix 2) established -0.10 m AHD as the maximum permissible level in the Vasse estuary during summer-autumn. Relevant extracts are as follows.

> "The level of -0.1 m AHD has been found to be acceptable by farmers in the area ...". "Under no circumstances should salt water be allowed to come back behind the gates to allow the levels to become higher than -0.1 m AHD".

Since August 1990 summer-autumn water levels have, on occasions, exceeded -0.1 m AHD. Damage to pastures appears to have resulted. In January 1997 another landowner approached the Water Corporation about salt appearing in his paddocks and the hay crop not being as heavy as in previous years.

10.3.2 Impacts on fringing vegetation

The Vasse estuary is fringed by native samphires, sedges, melaleucas and eucalypts. These plant communities add to the aesthetic appeal of the estuary and provide important habitat for wildlife as well as having significant inherent nature conservation value. During the past two decades efforts have been made to conserve these communities by acquiring and declaring parts of them to be nature reserves when opportunities to do so have arisen.

Fringing plant communities are, by definition, living at or near their environmental tolerance limits. They are sensitive to small increases in the level and duration of inundation and waterlogging, particularly when combined with increases in salinity. It is not surprising, therefore, that the fringing vegetation of Vasse estuary has suffered in recent years.

In April 1990 the landowner who wrote to the Water Corporation expressing concern about seawater reaching the western end of Vasse estuary (see section 10.3.1) stated that "Salt water is already killing off the sedge grasses and a magnificent stand of Melaleuca".

In November 1996 the conservation group "Friends of the Tuart Forest" expressed concern to the Busselton Shire Council's environment forum that increasing numbers of melaleucas and Flooded Gums *Eucalyptus rudis* were dying around the estuary. It was suggested that increased soil salinity due to seawater being allowed into the estuary during summer could be responsible. Following an inspection of sites where deaths had occurred, the forum wrote to the Water Corporation and Water & Rivers Commission seeking information on water and salinity levels in the estuary and to CALM seeking an investigation into the cause of the deaths. CALM has since conducted some soil sampling beneath healthy, dying and dead trees at several locations around the margins of the estuary. The results of this work are not yet available, however the distribution of dead and dying trees is consistent with the cause being raised water levels.

The potential for seawater allowed back into the Vasse estuary to kill fringing vegetation has previously been recognised. In April 1987 the President of the Busselton Naturalists Club wrote to the WA Environmental Protection Authority concerning management of flows. A relevant extract is as follows.

> "... by controlling sea water levels in the estuaries accurately, it should not be difficult to ensure that sea water does not encroach onto existing fringing vegetation and instead only cover*(s)* the mudflats".

10.3.3 Impacts on use by waterbirds

During the mid 1980s more than 15 000 waterbirds made use of the Vasse estuary each year. More than 30 000 used the Vasse and Wonnerup estuaries combined. On this basis Vasse-Wonnerup was listed in June 1990 as a Wetland of International Importance under the Ramsar Convention. Most of the birds using Vasse estuary in the mid 1980s did so during summer and autumn as waters receded and vast food resources became available for a wide variety of species (Lane 1990).

Raising water levels in the Vasse estuary during summer-autumn by allowing seawater to enter has the potential to adversely affect at least some species of waterbirds both directly - by preventing access to and destroying food resources - and indirectly by destroying fringing vegetation that provides habitat for feeding, nesting and roosting.

A survey conducted by Ninox Wildlife Consulting in February 1989 revealed 10 470 waterbirds throughout the Vasse and Wonnerup estuaries. This was substantially lower than a count of 26 000 waterbirds by the Royal Australasian Ornithologists Union three weeks earlier. Ninox suggested that the difference might be linked to the Vasse estuary floodgates having been opened during the intervening period (Ninox 1989).

There have not been sufficient surveys since 1988 to determine the impact of floodgate openings on waterbird numbers. Given the significance of the site it is important that counts be conducted. A more detailed analysis of results of previous surveys is also needed, for comparative purposes.

11. OPTIONS FOR REDUCING FISH DEATHS

Many methods of preventing fish kills in Wonnerup Inlet and the Vasse estuary exit channel have been suggested in the past. Most have not been pursued or have been rejected because they would have caused other, more serious problems or were considered prohibitively expensive.

11.1 Measures implemented in the past

The only suggestions that have been taken up in the past have been temporary openings of the sand bar at the mouth of Wonnerup Inlet; netting and removal of fish prior to summer and partial openings of the Vasse estuary floodgates for varying periods each summer. These measures, and their effectiveness, have been discussed in Section 9.

11.2 Options discussed by M^c^Alpine, Spice & Humphries (1989)

In 1989 the Environmental Protection Authority of WA published a document entitled *The Environmental Condition of the Vasse Wonnerup Wetland System and a Discussion of Management Options* (McAlpine, Spice & Humphries 1989). In this document the authors made a preliminary assessment of many of the suggestions that had been put forward in the past for improving water quality and preventing fish deaths, plus several suggestions that were new. A list of these is presented in Appendix 6. For more detail, readers are referred to the original report.

The principal conclusions reached by the EPA researchers with respect to options for preventing or minimising fish deaths were as follows.

> "It is highly desirable, if not essential, to continue excluding marine water from the wetlands using a system of floodgates. Local management of summer water quality will be necessary to prevent the continuation of fish kills near the floodgates as the lagoons *(broad expanses of the estuaries)* dry out. Water quality could be managed using a number of the options described in Section 3.1 *(these are listed in Appendix 6)*, including a barrage to create a lock situation, oxygenation and possibly dredging."

The three options specifically referred to may be summarised as follows.

> *a) Barrage and lock.* The option put forward by the authors was to construct a barrage across the Vasse estuary upstream of the floodgates. The suggested location was a short distance downstream from the Malbup Creek entrance. The barrage would be built to a height

of +0.75 m AHD; the aim being to prevent seawater from being able to pass upstream of it when the floodgates were open. The floodgates would be closed when the sea threatened to rise above this level. Winter outflows would pass through a gate in the barrage as well as over the top. The gate would also allow fish to move downstream as the waters on the upstream side of the barrage dried up each summer. When all fish had passed through the gate it would be closed. The floodgates would then be opened to allow free exchange of water with Wonnerup Inlet and, if the bar was open, the sea. The estimated cost (in 1989) of an earth barrage was $2500 to $17 000 per kilometre. The lesser figure assumed all materials were available on-site and that a bulldozer alone could carry out the work.

b) Oxygenation. Two alternatives were put forward - construction of a fountain and bubbling with compressed air. It was suggested that the fountain would need to operate for 8-10 hours each night for 4 months every year. As well as propelling a jet of water into the air it would create currents that would distribute oxygenated water some distance along the channel. Bubbling of air was thought to be a less effective option. Both options had the disadvantage of stirring fine sediments from the bottom. This would reduce oxygen levels initially and would probably increase the likelihood of algal blooms by enhancing transfer of nutrients from sediments to the water. The estimated cost of a fountain to service 50 m of the Vasse estuary exit channel was $10 000 initially plus $5000 per year. The bubbler system cost was thought to be similar.

c) Dredging. It was suggested that dredging of either Wonnerup Inlet or the Vasse estuary exit channel to remove accumulated sediments and create deeper waterbodies might reduce water temperatures and deoxygenation during summer. Deoxygenation would become *more* likely during winter however, and in the long term more sediment would accumulate. Dredging was not expected to greatly improve water quality. These options were costed at $200 000 (Wonnerup Inlet) and $500 000 (Vasse estuary exit channel).

Low-cost options commented upon favourably elsewhere in the report were: temporary openings of the sand bar to improve water quality in Wonnerup Inlet ($5000 per year), improved use of agricultural fertilisers (this would actually save money) to reduce nutrient loadings in the entire Vasse-Wonnerup system in the long term, and reduction of point sources of nutrients such as effluent from dairy herd operations.

Permanent opening of the sand bar was suggested as a measure that would ensure good water quality within Wonnerup Inlet. However, it would also involve a capital cost of approximately $70 000 and a maintenance cost as high as $150 000 per year.

The practice adopted in 1988 of partially opening the Vasse estuary floodgates for short periods when conditions are such that fish deaths appear likely or have begun was considered in the context of replacement of the floodgates with a similar structure. As described in a previous section, partial openings during summer allow fish to move into Wonnerup Inlet and seawater to flow through the gates and into the estuary channel. The authors had concerns about potential adverse effects of this practice, however, and suggested that it required further evaluation. In particular they were concerned about the potential for stratified conditions to develop in the channel (with the lower, saltier layer becoming deoxygenated), for hypersaline conditions to develop, for pastures to be adversely affected and for algal biomass to increase. They also suggested that, if the practice was to be continued, water quality would need to be monitored to determine when the gates should be opened. The sand bar would also need to be managed to ensure that water quality in Wonnerup Inlet was adequate for fish.

McAlpine, Spice & Humphries did not favour the other options they had examined because they were considered unlikely to produce significant benefits, would worsen the current situation or would cause other serious problems. Some were also very expensive.

It is important to note that the potential management options contained in the McAlpine, Spice & Humphries report were "for discussion and further evaluation". The report was seen "as a step towards producing a management plan for the wetlands and that catchment" (see Summary section of their report). The authors also indicated (p.33) that "there is very limited information on the biology and the hydrodynamics of the Vasse-Wonnerup wetland system available, and nothing on the interactions between them. Before a final management scenario can be fully evaluated, more information about the wetland system is required". They then listed a number of areas they believed required further study.

11.3 An additional measure

A potentially useful measure not discussed by McAlpine, Spice & Humphries is partial shading of the Vasse estuary exit channel to reduce water temperatures during summer-autumn.

High water temperatures are believed to be an important contributing factor to fish kills in the channel. At present there is no shading of the channel for the first 180 m upstream of the floodgates and only limited shading for another 150-200 m. Some reduction in water temperatures along the northern side of the channel could be achieved by planting trees and shrubs along this shoreline. Given the channel's orientation (ENE-WSW), plantings along the southern shoreline could also be useful in providing some shade over the water in the early morning. Full shading of the entire 40 m width of the channel is not practicable and is not considered necessary to achieve beneficial effects.

Suitable species for the shade plantings would be the indigenous melaleuca and peppermint *Agonis flexuosa* found further west along the channel. These could be expected to grow to a height of 5-7 m in this situation. Because melaleuca and peppermint are slow-growing it might be desirable to also plant Flooded Gum *Eucalyptus rudis* and Tuart *E. gomphocephala.* These species are faster-growing and taller and occur naturally in the vicinity of the wetlands.

Potential effects of plantings on wind speeds during the hottest months of the year need to be taken into account. A significant reduction in wind action would increase the probability of deoxygenated conditions developing. On the other hand, plantings could have a channelling effect resulting in an increase in air speed over the water surface when the wind is from certain quarters, for example from the east or south-west. This would be beneficial.

