J. LAMB

Monitoring of fish behaviour in the lower reaches of the Vasse - Wonnerup Wetland System during the summer of 1999/2000

Including

Recollections of five local fishermen on fish within the wetland system

A report prepared for the Vasse Estuary Technical Working Group
Funded by the GeoCatch Network Centre

Prepared by
S.V. Elscot

~ July 2000 ~

GREEN IGUANA
Environmental and Heritage Research
45 Gibney Street
Dunsborough WA 6281
green_iguana@bigpond.com

CONTENTS

PLEASE NOTE: Appendices 2 – 15 are included in a separate volume.

LIST OF TABLES

LIST OF PLATES

LIST OF FIGURES

1 INTRODUCTION[1]

Historically, the Vasse – Wonnerup wetland system consisted of a complex of brackish seasonal lakes, marshland, and saline lagoons, receiving freshwater from most of the rivers between Dunsborough and Bunbury. During the past 130 years, the estuaries catchments have been largely cleared for agriculture (primarily milk and beef production) and extensive drainage networks have been constructed to minimise flooding of the low-lying land. Several of the rivers that formerly discharged into the estuaries have been either partially (the Vasse and Sabina Rivers), or wholly (the Capel, the Carbunup and Buayanup Rivers) diverted to sea, forming short canal-like estuaries. The estuaries now receive flow from only four rivers: the Vasse, Sabina, and Abba Rivers discharge into the Vasse lagoon; and the Ludlow River flows into the Wonnerup lagoon. In 1908, floodgates were installed on the estuaries' exit channels to allow outflow but preventing inflow of seawater.

These considerable changes to the hydrology of the system have greatly altered both the water levels and quality of the estuaries. Water levels now fluctuate dramatically during winter, stabilise during spring and decline during summer. By autumn, large expanses of both estuaries are dry. Water is retained in the lowest reaches of the Vasse, primarily the exit channel. A very small volume of water is retained in the Wonnerup Estuary channel. During winter, spring and early summer, the estuaries' waters are fresh – brackish. Since 1988, increasing amounts of seawater have also been allowed back in to the estuaries during summer and autumn. As a result, remnant waters of late summer and autumn are highly saline due to the concentrating effects of evaporation. In 1988, the old wooden floodgates were replaced with metal floodgates, which allowed a marked increase in the amount of seawater leaking past the floodgates. Both estuaries are highly enriched with nutrients, mainly of agricultural origin, which results in the frequent development of severe and sometimes toxic algal blooms in the lowest reaches of the Vasse Estuary during the summer and autumn. Lane *et al.* (1997) and McAlpine *et al.* (1989) have reviewed these changes in detail.

The Vasse-Wonnerup wetland system is internationally recognised for its waterbird habitat. Surveys during the 1980s revealed that more than 30,000 waterbirds of 60 species visit the wetlands each year (ANCA, 1996). Eighty-five species have been recorded in total. Nationally, the estuaries are an important migration stop-over point for a number of species of small waders, and regionally it is a major breeding area of the black swan *Cygnus atratus* and several duck species. The area is also a post-breeding and moulting refuge for a very high diversity of waterbirds. On this basis the Vasse-Wonnerup Estuary System 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.

1.1 Floodgates and Their Effect on Fish Movements

The floodgate structures installed across the exit channels of the Vasse and Wonnerup estuary lagoons are thought to be effective barriers to movement upstream and downstream by all except very small (perhaps 10 cm or less) fish whenever they are closed. The movement of small fish is possible when the gates are closed because there is considerable leakage past the structures, which are in poor condition.

[1] Much of the unsourced information in the introduction and description of the study area is derived from the report *Management of the Vasse – Wonnerup Wetland System in Relation to Sudden Mass Fish Deaths* (Lane *et al.* 1997), with consent of the senior author.

The floodgates close automatically (passively) whenever the water level on the downstream side (i.e. in Wonnerup Inlet) is higher than the water levels on the upstream sides (i.e. in the Vasse and Wonnerup estuaries). In most years they are therefore continuously closed from mid-summer (when evaporation causes water levels in the estuaries tò fall below low tide level) until soon after commencement of strong river flows in early-mid winter (when water levels in the estuaries rise above low tide level).

In addition, the installation of "stop boards" to a height of approximately 0.4 m AHD during spring each year (usually in September or October) largely prevents the movement upstream or downstream of all except very small fish from the time of installation until the time of removal (usually at the commencement of the first heavy rains at the beginning of winter).