12. RECOMMENDATIONS

In preceding sections of this report the Technical Working Group has reviewed the history of fish deaths in the lower reaches of Vasse-Wonnerup and has given consideration to a range of related issues including management of the sand bar at the mouth, operation of the estuary floodgates, problems with water levels and water quality, previously-implemented and suggested measures for preventing fish deaths, and impacts on other values such as waterbirds, fringing vegetation and adjoining pastures.

In this section the Working Group presents its recommendations for dealing with these issues.

12.1 Measures to commence in 1997-98

The Working Group believes the most promising, practicable and affordable measures for reducing the incidence and severity of fish kills in an environmentally-acceptable manner in the immediate future to be:

i) artificial openings of the Wonnerup Inlet sand bar during summer-autumn, particularly January and February;
ii) implementation of a fish & water quality monitoring program in the lower reaches of the Vasse-Wonnerup system;
iii) refinement of operational procedures for openings of the Vasse estuary floodgates, and
iv) partial shading of the Vasse estuary channel to reduce water temperatures during summer.

The Working Group recommends that these measures be commenced in 1997-98.

12.1.1 Openings of the sand bar

The bar should be opened as frequently as necessary to maintain adequate water quality to prevent fish deaths in Wonnerup Inlet during summer-autumn. How frequently should be determined on the basis of results from the fish & water quality monitoring program (see 12.1.2). Given the tendency for most kills to occur in February it is recommended that attempts be made to keep the bar open for as long as possible, preferably continuously, during January and February 1998. Past experience suggests that it may also be found necessary to open the bar on one or two other occasions during summer-autumn to prevent deaths. If successful these measures will not only minimise fish deaths in Wonnerup Inlet, they will also ensure that fish released from the Vasse estuary exit channel (via the floodgates; see 12.1.3) have better-quality water to move into and will thereby assist in preventing deaths in that part of the system. In making these recommendations the Working Group recognises that at times it will not be possible, due to the constant movement of sand, to keep the bar open for long. Even so, opening the bar more often should assist in reducing the frequency and severity of kills.

12.1.2 Fish & water quality monitoring program

Monitoring of water levels, water quality and fish behaviour in the lower reaches of the Vasse-Wonnerup system will enable conditions resulting in fish deaths to be more-precisely defined. Monitoring results will also assist decision-making with respect to openings of the Wonnerup Inlet sand bar and the Vasse estuary floodgates. The water quality monitoring program proposed for 1997-98 is presented in Appendix 8. The program includes continuous monitoring of water levels, dissolved oxygen, temperature and salinity, and periodic measurement of algal abundance and nutrient concentrations. The fish monitoring program will involve daily checks on fish behaviour throughout January and February 1998. Daily checks are also proposed in December 1997 and March & April 1998 during and immediately following hot weather. Volunteer assistance should be sought with the fish monitoring program. Proposed procedures for notification of agencies of imminent mass deaths or declines in water quality to near-critical levels are presented in Appendix 10.

12.1.3 Refinement of openings of the Vasse estuary floodgates

The operational guidelines adopted in 1990 after extensive consultation with interested parties should be adhered to. The timing of openings and closures should be refined and should take into account results from the proposed fish & water quality monitoring program. The refinements proposed for 1997-98 are described in Appendix 11. Because of the damaging effect of excessive levels of salt water on native vegetation and pastures and the possible adverse effect on waterbird populations, salt water allowed in through the gates should not be allowed to raise summer-autumn water levels above -0.1 m AHD. This point was emphasised in the 1990 guidelines and is most important.

12.1.4 Partial shading of the Vasse estuary exit channel

The northern shoreline and possibly parts of the southern shoreline of the Vasse estuary exit channel should be planted with locally indigenous species, including melaleuca and peppermint *Agonis flexuosa*, to provide shade and thereby reduce water temperatures during summer-autumn. This should assist in reducing fish kills. On the northern shore the plantings should begin at the floodgates and extend several hundred metres upstream. This bank of the channel is public land. The potential usefulness of plantings along the southern shoreline should also be investigated. Because peppermint and local melaleuca are slow growing, consideration should be given to planting Flooded Gum *Eucalyptus rudis* and Tuart *E. gomphocephala* in addition. These species occur naturally in the vicinity and are both faster-growing and taller. CALM would be an appropriate agency to plan and supervise the plantings. This proposal should be reviewed if substantial reduction of wind action on the water surface during the hottest months cannot be avoided as this would increase the likelihood of deoxygenated conditions developing and would consequently increase the risk of fish deaths.

12.2 Measures for possible investigation

In addition to the above measures to be commenced in 1997-98, the Working Group recommends the following.

12.2.1 Artificial aeration of waters of the Vasse estuary channel

The Working Group believes that the artificial aeration proposals of McAlpine, Spice & Humphries (1989) warrant further investigation and possibly a trial. It is recommended that if the measures proposed for implementation in 1997-98 are not successful, consideration should be given to seeking funds to undertake an investigation during 1998-99. Data obtained from the proposed fish & water quality monitoring program in 1997-98 will be useful in this regard.

12.2.2 Increased fish harvest before mid-summer

As indicated in section 9.2, from 1960 to 1965 Wonnerup Inlet was declared open to net fishing from August to October each year so that fish that might otherwise die in mass kills during summer could be caught and used profitably. Re-opening Wonnerup Inlet to net fishing would no doubt be unpopular with many line fishermen as it apparently was in the mid 1960s and is not proposed. There may, however, be some potential to modify the present fish harvesting regime in Wonnerup Inlet (not necessarily by introducing netting) so as to produce benefits not only in terms of increased catches, but also in terms of reducing wastage in the event of future kills. The Working Group recommends that in the event of the other measures proposed to prevent fish kills in Wonnerup Inlet proving unsuccessful, this potential be explored by Fisheries WA in consultation with the local community at an appropriate time.

12.2.3 Permanent opening of the mouth of Wonnerup Inlet

Closure of the sand bar at the mouth of Wonnerup Inlet increases the likelihood of mass fish deaths occurring in the Inlet during summer. Closure of the bar also makes prevention of fish deaths in the Vasse estuary exit channel more difficult. Temporary openings of the bar, by means of a backhoe or similar machinery, are not always possible to achieve and at times are impossible to keep open for more than a few days or even hours due to the constant movement of sand. In the event of the temporary openings proposed in section 12.1.1 proving to be too difficult to maintain and further mass fish death incidents occurring in the Inlet, it is recommended that consideration be given to permanent opening of the bar, for example using rock groynes or sand by-pass pumping. This option should not be pursued without prior and detailed environmental impact assessment. Some benefit might be obtained, however there might also be negative consequences such as an increase in the quantity of seaweed deposited in the Inlet. This could increase the likelihood of water quality deterioration and fish deaths. Permanent connection to the sea by means of a pipe could also have negative, as well as positive, impacts and would also need environmental assessment.

12.2.4 Other proposals

McAlpine, Spice & Humphries (1989) suggested that dredging of Wonnerup Inlet or a section of the Vasse estuary exit channel might be worth investigation as a means of perhaps achieving some improvement in water quality. The benefits in terms of preventing fish kills were uncertain, however, and the financial cost quite high. Some negative impact could also result. The Working Group recommends that resources *not* be put into investigating dredging at least until the success of measures recommended above has been determined and investigation of the Vasse River dredging proposal (aimed at preventing algal blooms in central Busselton) has been completed.

The barrage proposal (see section 11.2) outlined by McAlpine, Spice & Humphries would be expensive, probably more so than they suggested, and would dramatically alter the ecology of the lower reaches of the Vasse estuary. It is therefore recommended that it not be pursued, at least until the effectiveness of the measures proposed above has been determined. This proposal would also need to undergo full environmental impact assessment because of environmental, flood mitigation and other issues involved.

The Vasse estuary floodgates have been scheduled for replacement in 2003-04 due to their deteriorating condition. It is recommended that the design of the replacement gates include provision of a Supervisory Control & Date Acquisition System (SCADA) for remote and/or automatic water level control and monitoring. The structure should also include a fish escape facility such as a small "lock" system. It has been estimated that incorporation of these features during initial construction would add as little as 5% to the overall cost compared with 30-50% if done later as an "add on". Remote and/or automated operation and monitoring would significantly reduce labour costs and would enhance management of water levels and flows in comparison with a manual system.

12.3 Monitoring of impacts on other values

12.3.1 Monitoring of fringing vegetation

As discussed in section 10.3.2, remnant wetland vegetation fringing Vasse estuary is dying and this appears to be due to raised summer-autumn water levels following a change in floodgate operational practice (section 5.1.5). A formal monitoring program is needed to properly assess the vegetation changes that have occurred and future trends. In particular it is needed to assess the effectiveness of adherence to the 1990 floodgate operational guidelines in halting and reversing the current trend of increasing tree, shrub and other plant deaths. It is recommended that funds be sought to design and initiate a suitable monitoring program during 1998-99.

12.3.2 Assessment of use by waterbirds

As indicated in section 10.3.3, the Vasse and Wonnerup estuaries are listed under the Ramsar Convention on the basis of their use by waterbirds during the mid 1980s. Significant change has occurred in the hydrology of the Vasse estuary since 1988. Even a return to adherence of the 1990 floodgate operational guidelines (as proposed above) will not restore the former (pre-1988) hydrological regime. Surveys are needed to assess current usage of Vasse estuary by waterbirds, particularly during summer-autumn. Funds should be sought to initiate a suitable census program as soon as possible.

12.3.3 Monitoring of adjoining pastures

It is anticipated that landowners with properties adjoining the estuary will continue to monitor their own pasture and hay production. Agriculture WA is the appropriate agency for landowners seeking technical advice concerning methods for monitoring soil salinity and waterlogging on farmland. The Vasse-Wonnerup Land Conservation District Committee could also be approached for assistance.

12.4 Problems with odours

Nutrient-enriched waterbodies on the Swan Coastal Plain at times produce odours, some of which may be unpleasant. The type, source and timing of these odours can be expected to vary depending upon whether the waterbody in question is permanently inundated, dries seasonally or is tidal. Typical causes of odours are living or decomposing blooms of micro-algae; accumulation and decomposition of larger aquatic plants such as macro-algae, and exposure-without-drying of mudflats rich in organic material. As more people choose to live in close proximity to Vasse estuary, the number of complaints about odours can be expected to rise. In order for these complaints to be properly addressed it will be necessary to obtain reliable information on the source, nature and timing of those odours that are considered most objectionable. Consideration can then be given to appropriate management responses where practicable.