Upstream and downstream movement of fish of all sizes (up to at least 50 cm) is possible semi-continuously from early-mid winter (when the estuaries begin to flow) until installation of the stop boards in September-October. During this period the only time the floodgates close is when the sea level (water level in Wonnerup Inlet) is above the water levels in the estuaries. This occurs during storm surges (when the sea level may rise to 1.2 m AHD or more) and whenever there is a low river-flow period during winter and the water levels in the estuaries drop below high tide level due to the passive operation of the gates (they are designed to achieve this result) (J. Lane, pers. comm.).

1.2 History of Fish Deaths in the Vasse-Wonnerup Wetland System

The Vasse-Wonnerup wetland system has a long history of sudden, mass fish deaths. In 1905, prior to the installation of the floodgates, many fish were reported dead near the sand bar in Wonnerup Inlet. Further fish kills occurred between then and 1960, although there are only records concerning an incident in 1933/34. The dates or frequency of other kills during this period is not known, however in a Fisheries Department memorandum of 1960, the department and the local health authority expressed concern over the 'heavy fish mortality of recent years'. Since 1960, sudden mass fish deaths have occurred in 1966, 1984, 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 in summer, usually in February, and often after a spell of hot weather.

1.3 Environmental Factors Associated with Mass Fish Deaths

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 decaying seaweed (Wonnerup Inlet) may also be involved.

Available data shows that dissolved oxygen concentrations in the Vasse Estuary exit channel reach very low levels at times, and on occasions may be continuously at zero for several days. On at least some occasions, zero oxygen conditions may be localised rather than widespread, and fish may be able to escape the lethal conditions. Dissolved oxygen concentrations fluctuate daily due to the presence of plant life, notably phytoplankton, which produce oxygen during the day through photosynthesis, and consume oxygen at night through respiration. On a sunny day, dissolved oxygen concentrations are rarely below 50% saturation, and in the presence of an algal bloom may exceed 100% saturation (supersaturation due to photosynthesis). When the eventual death and decay of a bloom occurs, dissolved oxygen may drop to very low or zero concentrations for several days, as no oxygen is produced by photosynthesis and oxygen already present in the water is consumed by bacteria in the decay process. At times, the oxygen required for the breakdown of organic matter, coupled with the consumption by fish and other biota, may exceed the oxygen available in the water and deaths of fish and other biota may result (Meyer and Barclay, 1990).

Conditions that are known to foster the development of natural oxygen depletion include calm, cloudy, hot weather, which is most common during the summer months. Before lethal deoxygenation occurs, heavy growths of aquatic vegetation, or thick blooms of micro-algae may be present for several weeks. Dissolved oxygen may reach supersaturated concentrations between noon and 2.00pm, and decline to levels near critical for fish survival just before daybreak. When this fluctuation in dissolved oxygen occurs, the pH of the water correspondingly fluctuates from very basic readings of 10.0 and greater at midday, down to 6.9 or less before daybreak. This is caused by the large daily variation in CO_2 concentrations in the water column. These signs are readily apparent to a trained observer and can provide advance warning of impending potentially lethal oxygen depletion (Meyer and Barclay, 1990).

Wind, or lack of it, may also be an important factor in summer fish deaths. Wind acting on the surface of the water helps to oxygenate the water column, particularly when the wind is strong enough to cause the chop to break. When winds are calm, there is a much greater potential for oxygen depletion to occur. In Vasse – Wonnerup, light winds in late summer may be a contributing factor that results in a high proportion of fish kills occurring in February.

Alternately, as in the case of Wonnerup Inlet, large masses of drift seagrass and macroalgae may become trapped within the waterbody, and its subsequent decay results in the production of hydrogen sulphide or 'rotten egg gas', which is highly toxic to fish. The fish kill of February 1988, in Wonnerup Inlet, which occurred after the bar had been closed for two months, may have been caused by this process. The decomposition process may also deplete dissolved oxygen. Fish that are toxically affected by hydrogen sulphide or deprived of oxygen usually display visibly darkened gills (even chocolate-brown in the case of hydrogen sulphide), while hydrogen sulphide may also cause the blood to turn brown (Hunn and Schnick, in Meyer and Barclay, 1990).

Seawater either leaking into, or allowed into, the Vasse Estuary exit channel during summer and autumn may, at times, contain higher levels of dissolved oxygen than water on the upstream side of the floodgates, and may therefore improve the conditions for the fish in the immediate vicinity of the floodgates. The denser saline water may also form a separate layer beneath the less saline waters of the estuary. When this stratification occurs, the lower layer may become deoxygenated as no gas exchange with the atmosphere can occur, particularly when the sediments have a high demand for oxygen, as is often the case in the Vasse Estuary exit channel. When the water overlying nutrient-rich sediments becomes deoxygenated, the rate of phosphorous release from the sediments is increased, thereby facilitating the development of algal blooms. Seven days prior to the February 1997 fish kill, the waters upstream of the Vasse floodgates were underlain by saltier, less-oxygenated saline water (surface salinity of 16ppt, bottom salinity of 28ppt; dissolved oxygen concentrations at 1002 hours were 11mg/l and 6mg/l respectively).

Algal blooms regularly occur in the Vasse Estuary exit channel during summer because of the high light availability, warm water and high concentrations of available nutrients. In certain circumstances, a single species of toxic algae (such as some blue-green algae and dinoflagellate species that release toxins which kill other algae) may become dominant. When competition for nutrients occurs as algal blooms intensify, the level of toxins released increases (Herman and Meyer, in Meyer and Barclay, 1990). The toxins kill off susceptible algae until the single dominant species remains. The concentration of toxins in the water continues to rise as the alga competes with itself and eventually, the water may become toxic tó fish and other biota.

Blooms of *Nodularia*, a species toxic to humans and livestock, regularly occur in the Vasse Estuary. Hosja and Deeley (1994) suggest that fish and crabs will avoid areas affected by dense *Nodularia* blooms. The Fish Health Section of Agriculture WA and the Waterways Commission undertook a laboratory trial in which black bream were not affected by densities of *Nodularia* exceeding 10^6 cells/ml, although the trial lasted only one week due to problems with ammonia (Hosja and Deeley, 1994). *Nodularia* blooms also increase the nitrogen content of the estuary waters through its ability to atmospherically fix nitrogen. In contaminated waters this may stimulate blooms of other potentially toxic species (Hosja and Deeley, 1994).

The prymnesiophyte *Prymnesium parvum*, which is toxic to fish, has occurred in large blooms in the Vasse – Wonnerup wetland system (Hosja and Deeley, 1994). This is the only isolation of the species in Australia.

There are several physical signs associated with mass fish deaths that characterise the agent of the kill. These signs can help the trained observer to identify the cause of deaths. Table 1 summarises the apparent signs that characterise fish deaths caused by deoxygenation, toxic algal blooms and pesticide toxicity.

High water temperatures are also believed to be an important contributing factor to fish kills in the Vasse Estuary channel, which currently has little shade near the floodgates (although some trees planted along the north bank in 1998 and 1999 are healthy and continue to grow). As water temperatures increase, the amount of dissolved oxygen decreases, and this causes fish to undergo an increase in gill ventilation, oxygen consumption and respiration rate to maintain constant blood oxygen levels (Crawshaw, 1977). Therefore, as the water warms, the amount of oxygen available decreases, whilst the respiratory needs of the fish increases.

The water temperatures and dissolved oxygen concentrations that are lethal to fish vary between species. Black bream can tolerate water temperatures from 8° to 33°C. A similar fish, the pink snapper, needs dissolved oxygen concentrations of 3.5 parts per million to grow and survive, and can tolerate concentrations as low as 1.5ppm for short periods. Presumably, black bream would have similar requirements.

The relationship between the Vasse Estuary's water level and the incidence of fish deaths is unclear. Data collected since mid-1992 do not support the theory that higher water levels in summer reduce the likelihood of fish deaths occurring. In February 1997, a fish kill occurred when the water level was +0.12m AHD, yet no kills occurred during the summer of 1994/5 when water levels were just –0.11m AHD.

Table 1. Summary of physical signs associated with fish deaths caused by oxygen depletion, toxic algal blooms, and pesticide toxicity.