12.5 Catchment management

As indicated in previous sections, excessive nutrient levels are a major contributing factor to the occurrence of fish kills in Wonnerup Inlet and the Vasse estuary exit channel. The Working Group recognises that efforts are being made by landowners and other sectors of the community including government to reduce fertiliser losses from the catchment and to eliminate point sources of nutrients such as dairy herd wastes. Although a major reduction in nutrient loads to the estuary will take years to achieve and will not alone entirely prevent fish kills, it will assist in reducing their frequency and severity. If nutrient loads to the estuary are not reduced the fish kill problem will almost certainly worsen. The formation in 1997 of the catchment-coordinating body *GeoCatch* was an important step in assisting and coordinating efforts to better manage the catchments of Vasse-Wonnerup and Geographe Bay. The Working Group's findings on technical aspects of the fish death problem further emphasise the complex nature of many local environmental problems and the need for a cooperative approach to solving them.

13. ACKNOWLEDGEMENTS

The following agencies were represented on the Vasse Estuary Technical Working Group:

Agriculture WA	(E.Wright, W.Oldfield)
Busselton Shire	(J.Bettink, J.Wroth)
CALM	(C.Broadbent - Chairman)
	(P.Hanly, J.Lane)
Fisheries WA	(R.Tregonning)
GeoCatch	(C.Thorstensen)
Water Corporation	(G.Holtfreter)
Water & Rivers Commission	(K.Hardcastle)

The assistance of all representatives and their agencies is gratefully acknowledged.

Thanks are also due to Mr & Mrs Les and Betty Cuthbert of Dunsborough for searching early issues of the *Busselton Margaret Times* for articles concerning Vasse-Wonnerup; management of *BMT* for providing access to the newspaper collection; Bill Sims of the Water Corporation for locating early plans (elevation transects) of Vasse-Wonnerup; Mark Botica of the Water Corporation for assistance in locating early records of management of the Vasse-Wonnerup system; Tony Lamberto and Don Wallace of the Department of Transport for tidal data and advice; Kevin McAlpine and Geoff Bott of the Department of Environmental Protection for information concerning their late 1980s study of the Vasse-Wonnerup system; Eddy Lim (Dames & Moore), Jenny Davis (Murdoch University), Bernie Masters and Brad Kneebone for salinity data; Yvonne Winchcombe and Richard Ford of CALM for preparation of the graphs and maps respectively of this report, and Grant Pearson and Alan Clarke of CALM for technical assistance.

14. REFERENCES

Bamford, M.J. & A.R. (1995). *Waterbirds of the floodplains of the Vasse and Wonnerup estuaries; patterns of usage and the effect of disturbance.* Unpublished report for the WA Department of Conservation and Land Management.

Bretnall, R. (1987). *The Busselton regional flood study.* Report No. WS4. Surface Water Branch. Water Authority of Western Australia.

Bunbury, Lt-Col W. St Pierre and Morrell, W.P. (Eds.) (1930). *Early days in Western Australia, Being the Letters and Journal of Lt H.W. Bunbury, 21st Fusiliers.* Oxford University Press, London.

Cross, J. (1833). *Journals of several expeditions made in Western Australia.* Facsimile edition 1980, University of WA Press, Perth.

Dames & Moore (1996). *Groundwater and estuary monitoring program, Port Geographe, Busselton.* Unpublished report dated 19 September 1996, for Tallwood Nominees Pty Ltd, Perth.

Davis, J.A. (1990). *Port Geographe midge study: final report.* Unpublished report by Dr J. Davis, School of Biological and Environmental Sciences, Murdoch University, Western Australia, for LeProvost, Semeniuk & Chalmer Environmental Consultants.

Davis, T.J. (1994). *The Ramsar Convention Manual: a Guide to the Convention on Wetlands of International Importance especially as Waterfowl Habitat.* Ramsar Convention Bureau, Gland Switzerland.

Fisheries Department WA (1993) *Black Bream.* Fishing WA No.10.

Gaughan, D.J., Fletcher, W.J. and Tregonning, R.J. (1996). *Spatial and seasonal distribution of eggs and larvae of Sandy Sprat, Hyperlophus vittatus (Clupeidae), off south-western Australia.* Mar. Freshwater Res., **47**, 971-9.

Government of Western Australia (1990). *Wetlands nominated by the Government of Western Australia for Inclusion on the List of Wetlands of International Importance (Ramsar Convention).* Nominating document prepared by Department of Conservation & Land Management, Perth. 43 pp.

Hosja, W. and Deeley, D. (1994). *Harmful phytoplankton surveillance in Western Australia.* Waterways Commission Report 43.

Jaensch, R.P (1996). *Vasse-Wonnerup wetland system.* Pages 904-6 in *A Directory of Important Wetlands in Australia. 2nd Edition.* Australian Nature Conservation Agency, Canberra.

Lane, J.A.K (1990). *Swamped with birds.* WA Department of Conservation and Land Management magazine *Landscope* 5(2):17-22.

Loneragan, N.R. (1993). *Defining key factors relating fish populations in estuaries and their habitats.* In D.A. Hancock ED, Sustainable fisheries through sustaining fish habitat. Australian Society for Fish Biology Workshop. Bureau of Resource Sciences.

McAlpine, K.W., Spice, J.F. and R. Humphries (1989). *The environmental condition of the Vasse Wonnerup wetland system and a discussion of management options.* Environmental Protection Authority Technical Series No.31.

Morgan, D., Gill, H. and Potter, I (1996). *The distribution of freshwater fish in the south-western corner of Australia.* Technical Series Rept. WRT4 1996, Water & Rivers Commission, Perth.

Ninox (1989). *Port Geographe Project - Summary of results - February 1989.* Unpublished report by Ninox Wildlife Consulting for LeProvost, Semeniuk & Chalmer Environmental Consultants, Perth

APPENDIX 1. Early descriptions of the Vasse-Wonnerup system.

On 25 November 1829, Mr Collie and Lieutenant Preston of the British Royal Navy explored Wonnerup Inlet and the lowest reaches of the Vasse estuary in whale boats. They left Port Leschenault (now the site of the City of Bunbury) at 4.45 am that day and arrived at the entrance to Wonnerup Inlet at 9.50 am. Their account of this visit reads as follows (Cross 1833).

"... we entered Port Vasse (*Wonnerup Inlet*) at fifty minutes past 9, through a narrow entrance, with only one foot and three quarters (*approx. 0.5 m)* of water at low water, but tide flowing, and so indistinct, that had it not been for the pelicans and gulls which were sitting on the beach close by it, we should have had difficulty in perceiving it at a few yards' distance. Both here, at Port Leschenault (*Bunbury*), and the Estuary of the Murray River (*Mandurah*), we always found these birds assembled at the entrance, whether of the harbour itself or of the rivers into it, and they were of considerable utility in directing us. A short way inside the beach we found the channel again very shallow; also narrow, and the main branch taking a northerly direction, parallel to the beach, and only separated from it by a few sandy knolls; another branch continued past the opening for one or two hundred yards (*100-200 m*) to the southward, and terminated without any communication. The land adjoining, and to the distance of some hundred yards, is an uneven plain, composed of raised and low places, the former being a tolerable mixture of sand and mould, producing some herbs, shrubs, chiefly liguminous, and trees, for the most part septospermi; the latter is covered with rushes, and swampy. A few hundred yards farther on, along the beach, to the south, there is another similar opening, which, after a narrow channel of good depth, that is bounded on the left by a cliff of calcareous sandstone, and split by an island, becomes so shallow, that our boat could with difficulty be dragged over; it then expands into a considerable sheet of water, the circuit of which we did not complete; but it appeared to be generally very shallow, and on its banks, salt marshes, or a low black clayey, and, at present, dry soil, extended some distance, especially between it and the beach. Inland of this recent formation, a similar, but little more elevated surface, still showing that it had been lately flooded, producing grass and other herbs, without any trees or shrubs, for many acres. Port Leschenault having offered the best prospects of land in its vicinity, and the greatest extent of harbour, which we had every reason to suppose extended many miles in the form of a lagoon, to the northward, behind the sand hills; and Geographe Bay having been formerly surveyed, we had every inducement to return as soon as possible to Port Leschenault; we therefore left Port Vasse at 1 p.m. ..."

In 1836-37 Lieutenant H.W. Bunbury of the 21st Fusiliers spent some months in the vicinity of Vasse-Wonnerup. His description is as follows (Bunbury & Morrell 1930).

"The river called the Vasse ... is not a stream of any importance, having but a short course and not running throughout the year." ... "The river is fresh during the winter and early part of the summer at Mr Bussell's house (*Cattle Chosen*), up to which there is plenty of water for boats from the "B" tree near the beach, but instead of falling into the sea it discharges itself into the more western of the two estuaries, where it is extremely shallow and even quite dry across in the summer".

"These two estuaries (*Vasse and Wonnerup*), which were hitherto very imperfectly known, extend between them about nine or ten miles from E.S.E. to W.N.W., and are divided about half way by what is usually called Wonnerup Island, but it is not entirely surrounded by water except in the wet season or at spring tides. Here are the inlets or communications with the sea, two in number, with bar entrances frequently changing in both depth and situation, the sands at the mouth constantly shifting and being in some places quick and very dangerous. A boat can usually cross the bar, but once in the month of April, with low water at spring tide, we did not find it more than ankle deep and had to unload and drag the boat over upon skids. The two inlets are united by a narrow creek but the inlets or creeks communicating with the estuaries run in different directions, winding very much, with a tolerably deep channel all along, and sandy banks in most parts, though here and there stone appears of a sandy soft nature cemented with lime, too soft and crumbling for building purposes".

"A considerable portion of the island is low and wet, covered with Samphire and flooded as early in the season as May, but all the remainder, except that part near the sea, consists of good but shallow black earth, resting on a bed of white sand and shells and covered with most luxuriant grass. There is a great abundance of good feed for horses and cattle all about the Wonnerup and the grass appears to me to be richer and more succulent than in any other part of the Colony I know, making excellent hay and keeping stock fat throughout the summer".

"Between the estuaries and the sea runs a belt of land varying in width, of a sandy nature but fertile, bearing luxuriant grass, furze trees and small Peppermints which are the only trees growing very near the sea; on the southern or inner edge of the estuaries a narrow strip of tea tree swamp, thick with tangled creepers, coarse grass, reeds and rushes, and composed of rich black vegetable mould, extends along the whole of their course, and within that is a strip of Tooat country, varying from one to two miles in width, bounded by the estuaries on the one side and by the above mentioned clay plains on the other, and extending in an uninterrupted line from the south bank of the Capel to the Sabina, to the westward of which stream I have never seen any, except one small group on Mr Bussell's land".

"I don't think there is much difference in size between the two estuaries and they are both very shallow in most parts, though there are places where the Natives can cross either of them by wading in the dry season".

"Into the Wonnerup estuary fall two stream, the Capel and the Ludlow, the former of which enters at the north east extremity, running through the tea tree swamps and spearwood and across a hard sandy flat where there is a very good ford. From what I know of this stream, it runs to the north west towards the coast from the weirs where I first saw it as far as Mallocup, where it enters a vast swampy lagoon at the back of the beach and then, turning at a right angle, runs about four miles S.W. parallel with the sea, through a very rich country, until it enters the estuary. The Ludlow is but a small stream, a salt creek extending about half a mile up, and then water occurring only here and there in pools".

"Four streams fall into the Vasse estuary, viz: the Abba, Sabina, Vasse and New River; the first of which falls into it from the S.E. at the head, close to the salt creek which runs up to the N.E. and, nearly joining a similar one from the other estuary, cuts off the Wonnerup Island from the main. The Abba is fordable at the mouth and is salt about three quarters of a mile up; there a little fresh stream constantly trickles down and there is a crossing place over a fallen tree, or Waddi bridge as it is called in New South Wales. There is a constant succession of pools above this, though small ones, for about a mile and a half, when, having crossed the clay plains and got between gently sloping banks of sandy soil with Mahogany trees and scrub one finds two considerable deep pools of excellent water, full of Cobblers and Unios and swarming with Ducks and Teal. Above this I know of hardly any water in the dry season".

"The next stream is the Sabina, distant about a mile and a quarter at the mouth, where a low spit of land projects out into the estuary. The salt water extends very little way up, but, the banks being in many parts steep and broken, it is a more difficult brook to cross than the Abba, although in summer it contains less water".

"The Vasse is the principal stream falling into this estuary, but it is much inferior in importance to the Capel, except in point of situation, where it has the advantage of being near a good anchorage in the bay for the shipment of produce; vessels may come within three quarters of a mile of the beach in the fine season with safety, and the water is always smooth with no surf to land through, the bottom hard sand, holding well and gradually shoaling from 6 to 3 and 2 fathoms. A signal is erected by Mr Bussell to mark where boats should land to be near the road to the settlement, in the shape of a cask painted white and placed on a pole. From this, commonly called the "Tub", it is a mile and a half to Yondorup; one can either cross by the ford over the Vasse near the estuary or else in a boat at the B tree a little higher up".

"Close above this the New River joins the Vasse: it more deserves the name of a creek or a swamp than of a river. It comes from the westward, having run parallel with the sea bank for seven or eight miles, it is in most parts swampy and muddy, so as to be difficult to ford".

....

....

"At Wonnerup there is an excellent landing place for boats in the western Inlet (*western arm of Wonnerup Inlet*) whenever the bar can be crossed by laden boats, but the water is too shoal, with heavy rollers in bad weather, to attempt it when it blows fresh; in that case the Tub (*the ocean beach at Busselton*) is the best place to run for".

APPENDIX 2. The 1990 guidelines for operating the floodgates and managing the sand bar.

The Water Authority's "Update to Hand Book of Basic Data" (August 1990) reads as follows with respect to operation of the floodgates and management of the sand bar at the mouth of Wonnerup Inlet.

2.9 Vasse and Wonnerup Floodgates

2.9.1 General

"The Vasse and Wonnerup floodgates protect the low lying agricultural land surrounding the Vasse and Wonnerup Estuaries from flooding with sea water".

"They also have a check board facility on each flood-gate to allow fresh water to be retained at the end of winter to control the drop in water table on these flats. This is done to maintain water in the estuary system for as long as possible and to hold back any summer run-off".

"Due to high temperatures and low levels in the estuaries, there is a strong possibility that fish fatalities will occur in the Vasse estuary and between the floodgates if the bar is closed, with resultant criticism of the Authority".

"The Authority's major obligation is the interest of the drainage ratepayers and this will be the overriding consideration. It will however, be necessary to take action to facilitate better environmental management where the interest of the ratepayers can be protected".

2.9.2 Maintenance

"The gates must be lifted each year and scraped clear of marine growth and any corrosion on steel work protected. The structures should be annually sprayed for protection against white ants and fire".

2.9.3 Operation

2.9.3.1 WINTER

"Immediately after the first rains produce run-off, the boards can be removed. To prevent vandalism, these boards should be stored in the Depot."

"Due to the fact that the ocean outlet for these two structures will block easily, it may be necessary to open this bar by mechanical means on several occasions throughout the winter. Experience has shown that to attempt to open the bar without sufficient head is a waste of time, and the gauge board at the Vasse Floodgate should attain a reading of at least 0.7m AHD, or the attempt will probably fail (unless the sea is extremely quiet with low tides. This is unlikely at times when the bar is blocked and the Estuaries are between 0.4m and 0.7m AHD in height)".

"Before the run-off has finished for the season, it is necessary to fix the stopboards to a height of 0.40m AHD so that the fresh water is retained, to facilitate the breeding of waterfowl. (It is desirable - but difficult - to keep the water at 0.40m AHD)".

2.9.3.2 SUMMER

"The water levels should be monitored at the Vasse Floodgates on a minimum monthly basis until the level reaches 0.1m AHD and then on a minimum weekly basis. If three consecutive days of temperatures in excess of 30 degrees occur, preparation should be made to allow fish to pass through the gates if they show any signs of stress (swimming on surface)".

"When the level reaches -0.1m AHD, farmers on the Vasse estuary should be notified and the gates opened to maintain the level at -0.1m AHD".

"Under no circumstances should salt water be allowed to come back behind the gates to allow the levels to become higher than -0.1m AHD"

"The level of -0.1m AHD has been found to be acceptable by farmers in the area and appears to be satisfactory to relieve stress on the fish. It should be reviewed periodically with interested parties. Tests have also shown that at this level the salt is diluted to acceptable levels when the Vasse estuary fills with run-off water so that no damage is done to surrounding pastures"

"In the event of the sand bar being closed and no water available to come back, a decision to open the sand bar must be made in conjunction with the Regional Operations Engineer as a matter of urgency".

APPENDIX 3. Vasse estuary water level records

A knowledge of past water levels is important in developing an understanding of the ecological character of the Vasse estuary and changes that have occurred to it. Historical water level data also assist in predicting likely ecological consequences (e.g. to fringing vegetation) of future alterations to the estuary's hydrological regime.

During preparation of this report efforts were made to locate all previous records (i.e. measurements to a known datum) of water levels in the Vasse estuary from earliest european settlement (1830s) to the present day. A search was made of current and archived files of the Water Corporation and its predecessors (WA Water Authority and Department of Public Works). Data were also obtained from the Water & Rivers Commission (1992-93) and from Department of CALM records (principally 1994-1997).

Water level records from Wonnerup estuary were also collated. However, with one exception these are not reported here.

Water level records to 1966

The only water level records found for the period from first european settlement to the late 1960s were a small number from winter-spring of 1926, 1928, 1938, 1940 & 1942-44. No actual *measurements* of water levels prior to installation of the Vasse estuary floodgates (in 1908) were found (for *descriptions* of water depths in 1829 and 1836-37 see section 5.1.1 of this report). All of the 1926 to 1944 recordings were made by the Public Works Department and most were readings of PWD gauge boards (initially in imperial and subsequently in metric units) installed on the upstream side of the floodgates. All of these 1926-44 records are listed in Table 1.

Table 1. A list of all known, measured water levels of the Vasse estuary from earliest european settlement (1830s) to 1966.

Date (1900s)	Water level (ft RL)	Water level (m AHD)*	Comment
winter 26	106.725	1.14	Water 16-18 inches deep over Wonnerup Causeway.
23.07.28	105.60	0.80	Water 3-4 inches deep over Wonnerup Causeway.
21.09.28	103.85	0.27	
11.10.38	103.36	0.12	The sand bar was closed on this day.
09.11.38	103.34	0.11	This measurement is approximate.
26.07.40	103.79	0.25	"Vasse estuary is now filling quickly". Sand bar is still unbroken.
14.08.40	103.56	0.18	Bar broke open c. 28/7 for a few days. Water level fell considerably.
21.08.40	103.60	0.19	
04.10.40	104.44	0.45	Which estuary unspecified. Bar was not opened.
04.11.40	104.04	0.33	
11.11.40	103.94	0.30	
19.11.40	103.73	0.23	
26.11.40	103.56	0.18	
03.12.40	103.37	0.12	
15.10.42	104.33	0.41	The sand bar was opened on this day.
16.10.42	103.88	0.28	Two 8 inch boards were installed on this day
22.10.42	103.70	0.22	
29.10.42	103.08	0.03	
04.11.42	103.02	0.02	
06.10.43	102.83	- 0.04	Two 8 inch boards have been installed. A third will be added.
18.09.44	103.42	0.14	Three 8 inch boards were installed on 4 Sept. One 6 inch board still to be added.

* These levels have been derived from the RL levels and assume that RL 100 ft equals -0.905 m AHD.

In 1963 the water level in Wonnerup estuary reached +1.13 m AHD. Because the Vasse and Wonnerup estuaries are well-connected by Malbup Creek during floods, the waters of Vasse estuary would probably have reached a similar level at that time. However, when Vasse estuary is in flood the water level in its mid and upper reaches may be tens of centimetres higher than at the floodgates so caution must be exercised in comparing water level readings from the floodgate gauge board with levels measured elsewhere. The winter 1926, July 1928 (Table 1) and 1963 (Wonnerup estuary) levels are probably best compared with the peak levels of Figure 4 in section 5.1.5 of this report.

Water level records (non-continuous) from the late 1960s onwards

Many more "non-continuous" water level records (gauge board readings) have been located for the period 1967 onwards (principally 1979 onwards). The great majority of these readings were taken by drainage authority employees at approximately weekly intervals during winter-spring each year and related to ensuring the proper operation of the floodgates and to the timing of installation of stop boards. The 1979 onwards winter-spring readings are too numerous to usefully list here and are instead presented graphically in Figure 3 in section 5.1.4 of this report.

For interest, a list of the *highest* water levels *recorded* each year from 1967 onwards is presented in Table 2. Because flood peaks in Vasse estuary are very short-lived (see Figure 4) and the gauge board readings were taken at longer intervals (usually one week), these levels are unlikely in most cases to be the highest *reached* each year.

Table 2. Highest water levels *recorded* in Vasse estuary each year, from 1967-96.