PHYSICAL SIGNS ASSOCIATED WITH FISH DEATHS	DEOXYGENATION	TOXIC ALGAL BLOOM	PESTICIDE TOXICITY
Fish behaviour	Gasping and swimming at the surface	Convulsive, erratic swimming, lethargy	Convulsive, erratic swimming, lethargy; if organophosphate pesticide, pectoral fins are extended forwards
Species selectivity	Species selectivity is evident, species with the highest oxygen requirements die first	None, all species affected	Usually one species killed before others, depending on fish sensitivity and pesticide levels
Size of fish	Large fish killed first, eventually may kill all sizes and species	Small fish killed first, eventually all sizes killed	Small fish killed first, eventually may kill all sizes
Time of fish kill	Night and early hours of the morning; if the kill is incomplete, it usually subsides soon after sunrise and may resume the following night	Only during hours of bright sunlight, around 9.00am to 5.00pm	Any hour, day or night
Plankton abundance	Algae dying, little zooplankton present, or they are dead and dying	Dominance of one algal species, little zooplankton present	If insecticide, no zoolpantkon are present but algae are normal; if herbicide, algae may be absent
Dissolved oxygen	Less than 2 ppm, usually less than 1 ppm	Very high, often saturated or supersaturated near the surface	Normal range
Water pH	6.0 – 7.5	9.5 and above	7.5 to 9.0
Water colour	Brown, grey or black, often very smelly	Dark green, brown or golden, sometimes with a musty odour	Normal colour and little or no unusual odour
Algal bloom	Many dead and decaying algal cells, may be visibly abundant (black and slimy) or visible under a microscope	Abundant algae, predominantly of one species	Normal bloom of mixed species unless herbicide used; then algae absent or reduced

(Source: Meyer and Barclay, 1990)

Although natural phenomena may lead to mass fish deaths, the most common effect of environmental changes in waters is to impose stress on the fish present. If the environmental change results in a high enough stress level, the fish's immune response may weaken, predisposing the affected fish to infectious diseases and parasites. If fish are already carrying a significant load of parasites, or harbouring a bacterial infection, or are weakened by malnutrition, the result of the additional effects of an environmental stress may be a fish kill. If the magnitude of the fish kill exceeds the loss that might be expected from the apparent pathogen or parasite, the environmental stress can then be considered the primary cause of death (Meyer and Barclay, 1990).

1.4 Historical and Current Management of the Fish Death Phenomenon

Following major fish deaths in the Vasse Estuary channel in 1988, a study to understand the causes of the problem was undertaken by the Environmental Protection Authority. The Estuarine Impacts Branch of the DEP monitored river flows and nutrient loads to the Vasse-Wonnerup lagoons during 1987-1988. An assessment of the environmental condition of the estuaries and a discussion of management issues and options was published (McAlpine *et al.*, 1989). It was concluded that the Vasse - Wonnerup system was "the most grossly enriched major wetland system known in Western Australia."

In March 1997, community concern over continued sudden, mass fish deaths in the Vasse Estuary exit channel, and the death of the fringing vegetation and adjacent pastures, led to the formation of the Vasse Estuary Technical Working Group (VETWG). The VETWG has reviewed the history of the management of the Wonnerup Inlet sand bar and the Vasse and Wonnerup estuary floodgates, the historical changes to water levels and quality, and the history of fish deaths and methods previously used to prevent them (Lane *et al.*, 1997). The report also discussed management options for the estuaries and made a number of recommendations to reduce the incidence of sudden, mass fish deaths.

In the past, three measures have been used in efforts to reduce the incidence and severity of fish kills: artificial opening of the sandbar at the mouth of Wonnerup Inlet; increased harvesting of fish by netting; and partial openings of Vasse and Wonnerup floodgates to allow fish to escape and to increase water levels.

During the early 1900's, 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 near the mouth of the inlet. Regular digging of the bar resumed soon afterwards. At times it has been difficult to keep the bar open. In February 1988, several attempts were made to open the bar and on each occasion it closed within a few hours. Experience has shown that summer openings of the sand bar are effective in preventing fish kills in Wonnerup Inlet and can also assist in preventing deaths in the estuary channels.

In 1960, the entire Vasse - Wonnerup Estuary was opened to net fishing in order to reduce the number of fish that might otherwise die in summer. A ban on the use of nets in Wonnerup Inlet and the Deadwater was reinstated shortly after, however the Vasse and Wonnerup estuaries remain open to the use of nets by licensed commercial fishermen. Whilst netting does not prevent fish kills from occurring, it has certainly reduced the number of fish that have died during mass death 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 the free movement of fish. Apparently, this was the first time that openings of the floodgates had been agreed to since their installation. In March 1988, the Water Authority sought landholder, government and community views on an appropriate water level to be retained in the Vasse Estuary during summer/autumn. After consideration of responses, the possible damaging effect of excessive levels of salt water on native vegetation and pastures surrounding the estuary, and the potential adverse impact on waterbird populations, it was agreed that salt water should not be allowed to raise the estuary water levels above –0.1m AHD. Prior to 1988, the water level declined to around –0.4m AHD by autumn of most years. In 1990 a revised set of guidelines for operation of the floodgates was prepared. This formalised -0.1m AHD as the water level to be retained in the Vasse Estuary during late summer/autumn each year.