Date	Water level (m AHD)
25.08.67	0.32
05.07.68	0.66
01.08.69	0.46
26.06.70	0.77
17.09.71	0.89
05.07.72	0.54
13.09.73	0.64
27.06.74	0.77
30.10.75	0.61
29.07.76	0.46
11.08.77	0.66
29.06.78	0.64
23.08.79	0.57
01.10.80	0.55
23.07.81	0.70
16.07.82	0.70

Date	Water level (m AHD)	Comment
30.06.83	0.68	
21.06.84	0.60	
27.06.85	0.50	
31.07.86	0.60	
06.08.87	0.80	
22.09.88	0.70	
27.07.89	0.75	
12.07.90	0.50	Also 0.50 mAHD on 19/7, 27/9 and 11/10
...........91	?	Insufficient records available
02.07.92	0.65	Erroneous record of 2.50 mAHD on 23/7/92
...........93	?	Insufficient records available
...........94	?	Insufficient records available
23.06.95	0.60	
04.07.96	0.80	Also 0.80 mAHD on 18/7 and 1/8. Erroneous record of 1.50 mAHD on 3/10
...........97	?	Records not yet obtained

Summer-autumn water levels prior to 1992 (when continuous recorders were installed)

In the context of this report, the water level of the Vasse estuary during summer and autumn each year is particularly important. Regrettably, very few measurements were made of water levels at this time of the year prior to installation of continuous recorders in July 1992. From a drainage perspective this was quite normal as regular monitoring was not necessary during the dry season due to the low probability of flooding rains. Some pre- July 1992 readings were taken however and these are presented in Table 3.

It is evident from Table 3 that, with the exception of the reading in May 1983, all Water Corporation readings during summer-autumn prior to 1988 were taken following above-average rainfall and were related to the possible need to prepare for river flow to the estuary. These readings do not give a true picture of normal summer-autumn water levels in Vasse estuary prior to 1988. As indicated in section 5.1.4 of this report, aerial photography examined to date indicates that the summer-autumn water level in Vasse estuary prior to 1988 normally declined to a minimum of around -0.4 m AHD

Summer-autumn readings located for the period 1988-91 mostly relate to efforts to prevent fish deaths. Summer-autumn gauge readings have been taken in subsequent years (1992-97), however they are not reported here due to the availability of continuous water level recordings for this period (see below).

Table 3. A list of all known summer-autumn (Dec-May) water level records from Vasse estuary from earliest european settlement (1830s) to July 1992. Records known to have followed unseasonal rains are in italics.

Date (1900s)	Water level (m AHD)	Rainfall (mm & % of average) in month or two before water level record, and other Comments	Source of record
07.05.80	*0.25*	*82 mm (195%) in April.*	*Water Corp*
14.05.80	*0.00**		*Water Corp*
21.05.80	*0.25*		*Water Corp*
28.05.80	*0.20*		*Water Corp*
28.05.81	*0.00**	*126 mm (107%) in May*	*Water Corp*
08.02.82	*0.03*	*47 mm (492%) in January*	*Water Corp*
26.05.83	0.23	8 mm (19%) in April and 65 mm (55%) in May	Water Corp
17.05.84	*0.02*	*164 mm (139%) in May*	*Water Corp*
25.05.84	*0.12*		*Water Corp*
31.05.84	*0.14*		*Water Corp*
10.04.85	*0.09*	*94 mm (226%) in April*	*Water Corp*
21.05.86	*0.00**	*143 mm (122%) in May*	*Water Corp*
29.05.86	*0.10*		*Water Corp*
17.12.87	0.21	D. Munro reading was 3 ft 8 ins, presumably RL 103.67	CALM
< 15.3.88	- 0.30		Water Corp
16.03.88 ?	- 0.01	Two gates closed, one left open 25 mm.	Water Corp
> 15.3.88	- 0.10		Water Corp
03.02.89	- 0.12	Gate opened. Some boards left in.	Water Corp
08.02.89	- 0.12		Water Corp
10.02.89	- 0.12	All boards taken from 1 bay at 0830. Most replaced at 1600. Gate still wedged open.	Water Corp
11.02.89	- 0.095	Gate shut.	Water Corp
13.02.89	- 0.12		Water Corp
14.12.89	0.20		Water Corp
18.12.89	0.20	Two gates wedged open.	Water Corp
22.12.89	0.15	Gates open.	Water Corp
28.12.89	0.10	Gates open.	Water Corp
03.01.90	0.10	Gates open.	Water Corp
15.01.90	0.00	Gates open. Level "0.12 m higher than last year".	Water Corp
19.01.90	- 0.05	Gates open.	Water Corp
01.02.90	- 0.05	Gates open.	Water Corp
03.03.90	0.05	Gates shut (cyclone warning).	Water Corp
03.05.90	*0.10*	*Gates stay shut. 123 mm (123/42 %) in April.*	*Water Corp*
21.04.91	- 0.10	Water level on ocean side of floodgates 1.70 (just overtopping structure) due to effect of Cyclone Fifi and other lows in the north.	Water Corp

* There is some uncertainty about the accuracy of 0.00m readings. Examination of winter-spring values suggests that for a number of years negative values were recorded as 0.00m.

Continuous water level recordings (Jul 1992 - Dec 1993 and Aug 1994 onwards)

In July 1992, the WA Water Authority installed a continuous water level recorder near the south shore of the Vasse estuary, midway between the mouths of the Abba and Sabina Rivers. This operated until December 1993. CALM installed two water level recorders in August 1994. One of these is located in the same place as the Water Authority's recorder. The other is near the north shore, roughly midway between the mouths of the Sabina and Vasse Rivers. A continuous trace of records from these instruments is presented in Figure 4 in the main body of this report.

100 year and 25 year flood level estimates

The following information is presented for reference purposes.

The 25 year flood level in the Vasse and Wonnerup estuaries without flood fringe development has been estimated to be +1.25 m AHD (Bretnall 1987). The 100 year flood level without development of the "flood fringe" (that portion of the floodplain in which land fill was considered acceptable from a flood management perspective) was estimated to be +1.35 m AHD. The 100 year flood level with flood fringe development was estimated to be +1.45 m AHD.

APPENDIX 4. Vasse estuary salinity records

Knowledge of seasonal, year-to-year and longer term variations in the salinity of Vasse estuary is important in developing an understanding of the ecological character of the estuary and changes that have occurred to it. Historical salinity data also assist in predicting likely ecological consequences (e.g. to fringing vegetation) of future changes to the estuary's salinity regime.

During preparation of this report, efforts were made to locate all previous records (i.e. measurements) of salinities in the Vasse estuary from earliest european settlement (1830s) to the present day. A search was made of current and archived files of the Water Corporation and its predecessors (WA Water Authority and Department of Public Works). Data were also obtained from environmental consultants' reports relating to the Port Geographe canal estate development (Davis 1990; Dames & Moore 1996; D&M unpublished data to September 1997); from Department of CALM records and from former surveyors of waterbirds on Vasse-Wonnerup (B. Kneebone and B. Masters).

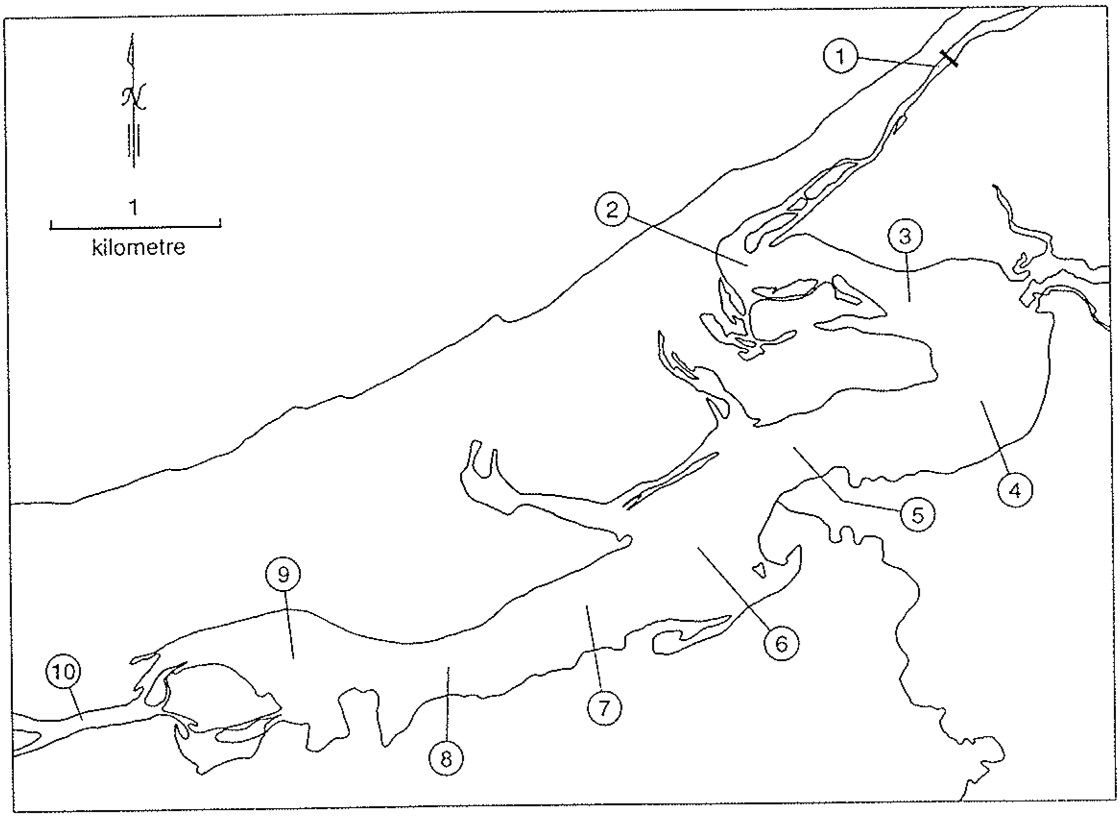


Figure 1. Location of salinity sampling points referred to in Tables 1 and 2 of this Appendix.

A summary of all of the Vasse estuary salinity data obtained from the above sources is presented in Table 1 of this Appendix. Salinity records from Wonnerup estuary were also collated, however these are not reported here.

Frequent (monthly or more often) monitoring of salinity for an extended period (12 mths or more) has been undertaken at only one location in Vasse estuary. This is location '1' (immediately upstream of the floodgates) where the Water & Rivers Commission has monitored salinity at fortnightly intervals for 12 months (Aug 96 - Jul 97). A summary of the results of this work is presented in Table 2.

Table 1. A summary list of measured salinities in Vasse estuary from earliest european settlement (1830s) to 1997. Refer to Fig 1 of this Appendix for approx. location of sampling points. Surface salinities only are shown. Salinity stratification rarely extends upstream of locn 3 due to shallow depth of estuary and exposure to wind. All dates are 1900s.

Date	1	2	3	4	5	6	7	8	9	10	Source
18.10.78	3	-	-	-	-	-	-	-	-	-	CALM
27.01.82	-	8	-	-	-	-	-	-	-	-	BKneebone
27.12.82	-	3	-	-	-	-	-	-	-	-	BKneebone
17.04.85	37	-	-	-	-	-	-	-	-	-	CALM
25.01.87	-	30	26	-	-	-	-	-	-	-	BMasters
15.02.87	-	31	32	-	-	-	-	-	-	-	BMasters
12.11.87	2	2	1	1	2	2	1	1	-	-	CALM
17.12.87	3	3	3	3	4	4	-	-	-	-	CALM
15.09.88	-	1	-	-	2	-	1	-	-	-	J.Davis
20.10.88	-	2	-	-	2	-	2	-	-	-	J.Davis
02.11.88	-	3	-	-	2	-	1	-	-	-	J.Davis
17.11.88	-	2	-	-	2	-	2	-	-	-	J.Davis
29.11.88	-	2	-	-	3	-	2	-	-	-	J.Davis
13.12.88	-	5	-	-	3	-	3	-	-	-	J.Davis
29.12.88	-	7	-	-	5	-	5	-	-	-	J.Davis
01.02.89	-	18	-	-	15	-	15	-	-	-	J.Davis
24.02.89	31	31	30	30	36	38	41	51	-	-	WCorp
03.03.89	-	20	-	-	21	-	20	-	-	-	J.Davis
03.02.89	30	-	-	-	-	-	-	-	-	-	WCorp
08.02.89	31	-	-	-	-	-	-	-	-	-	WCorp
13.02.89	31	-	-	-	-	-	-	-	-	-	WCorp
30.03.89	-	22	-	-	39	-	39	-	-	-	J.Davis
30.03.89	27	29	33	38	44	46	48	50	-	-	WCorp
25.04.89	-	23	-	-	35	-	30	-	-	-	J.Davis
26.05.89	-	18	-	-	20	-	23	-	-	-	J.Davis
22.06.89	-	14	-	-	16	-	12	-	-	-	J.Davis
...........89	-	-	-	-	-	-	-	-	6	1	WCorp
25.07.89	5	3	3	-	-	-	-	-			WCorp
27.07.89	-	5	-	-	7	-	7	-	-	-	J.Davis
29.07.89	-	-	-	4	3	1	2	5		<1	WCorp
22.09.94	2	2	2	-	1	1	-	1	1	-	D&M
14.12.94	31	7	7	-	8	29	-	-	-	-	D&M
09.03.95	26	26	20	-	>33	>33	-	-	-	-	D&M
06.07.95	7	4	4	-	4	5	-	5	-	-	D&M
01.09.95	1	1	1	-	1	1	-	-	-	-	D&M
18.12.95	17	12	7	7	7	7	6	-	4	1	CALM
05.01.96	15	13	11	-	10	7	-	6	-	-	D&M
05.01.96	14	13	10	-	-	-	-	-	-	-	CALM
06.01.96	-	-	-	-	9	-	6	-	6	1	CALM
07.03.96	>33	>33	>33	-	>33	>33	-	>33	-	-	D&M
05.06.96	27	27	27	-	30	>33	-	>33	-	-	D&M
19.09.96	1	1	1	-	1	1	-	1	-	-	D&M
13.12.96	6	5	4	-	3	3	-	2	-	-	D&M
01.03.97	>33	31	31	-	32	>33	-	-	-	-	D&M
17.03.97	36	37	36	36	35	33	33	33	31	5	CALM
17.06.97	10	9	3	-	9	10	-	10	-	-	D&M
12.09.97	1	1	1	-	2	2	-	2	-	-	D&M

Table 2. Average monthly surface salinity on upstream side of Vasse estuary floodgates (sampling location 1) in 1996-97. Not evident from this table is a sudden decrease in salinity (from 31 ppt on 3/6/97 to 2 ppt on 24/6/97) that occurred following commencement of river flow (source of data: K. Hardcastle, W&RC).

Month	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
Salinity	1	2	2	7	7	16	31	38	40	37	11	10

APPENDIX 5. The use of estuaries by fish

Estuaries as fish habitat

Estuaries are characterised by the mixing of waters derived from both oceanic and riverine sources. They are environments in which the parameters most critical to aquatic life, the water chemistry (including salinity) and temperature, can fluctuate markedly, and sometimes rapidly, over the year. Despite this, estuaries in general are amongst the most productive environments in the world and often support abundant fish life. Juvenile fish in particular are likely to benefit from the abundance of food, relatively warmer water temperature, and the protection from predation which is provided by the aquatic vegetation in the estuary and by the presence of turbid water. These benefits are in turn dependent on the condition of the estuary waters and it is typical of many estuaries that the number of fish of each species and the species composition of the fish community undergo seasonal changes (Loneragan 1993).

The types of fish in estuaries

Estuaries may host essentially freshwater fish which move within the river and estuary in response to changes in salinity. Estuaries also support saltwater fishes. Some saltwater fishes are resident in estuaries all year round, moving into pockets of saline water during the winter in order to avoid the flush of fresh riverine water. Other saltwater fish are only present during specific times. Some species use the estuary as a nursery, with the juvenile fish either migrating into the estuary or spawned in the estuary taking advantage of the productive spring and summer estuarine conditions as they grow until the winter run of fresh water drives the young adults out to the ocean. Whitebait, for example, are spawned in the ocean but when they develop into juveniles they migrate into marine bays and estuaries open to the ocean where they continue their growth (Gaughan, Fletcher & Tregonning. 1996). Other examples of essentially marine fish which may make use an estuary as a nursery during summer are mulloway and tailor.

In addition to these fishes which regularly make use of estuaries in the course of their life history, there are other marine species which are opportunistic and which may move into estuaries which are open to the sea when conditions are suitable. Whiting and Australian herring are examples of fish that make use of an estuary in this way. In addition, some marine species are transient within estuaries and are found irregularly in that environment.

List of the fishes known to occur in the Vasse estuary and river

Fish that use the estuary opportunistically[1]	
Australian Herring	*Arripis georgianus*
Marine fish that use the estuary as a nursery[1]	
Sea Mullet	*Mugil cephalus*
Yellow Eye Mullet (Pilch)	*Aldrichetta forsteri*
Mulloway	*Argyrosomus holoepidotus*
Yellow-finned Whiting	*Sillago schomburgkii*
Whitebait	*Hyperlophus vittatus*
Freshwater fish that also occur in the estuary[1]	
Black Bream	*Acanthopagrus butcheri*
Freshwater fish found principally in the river system[2] *(*introduced species)*	
Western Minnow	*Galaxias occidentalis*
Western Pygmy Perch	*Edelia vittata*
Night Fish	*Bostockia porosa*
Blue Spot Goby	*Pseudogobius olorum*
Mosquitofish*	*Gambusia affinis*
Carp*	*Carassius* species
Redfin Perch* (possibly)	*Perca fluviatilis*

Sources: [1] *Fisheries WA staff and professional fishermen.* [2] *Morgan, Gill & Potter (1996).*

APPENDIX 6. Description of a mass fish death incident prior to installation of the floodgates

The following description of a major fish death incident in the lower reaches of Vasse-Wonnerup in 1905 - three years before floodgates were installed - has been obtained from an early edition of a local newspaper, *The South-Western News*.

> **"Wonnerup Estuary: In a disgraceful condition"**
>
> "The state of the Wonnerup estuary about the locality of Ballarat* and indeed for some considerable distance towards Busselton, is becoming a serious matter to the health and welfare of the town. The chief cause of the trouble appears to be that owing to siltage the mouth of the Estuary has become closed to the tides, and the water inside, consequent upon the absence of rains, becomes dead and stagnant. Some time ago a contract was entered into between a local resident and the Government for the keeping open of a cut sufficient to allow the sea water at high tide to enter the mouth, and so flush the Estuary. The work was carried out for some time, but recently, the contractor is reported to have stated that he is unable to continue the work and is applying to the Department for the cancellation of the contract. Meanwhile the evaporation through the warm weather has largely reduced the quantity of water in the estuary, with the result that hundreds and thousands of fish of all kinds are left rotting upon the banks. The stench emitted from these decayed fish is very foul, and unless steps are taken to immediately open the mouth of the Estuary, sufficient to allow a good volume of sea water to enter, the residents of Wonnerup, and probably Busselton, may look for a typhoid or other epidemic. The local Board of Health have become seized with the seriousness of the position, and are making representation to the proper authorities forthwith. Up to the present, no information is to hand regarding the movements of the Wonnerup people in the matter, and if no move up to the present has been made, special representation should be made from the Progress Association at once" (Source: *The South-Western News, February 3, 1905*)
>
> ** The locality of "Ballarat" is where the Vasse estuary floodgates are now situated. This is where Vasse estuary joins Wonnerup Inlet. The name "Wonnerup Estuary" has therefore been incorrectly applied in the above article, at least in relation to geographic names currently in use.*

Another article in the same issue of *The South-Western News*, under the heading "Busselton Municipal Council - Monthly Meeting", reads:

> "Mr. Hough drew attention to the foul state of the Wonnerup** and Vasse estuaries, owing to the presence of large quantities of putrid fish, and pointed out that the present state of affairs is a serious menace to the public health. The Board decided to communicate with the authorities, asking that immediate action be taken to remedy the nuisance".
>
> *** Given the description in the previous article, in this article "Wonnerup" possibly refers to the area now known as Wonnerup Inlet, rather than to Wonnerup estuary.*

APPENDIX 7. Summary of management options discussed by McAlpine, Spice & Humphries (1989)

The following table is a summary of options discussed by McAlpine, Spice & Humphries (1989) for managing the environmental condition of the Vasse-Wonnerup wetland system, particularly in relation to sudden mass fish deaths in the lower reaches of the system.

OPTION	COST ($1000s)	COMMENTS (OF McALPINE, SPICE & HUMPHRIES)
1. Bar Management		
a) Leave the bar as it is allowing it to open and close without any manipulation.		No benefit. "Not recommended".
b) Open the bar when necessary.	5 per year	Monitoring and criteria for opening needed.
c) Maintain the bar permanently open.	70 plus ≤150 per year	
2. Floodgates		
a) Replace the existing structure with a similar one-way flow structure, but with the facility to allow marine water back into the lagoon from Wonnerup Inlet for short periods when necessary.	500 per structure	Not considered the most favourable option. Would require further evaluation.
b) Construction of storm surge gates allowing two way flow and c) removal of the floodgates.	400 each; plus 7(a) or 7(b) costs	Cannot be adequately evaluated without additional studies.
d) Relocation of the floodgates upstream to increase the length of the tidal reach within Wonnerup Inlet.		
e) Increase the height of the gauge boards immediately behind the floodgates.	Little or no extra cost	Unlikely to improve water quality. "Not recommended"
f) Remove the floodgates from Wonnerup Lagoon.		Fish kills would continue in Vasse estuary.
3. Catchment Management		
a) Manage fertiliser applications.		Favoured.
b) Manage nutrient discharge at point sources.		Favoured.
c) Convert pastured land on the coastal plain to forestry.		Suggested as a possibility.
4. Dredging		
a) Dredging of Wonnerup Inlet only	200	
b) Dredging of a channel from the floodgates into the lagoon basins.	500	
5. Levee Banks		
a) Construct levee banks around one or both lagoons using on-site materials.	330 or 580	Option of last resort.
6. River Re-diversion		
a) Redivert flow from the Vasse diversion drain back into the Vasse Lagoon.	Not costed	Would cause flooding & worsen eutrophication. "Not recommended".
b) Redivert flow from the upper Sabina River back down the lower Sabina River and into the Vasse Lagoon.	Not costed	Would cause flooding & worsen eutrophication. "Not recommended".
c) Redivert flow from the Capel River into the Wonnerup lagoon.	Not costed	Would cause flooding & probably worsen eutrophication.
d) Redivert all the original river flows back through the Vasse-Wonnerup system.	Not costed	Would cause flooding & probably worsen eutrophication

Table continues on next page

Table continues from previous page

OPTION	COST ($1000s)	COMMENTS (OF McALPINE, SPICE & HUMPHRIES)
7. Control of landuse fringing the lagoons a) Do nothing.		No benefit.
b) Compensate for loss of productivity.		Needed if estuary to be flooded with salt water.
c) Acquire the land fringing the lagoons.	Market value	Needed if estuary to be flooded with salt water.
d) Enter into a voluntary agreement with landowners to manage specific habitat areas requiring protection and those pastures that become flooded.		A suggested means of protecting conservation values.
8. Artificial aeration a) Construct a fountain to aerate remaining water over summer.	10 plus 5 per year	May promote algal growth. Further study required.
b) Aerate the water column by bubbling compressed air.	10 plus 5 per year	May promote algal growth. Further study required.
9. Increase volume of water in the lagoon a) Pump groundwater into the lagoons over summer.	65 plus running costs	Poor result likely. "Not recommended".
10. Barrage across the lagoon a) Construct a barrage across a section of the lagoon upstream of the floodgates.	2.5-17 per km	Favoured.