Summer/autumn openings of the floodgates have produced mixed results in the past. On several occasions, when the floodgates were opened for up to 8 hours, fish deaths have been prevented. On other occasions the floodgates have been open for longer periods and deaths have occurred. Fish kills are not a frequent occurrence in the Vasse – Wonnerup, however they attract considerable community and media interest when they do occur.

Many measures to reduce the incidence and severity of fish kills have been proposed in the past. Other than openings of the sand bar, netting of fish, and partial openings of the floodgates to release fish, none have been pursued. Some ideas have been too costly, while others may potentially cause greater problems, or need expensive investigations before their benefits could be determined.

1.5 Scope of this Report

Depletion of dissolved oxygen, excessive water temperature, toxic algal blooms, toxic substances, bacterial and viral infections, and parasitic infestations all have the potential for inducing widespread deaths of fish within a system (Meyer and Barclay, 1990). While the principal factors associated with most fish kills in the Vasse – Wonnerup system are known, the precise conditions leading up to or causing the kills are not well understood. The VETWG concluded that information on these conditions is necessary to guide successful efforts to minimise the occurrence of fish deaths (Lane *et al*, 1997). They suggested that this information could be gained from intensive monitoring of key parameters such as dissolved oxygen, temperature, micro-algal abundance, depth and salinity, and by monitoring the fish themselves.

The VETWG recommended that daily monitoring of fish behaviour in the lower reaches of both estuaries, together with measurements of water levels and visual assessments of water quality be undertaken, as this would enable conditions resulting in fish deaths to be more precisely defined. The specific aim of the monitoring program was to assist the VETWG with its efforts to reduce the incidence and severity of sudden, mass fish deaths in the lower reaches of the wetland system, and to develop an improved understanding of the conditions responsible for these deaths.

Monitoring of fish behaviour was undertaken during the 1997/98 summer period, and again during the 1998/99 summer period (White, 1999). The Bunbury Water and Rivers Commission has undertaken weekly sampling of all the key physical water parameters for the duration of the summer/autumn period each year since 1997.

In 1999/2000, the monitoring observations were reported immediately each day to the VETWG member and project manager, Mr Jim Lane. The information was used to assist the VETWG make decisions regarding openings of the Wonnerup Inlet sandbar and the Vasse and Wonnerup floodgates to allow the release of fish. The VETWG recommended that the results of the monitoring program should be used to refine the timings of the openings and closures of the floodgates to minimise the input of seawater into the estuary, and to maintain water levels at the agreed –0.1m AHD.

This report presents the results of monitoring the fish behaviour in the lower reaches of the Vasse – Wonnerup Wetland System, from December 16th, 1999 to April 15th, 2000. The report collates observations collected on water levels, visual water quality, waterbirds, and the behaviour of fish both upstream and downstream of both sets of estuary floodgates. Additionally, data on weather conditions (rainfall, temperature), together with the results of the Water and Rivers Commission's weekly sampling of key physical parameters (temperature, salinity, DO, pH and turbidity) upstream of both sets of floodgates, are presented.

Unfortunately, a sudden, mass fish death incident occurred on the morning of February 15th, 2000. Due to the monitoring program, the event was witnessed, and many observations were recorded and fish and water samples were promptly taken. Although the monitoring program did not enable the fish kill to be avoided, the incident was very well documented. This report presents all of the available information regarding conditions leading up to the fish kill together with observations of the kill. As this represents the most documented fish kill within the system, this information may assist the VETWG to better understand the fish death phenomenon in the wetland system.

Currently, there is little known about the wider use of the wetland system by fish. In a preliminary attempt to identify new information about the ecology of fish within the estuary, five local people (recreational fishermen, commercial fishermen and elders of the local Aboriginal community) who possess considerable historical knowledge of the movement of fish within the estuary were interviewed. Their responses were summarised to provide an insight into the wider use of the estuary by the major fish species (yellow-eye mullet, sea mullet and black bream).

2 THE STUDY AREA

The Vasse-Wonnerup Wetland System extends in a northeasterly direction from the centre of Busselton to Forrest Beach over a distance of 14km. Its principal components are the Vasse and Wonnerup Estuaries (which are 9km and 5km long, up to 0.6km wide and generally less than 1m deep, even in winter), their floodplains, the Deadwater, "Swan Lake", and the lowest reaches of the Vasse, Sabina, Abba and Ludlow Rivers. The entire system discharges to the ocean via the Wonnerup Inlet. When the estuaries are in full flood during winter, they are narrowly connected by Malbup Creek. The mouth of the inlet is shallow and often closed by the formation of a sand bar, particularly during summer and autumn (Lane *et al.*, 1997). The Vasse-Wonnerup lagoons and their associated wetlands occupy an area of approximately 1500ha and have formed in the depressions between the Spearwood and more recently formed Quindalup dune systems (McAlpine *et al.*, 1989). The fish behaviour monitoring program was limited to the Vasse and Wonnerup Estuary channels, and Wonnerup Inlet, covering an area of around 250 – 300 metres immediately upstream and downstream of the Vasse and Wonnerup floodgates (figure 1). Weekly inspections of the sand bar at the mouth of Wonnerup Inlet were also undertaken.