For more information on the above options, refer to section 11.2 of this report or to McAlpine, Spice & Humphries (1989).

APPENDIX 8. Proposed water quality monitoring program for the lower reaches of the Vasse-Wonnerup system in 1997-98

The following program has been designed by the Water & Rivers Commission (Ms K. Hardcastle) and is proposed for initiation by the Commission in 1997-98.

1.0 Background

The Vasse-Wonnerup wetland system is a series of highly modified estuary basins with a common connection to Geographe Bay. Both the Vasse and Wonnerup basins have one-way floodgates positioned in their exit channels. These were installed in 1908 to prevent salt water inundation of fringing grazing lands. The operation of the floodgates has resulted in the conversion of what were once tidal estuaries into lagoons which are predominantly fresh but which become increasingly saline as they dry over the summer (McAlpine et al 1989).

The Wonnerup Basin is fed by the Ludlow River which is included in an ongoing monitoring program encompassing the whole of the Geographe Catchment. The Vasse Lagoon is fed by the Abba and Sabina Rivers, although the flow from the upper reaches of the Sabina Catchment is diverted to the sea via the Vasse Diversion drain, installed in 1927.

The lower reaches of the Vasse River, below the confluence with the Vasse Diversion drain, also feed into Vasse Lagoon. The design of the junction between the River and Drain is such that a certain level of flow can be maintained through the Busselton town section of the River although in practice this does not occur and there is little water movement in this section of the River. A stop board structure behind the old butter factory enables water levels to be maintained in the town for aesthetic purposes.

There is a history of fish deaths in the lower reaches of the Vasse-Wonnerup system, the cause of which is most likely the deoxygenation of the water associated with the breakdown of the frequent algal blooms. The system is considered to be eutrophic and experiences blooms of toxic micro-algae during the summer and autumn.

2.0 Project Aims

The general aim of the water quality monitoring program is to provide information to the Water & Rivers Commission and Land Managers on ecosystem health of the Vasse-Wonnerup lagoons and the lower reaches of the Vasse River. The program is designed to be ongoing and as such to detect long term changes in water quality.

It is hoped that this monitoring program will enable the early detection of conditions which facilitate fish deaths and enable action to be taken in order to avoid them.

The program will link to existing programs running in the catchment to provide a full picture of the environmental health of the system in terms of sources of pollution and the overall effects on the Vasse and Wonnerup basins.

Although the program is designed to run to a prepared format, it is planned that the program remain dynamic enabling changes to be made which reflect the changing requirements of community members and land managers.

3.0 Program Objectives

The objectives of the project are as follows:

- To report to the Water & Rivers Commission, Land Managers and the Community on the water quality and waterways system health of the Vasse-Wonnerup lagoons and the lower reaches of the Vasse River;
- To increase awareness of the effects of land degradation on water system health;
- To evaluate and provide feedback to the Water & Rivers Commission, Land Managers and the Community on the effectiveness of management methods.
- To develop an improved understanding of the conditions in these waterbodies that lead to algal blooms and fish deaths.
- To provide an early warning system in terms of conditions in the waterbodies which lead to algal blooms and associated fish deaths to enable evasive action, where possible, to avoid loss of fish.

4.0 Program Methodology

4.1 Monitoring System Design

The monitoring program is designed to regularly assess the health of the Vasse-Wonnerup Lagoons, the Deadwater and the town section of the Vasse River. A total of 12 sites will be sampled routinely throughout the program, two in the Vasse River, three each in the Vasse and Wonnerup Lagoons, two in the Wonnerup Inlet between the flood gates and the sandbar, and two in the Deadwater north-east of the Wonnerup floodgates. A list of the sites and their locations can be found in Appendix 1.

In addition to these routine sites phytoplankton density and species present will be monitored at an additional six sites in the Vasse Lagoon and River during bloom events to enable a more accurate understanding of bloom density and spread to be developed.

4.2 Sampling Frequency and Variable to be measured

The parameters to be measured and the frequencies of monitoring are listed in Tables 1 & 2.

Table 1 - Field Measurements

Variable	Frequency	Method	Reason
Sandbar status		◊ Record if open or closed and the direction of any flow	◊ implications for the operation of the floodgates
Water level	continuous recorder - telemetered and poled as required (upstream and downstream at both floodgates)	◊ Also Staff Gauges installed at AHD upstream & downstream of both floodgates and in Deadwater	◊ implications for the operation of the floodgates
Dissolved Oxygen	continuous recorder - telemetered and poled as required (Upstream of floodgates only)	◊ Datasonde 4 Hydrolab multi-probe ◊ profiled where possible	◊ standard requirement for aquatic life; ◊ indicator of organic pollution and trophic state
pH		◊ Datasonde 4 Hydrolab Multi-probe ◊ profiled where possible	◊ indicator of pollution
Temperature	continuous recorder - telemetered and poled as required (Upstream of floodgates only)	◊ Datasonde 4 Hydrolab Multi-probe ◊ profiled where possible	◊ indicates stratification ◊ affects other water quality parameters
Salinity/ Conductivity		◊ Datasonde 4 Hydrolab Multi-probe ◊ profiled where possible	◊ indicates stratification
Turbidity		◊ Datasonde 4 Hydrolab Multi-probe ◊ profiled where possible	◊ indicator of suspended material ◊ affects other water quality parameters

Note: unless otherwise stated physical parameters will be measured at monthly intervals from May to November; fortnightly from December to April, and weekly during bloom events.

Table 2 - Laboratory Measurements

Variable	Frequency	Method	Reason
Phytoplankton	collected every visit	◊ grab samples sent to WRC phytoplankton ecology unit	◊ implications for public health ◊ interpretation of chlorophyll data
Chlorophylls (a, b, c & phaeophytin)	monthly	◊ filtered samples sent to ANALABS	◊ standard indicator of phytoplankton density ◊ comparison with other systems in WA
Nutrients (NO_3, NO_2, NH_4, FRP, TP, TN)	monthly	◊ samples sent to ANALABS	◊ indication of eutrophic state
BOD	monthly December - April	◊ samples sent to ANALABS	◊ reflects microbial activity and amount of biological material in the water
Pesticides	quarterly	◊ samples sent to AGAL	◊ establish base level data for the system
Metals (As, Cd, Cr, Pb, Zn)	quarterly	◊ samples sent to AGAL	◊ establish base level data for the system

4.3 Data Analysis

Initially physical and chemical data will be analysed graphically until data is of a sufficient size to warrant statistical analysis. Data will be entered into the Water & Rivers Commissions EDICT database where it will be accessible to all WRC staff and also to any member of the public via a formal data request.

4.4 Reporting

The first report will be prepared at the conclusion of the first twelve months of sampling and will discuss the results of monitoring and implications for management of fish deaths.

Reactive reports will also be prepared when required to notify stakeholders of impending problems in the system.

REFERENCES

McAlpine KW, Spice JF, Humphries R (1989). *The Environmental Condition of the Vasse Wonnerup Wetland System and a Discussion of Management Options.* EPA Technical Series No.31. Perth WA.

Derrington C & Donohue R (1996). *Revised Water Quality Monitoring Program in the Leschenault* Water & Rivers Commission. Perth WA (unpublished).

Klemm VV (1989). *Organochlorine Pesticide Residues in the Preston River WA*. Waterways Commission Report No.12. Perth WA.

Claudius R (1996). *Principles and Management Strategies - Interpretation of Sediment and Water Quality Data - Leschenault Study.* Water & Rivers Commission. Perth WA (unpublished).

Appendix 1

Sample site locations

Site name	AWRC Code	Location
Vasse River 1	Q 6101063.7	Strelly Street Road Crossing (N6274347 E0346920)
Vasse River 2	Q 6101064.9	@ old rail crossing on causeway foreshore (N6274882 E0346688)
Vasse Estuary 1	S 610019.3	@ floodgates (N6278792 E0352702)
Vasse Estuary 2	Q 6101065.0	@ Ballarat Road foreshore (N6278107 E0352160)
Vasse Estuary 3	Q 6101066.2	@ Webster Road foreshore (N6277696 E0352097)
Wonnerup Inlet 1	Q 6101067.4	50 metres south of Layman Road Crossing (N6279048 E0353278)
Wonnerup Inlet 2	Q 6101068.6	500m upstream from mouth (N6279555 E0353521)
Wonnerup Estuary 1	S 610020.X	@ floodgates (N6279448 E0353845)
Wonnerup Estuary 2	Q 6101069.8	@ the elbow on Burnett property - Forrest Beach Road (N6278939 E0354093)
Wonnerup Estuary 3	Q 6101070.4	@ fence line on Burnett property - Forrest Beach Road (N6279084 E0354805)
Deadwater 1	Q 6101071.6	1000m upstream from Wonnerup Floodgates - side track from Forrest Beach Road (N6279900 E0354080)
Deadwater 2	Q 6101072.8	@ top end of basin - side track from Forrest Beach Road (N6281116 E0355173)

APPENDIX 9. Micro-Algae of the Vasse-Wonnerup system

The following information has been prepared by K. Hardcastle of the Water & Rivers Commission, Bunbury.

Micro algae are single-celled aquatic plants which are not readily visible to the naked eye. Their natural occurrence in water bodies is of no concern until they reach epidemic proportions in response to ideal growing conditions.