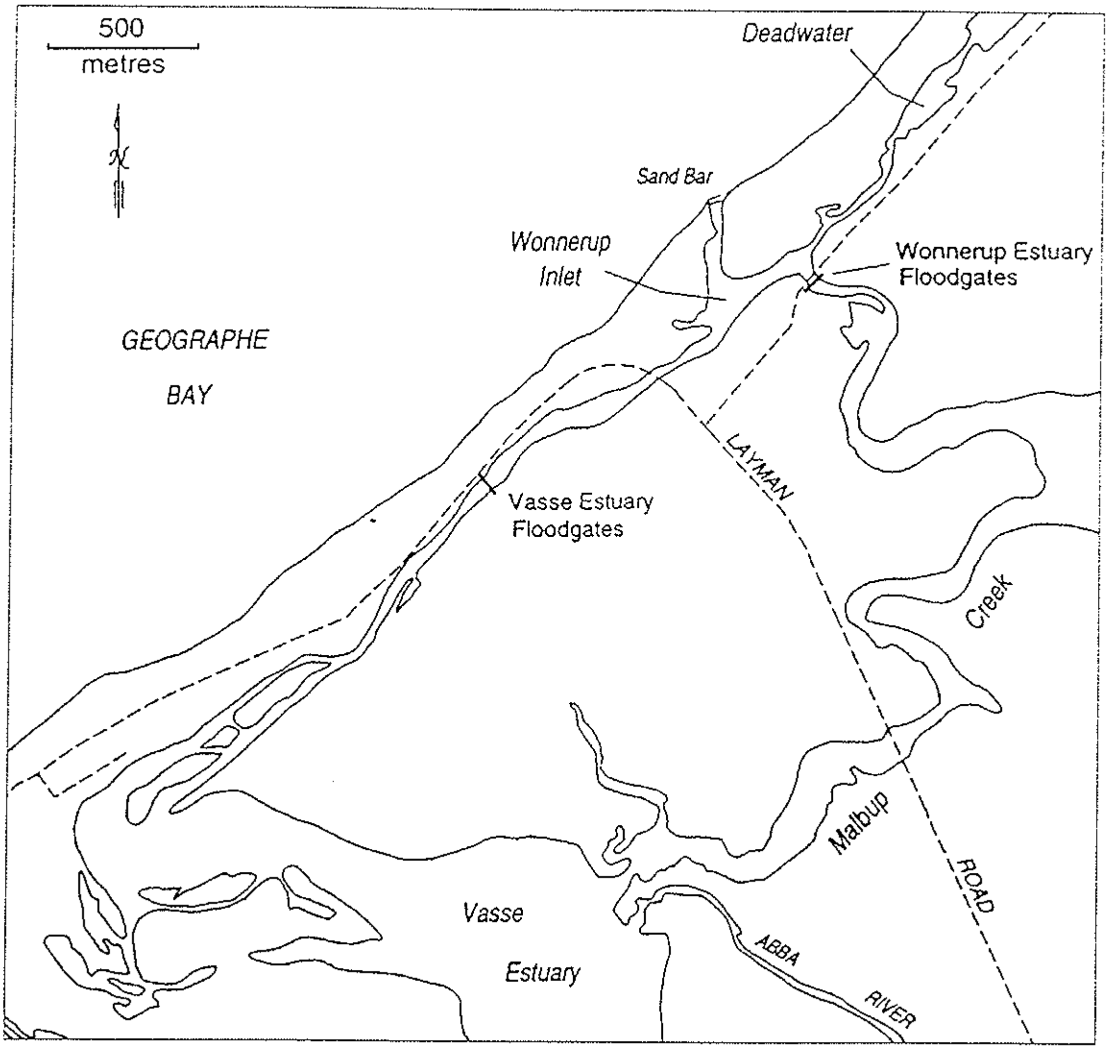


Figure 1. Map of study area.