The Agricultural and Resource Management Council of Australia and New Zealand (ARMCANZ) has developed Guidelines for the Recreational Use of Water Potentially Containing Cyanobacteria which set the level for contact recreation at 20,000 cells mL^{-1} (corresponding to a slight discolouration or the water), and for water supply at 500 - 2,000 cells mL^{-1}.

Micro-algae species recorded in the Vasse & Wonnerup Estuaries 1996 - 1997.

Classification	Density (cells / mL)	Comments
Diatoms • Rhizosolenia • Cerataulina • Chaetoceros	up to 4,400	
Dinoflagellates • Katodinium	low densities	
Cyanobacteria		
• Oscillatoria	up to 35,730	
• Anabaenopsis	up to 216,140	
• Anabaena	up to 25,600	Gazetted toxic species.
• Microcystis	up to 6,500	Gazetted toxic species.
• Merismopedia	up to 1,200	

The most likely impact on fish populations by micro-algae blooms is suffocation due either to reduced dissolved oxygen levels in the water column as the blooms break down or to clogging of gills with scum. Limited data are available, however it is possible that some species of Cyanobacteria may have a toxicological effect on the fish.

Toxicity Information:
Cyanobacteria have been associated with a range of health impacts including skin and eye irritations, hay-fever symptoms, and acute gastro-enteritis. They have also been implicated as potential tumour promoters.

Microcystis aeruginosa

Produces hepatotoxins which can cause liver damage and promote the growth of tumours. Direct contact with this species has been associated with skin irritations, allergic responses and gastro-enteritis. Livestock deaths attributed to poisoning by blue-green algae are most often associated with this species.

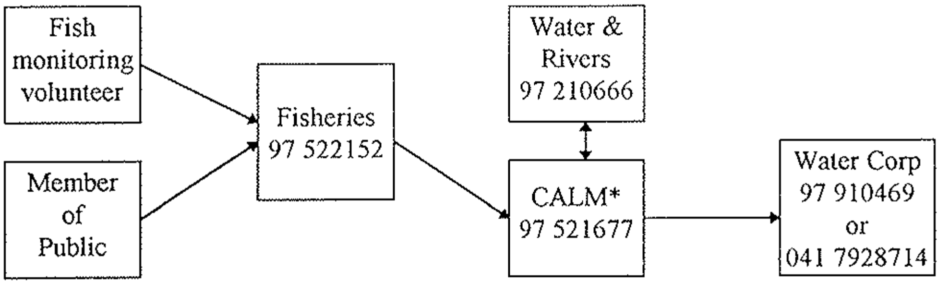
Anabaena circinalis

Allergic reactions to *Anabaena* have been confirmed by skin patch testing in Australia. Positive tests for neuro-toxin have also been recorded and toxicity testing continues for this species.

It is reasonable to assume that all Cyanobacteria constitute a problem for contact recreation and all such activities should be avoided when they are present. They are clearly visible as discolouration in the waterbody and/or the presence of froth and scum on the water surface.

APPENDIX 10. Proposed procedures for notification of agencies of impending fish deaths in Vasse-Wonnerup during 1997-98

NOTIFICATIONS CONCERNING STRESSED OR DYING FISH

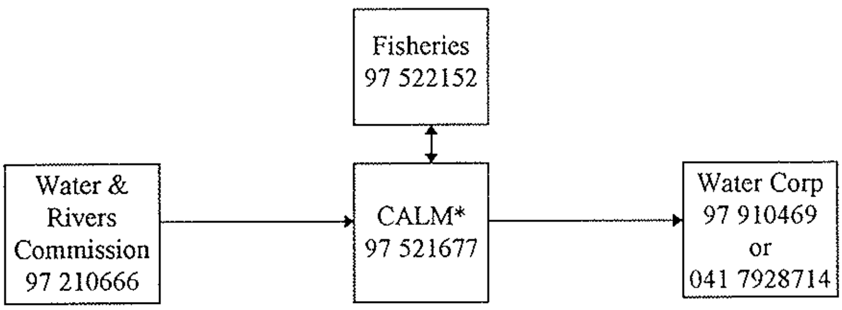


Volunteers will be sought by Fisheries WA to monitor fish on both sides of the Vasse estuary floodgates:

- each morning during Jan & Feb 1998,
- each morning during and immediately following hot weather in Dec 1997 and Mar & Apr 1998.

If stressed or dying fish are reported by Fisheries WA to CALM, those two agencies plus W&RC will make a joint inspection. CALM will then advise the Water Corporation (Bunbury) if the sand bar or the Vasse estuary floodgates need to be opened or if other action involving the Water Corporation is needed. CALM will also inform the Shire of action being taken.

NOTIFICATIONS CONCERNING DECLINES IN WATER QUALITY TO NEAR-CRITICAL LEVELS FOR FISH



Water quality monitoring will be undertaken by the Water & Rivers Commission in Wonnerup Inlet and upstream of Vasse estuary floodgates (and elsewhere in Vasse-Wonnerup) during summer and autumn of 1997-98.

If near-critical water quality conditions** for fish are reported by W&RC to CALM, those two agencies plus Fisheries WA will make a joint inspection. CALM will then advise the Water Corporation (Bunbury) if the sand bar or Vasse estuary floodgates need to be opened or if other action involving the Water Corporation is needed. CALM will also inform the Shire of action being taken.

* CALM's involvement arises from its government-designated responsibility to coordinate future management of the Vasse-Wonnerup system and to ensure the conservation of sites listed under the Ramsar Convention on Wetlands.

** A daily peak of $\leq$ 5 mg/l dissolved oxygen is to be regarded as "near-critical conditions for fish" during 1997-98. This figure may be revised in future years as more data become available.

APPENDIX 11. Refinements to operation of the Vasse estuary floodgates during 1997-98

In Section 12.1.3 of this report the Working Group has recommended that:

> "The operational guidelines adopted in 1990 after extensive consultation with interested parties should be adhered to. The timing of openings and closures should be refined and should take into account results from the proposed fish & water quality monitoring program. The refinements proposed for 1997-98 are described in Appendix 11. Because of the damaging effect of excessive levels of salt water on native vegetation and pastures and the possible adverse effect on waterbird populations, salt water allowed in through the gates should not be allowed to raise summer-autumn water levels above -0.1 m AHD. This point was emphasised in the 1990 guidelines and is most important".

For a full account of the 1990 guidelines for operation of both sets of floodgates and management of the sand bar, refer to Appendix 2. Paragraphs concerning the summer operation of the Vasse estuary floodgates are repeated below. Words in italics have been added for clarification and/or emphasis.

> "The water levels should be monitored at the Vasse Floodgates on a minimum monthly basis until the level reaches *(falls to)* 0.1m AHD *(plus 0.1m AHD)* and then on a minimum weekly basis. If three consecutive days of *(air)* temperatures in excess of 30 degrees occur, preparation should be made to allow fish to pass through the gates if they show any signs of stress (swimming on the surface)".

> "When the level reaches *(falls to)* –0.1m AHD *(minus 0.1m AHD)*, farmers on the Vasse estuary should be notified and the gates opened to maintain the level at –0.1m AHD".

> "Under no circumstances should salt water be allowed to come back behind the gates to allow the levels to become higher than –0.1 m AHD[1] *(or to maintain the level above –0.1 m AHD)*"

The refinements proposed by the Working Group for operation of the Vasse estuary floodgates in 1997-98 are as follows.

> *Notification and decision-making processes for openings of the Vasse estuary floodgates in 1997-98 are to be in accordance with those described in Appendix 10.*

> *Consideration is to be given to opening the Vasse estuary floodgates when fish on the upstream side are showing signs of stress (e.g. swimming with difficulty at the surface) or when the water quality monitoring program indicates that the dissolved oxygen concentration on the upstream side of the floodgates has declined to near-critical levels (e.g daily peak in dissolved oxygen concentration is ≤ 5 mg/l).*

> *If the water level in Vasse estuary (as determined by the gauge board at the floodgates) is at or above –0.1 m AHD at the time of opening of gates to prevent fish deaths, the gates are to be closed within 8 hours[2], unless fish are still dying and a longer period of opening is agreed upon by CALM, Fisheries WA and the Water Corporation at the time of the incident.*

> *The number of gates to be opened to prevent fish deaths is one or two, as in previous years. When gates are opened for this purpose, boards are to be removed from the bays of those gates so that large fish can pass downstream.*

[1&2] Note that occasional openings for short periods (e.g. < 8 hours) will not measurably alter estuary water levels due to the relatively small volumes of flow involved.

BUSSELTON-MARGARET TIMES, Thursday, February 19, 1998

Sandbar seen as key to estuary

by ALLAN MILLER

MASS fish deaths in the Vasse-Wonnerup estuary may be prevented if the sandbar between the ocean and the Wonnerup Inlet is kept open each January and February.

The importance of keeping the sandbar open during summer is highlighted in a comprehensive report, released this week, which aims to help solve the recurring problem of mass fish deaths.

Environmental experts, with assistance from volunteers Les and Betty Cuthbert of Dunsborough — who spent 300 hours researching archives of the *Busselton-Margaret Times* — have discovered 11 separate incidents of mass fish deaths in the Vasse-Wonnerup wetland system dating back to 1905.

There were five mass kills between 1905 and 1960 and there have since been mass deaths in 1966, 1988, 1989, 1997 and 1998.

CALM principal research scientist Jim Lane, one of the authors of the report, said most deaths appeared to be caused by low oxygen levels and high water temperatures.

But he said the Vasse and Wonnerup floodgates, built in 1908, remained crucial to the protection of Busselton. Their judicious use protected pastureland from high tides and saved Busselton from storm surges in summer.

Mr Lane said it was important that the Vasse and Wonnerup estuaries be checked each morning for the behaviour of fish to detect early warning signs of trouble.

Daily monitoring of water quality and oxygen content by the Water and Rivers Commission was also important.

Since January 2 the WA Water Corporation has undertaken to keep the sandbar at the mouth of the river open. Already it has paid off.

"Quick action last month saved thousands of mullet after they were seen gulping for air in the Wonnerup estuary," Mr Lane said.

"The floodgates at Wonnerup were opened and at the mouth of the inlet 4000 mullet were seen travelling out to sea in half an hour."

That close escape happened only a week after 800 mullet were killed by a toxic algal bloom in the ~~Wonnerup~~ estuary. Vasse

The report also recommends that tree-planting be undertaken on the banks of the Vasse to reduce water temperatures during summer.

Copies of the report are available for $5 from the CALM office in Queen Street, Busselton. It can also be seen at the Busselton library.

- The Vasse River has been found to contain high levels of cadmium in a sample of sediment from the upper catchment, says a report by the Busselton shire.

The surprise finding has ruled out the use of dredged river sediment as a landfill by Westralian Sands.