3 THE MONITORING PROGRAM

The Vasse Estuary, the Wonnerup Estuary and Wonnerup Inlet were inspected in the immediate vicinity of Vasse and Wonnerup floodgates on the following days during the 1999/2000 summer/autumn period:

December 16th – 30th 1999	Every second day
January 1st – February 29th 2000	Every day
March 2nd – April 14th 2000	Every second day

This encompasses the time period that has historically presented the greatest risk of a sudden mass fish death occurrence (Lane *et al.*, 1997). The inspections were made at 2.00pm, or thereabouts, until January 5th, to maintain continuity of data with the 1998/1999 monitoring program (White, 1999). After January 5th, inspections were made at either sunrise, to about half an hour after sunrise as it is the time of day when fish are most likely to experience oxygen stress, which may lead to death. Dawn is the time when dissolved oxygen levels are generally lowest, due primarily to nighttime respiration of phytoplankton, although benthic decomposition may also exert a large oxygen demand at any time during the day (Meyer and Barclay, 1990).

At each set of floodgates (Vasse floodgates always first, followed by the Wonnerup floodgates), both upstream and downstream, the following information was recorded:

3.1 Weather Conditions

A visual assessment of wind direction and speed (calm, light, moderate, fresh or strong), and cloud cover, together with any extra observations (such as rain), was made.

3.2 Water Levels

Readings of time and water depth at each gauge board, to the nearest cm, above or below the Australian Height Datum (AHD) were taken.

3.3 Flow Direction and Rate

A subjective, visual assessment of water leakage through the floodgates, including the direction and rate of leakage was made. The observed rate of leakage was described as either nil, very gentle, gentle, moderate or fast.

3.4 Water Quality

3.4.1 WATER COLOUR

A subjective, visual assessment of the colour of the water column and the presence or absence of surface scum was made.

3.4.2 WATER CLARITY

A subjective, visual estimate of water clarity was made according to the following rating scale (note that depths of visibility are visual estimates only, judged by apparent visibility of submerged pylons and other features):

CLARITY OBSERVATION	CLARITY RATING
Scum on surface – visibility into water <10cm	Very Poor
Visibility into water appears to be ~10 – 30cm	Poor
Visibility into water appears to be ~30cm – 60cm	Moderate
Visibility into appears to be >60cm	Good
Clear water column	Very Good

3.5 Fish Behaviour Monitoring

At each inspection, the numbers and behaviour of fish at or near the surface within 250m of the floodgates was observed for around fifteen minutes at each side of the floodgates.

3.5.1 SPECIES IDENTIFICATION

Where possible, fish were identified to species level, using the key of Hutchins and Swainston (1986). Only positive identifications were recorded, and any doubtful identification was not listed. Where the species could not be readily identified, only the size and shape of the fish were noted.

3.5.2 FISH BEHAVIOUR

The distance of each school of fish from the floodgates was recorded and their specific behaviour, such as regular surfacing, splashing or swirling in schools, was also described. Wherever possible, the abundance of each species or school of fish observed was recorded using a log abundance scale (i.e tens, hundreds, thousands etc.). For each day's observation, the total fish activity observed in the fifteen-minute period was allocated a subjective activity rating according to the following scale:

OBSERVED FISH BEHAVIOURS	ACTIVITY RATING
High fish activity (1000's of active fish visible)	4
Moderate fish activity (100's of active fish visible)	3
Some fish activity (schools of 10's of active fish visible)	2
Limited fish activity (occasional surface rings or splashes)	1
No visible fish activity	0
Limited numbers of fish (<10) exhibiting stressed behaviour or slow movement in the vicinity of floodgates	-1
Moderate numbers of fish (schools of 10's of fish) exhibiting stressed behaviour	-2
Large numbers of fish (>100) exhibiting stressed behaviour	-3
Fish deaths observed	-4

When applying the activity rating, only adult fish activity was used, and the abundance and behaviour of juvenile fish (young of the year) was disregarded.

Active fish behaviour includes fast swimming, feeding, quickly rising to the surface or swirling just under the surface (causing visible surface rings), and splashing or jumping out of the water.

In contrast, stressed fish behaviour includes very little or slow movement, resting in scattered schools at or near the surface, and gasping at the surface. Other indications that fish are stressed and need to be released include continuous swimming alongside the floodgate boards, or schooling close behind floodgate boards and jumping out of the water, sometimes hitting the floodgate boards, in apparent attempts to move downstream. Stressed fish are also identified by poor physical condition and frequently have scales missing.

Meyer and Barclay (1990) describe several fish behaviours associated with mortality caused by oxygen depletion, toxic algal blooms, and pesticide toxicity (see section 1.2). When fish are affected by oxygen depletion, they gasp and swim at the surface. Toxic algal blooms cause affected fish to exhibit convulsive and erratic swimming behaviour together with lethargy. When fish are affected by pesticide toxicity they exhibit similar erratic and convulsive swimming behaviour as caused by toxic algae, but if organophosphate pesticides are involved, their pectoral fins are extended forward.

3.5.3 ANGLING TRIALS

On occasions, fishing lines equipped with 4 – 6lb line, and size 14 to 6 hooks (small trout hooks) were set with either small bread or peeled river prawn baits floated just under the surface, or river prawn baits fished on the bottom with a running sinker. Alternatively, a variety of lures were used. Any fish captured was positively identified and its condition was visually assessed. All captured fish were returned to the water alive. The results were used to generate a species list for the various components of the system.

3.6 Waterbird Observations

The numbers and types of waterbirds (excluding small waders) visible within 250m upstream of each set of floodgates were recorded and their distance upstream was estimated. Their activity (roosting or feeding) was also recorded. Birds were identified using the key of Simpson and Day (1996). "Bushnell" 7 x 35 binoculars were used from early February onwards.

3.7 Other Observations

Other general observations, such as a distinctive odour or visible bubbles in the water, were also recorded. Changes to the status of the floodgates (open to inflow/outflow, number of stopboards in place) were also recorded.

3.8 Status Of The Sandbar At Wonnerup Inlet

The sandbar at the mouth of Wonnerup Inlet was inspected as follows:

December 16th – 30th 1999	Two day intervals
Jaunary 1st – April 14th 2000	Weekly intervals

At each inspection, the status of the sandbar (open all tides, open high tides, closed), and the width and depth of opening were recorded.

3.9 Rainfall And Temperature

Daily records of rainfall, temperature and wind for the duration of the monitoring program were obtained from the Bureau of Meteorology's Busselton Jetty, Busselton Airport and Busselton Hospital weather stations.

3.10 Phytoplankton and Physical Parameters

The Water and Rivers Commission Southwest Region undertook weekly sampling of water quality and phytoplankton at 10 sites in the wetland system, including a site upstream of each set of floodgates, for the duration of the monitoring program. They have kindly provided data on the change in phytoplankton species present and their density (number of cells/mL), and weekly measurements of water temperature, salinity, DO, and turbidity upstream of each set of floodgates to assist interpretation of the fish behaviour and water quality observations.

3.11 Management Actions

Immediately following each day's inspection, the observations were telephoned directly to the project manager and VETWG member, Mr Jim Lane, who used the information to assist the VETWG make decisions regarding openings of the floodgates and the sandbar at the mouth of Wonnerup Inlet.

4 WONNERUP SANDBAR STATUS

The mouth of Wonnerup Inlet was artificially barred by the Water Corporation on October 22nd 1999, to prevent water levels declining too rapidly in Wonnerup Estuary as the Wonnerup floodgate stopboards had "blown out" and the floodgate structure required repair. Water Corporation undertook the repairs between the 20th and the 22nd of December, and the Inlet mouth was artificially reopened on December 24th, 1999. The mouth remained open, and the exit channel remained deep, except for shallow shoals at both ends, for the remainder of the monitoring program.

5 RAINFALL AND TEMPERATURE

The Busselton Shire experienced falls of rain on 19 days during the summer monitoring period (figure 2). Five millimetres or more of rainfall was received on six days during the monitoring program (15/01, 23/01, 10/03, 17/03, 22/03 and 15/04). The most substantial falls occurred between January 15th and 18th (18mm on the first day, followed by 3mm each day for the next two days), January 22nd to 23rd (8mm on the first day followed by 4mm the next day), and March 10th (22mm).

During the period of monitoring, maximum daily temperatures ranged from 19° to 36°C whilst minimum daily temperatures ranged from 6° to 23°C (figure 3). Late December and the first week of January were considerably hotter than the remainder of the monitoring period, with daily maximum temperatures consistently in excess of 30°C and nightly minimum temperatures in excess of 15°C. Hot spells (periods of three days or more where temperatures exceeded 30°C) also occurred between January 27th - February 1st, February 5th - 7th, February 12th – 17th, February 26th – 29th, and March 3rd – 8th. Daily maximum temperatures did not exceed 30°C again after March 8th, and remained considerably cooler for the rest of the monitoring period. It is interesting to note that, for almost the entire duration of the monitoring period, when the maximum daily temperature did exceed 30°C, it remained above 30° for at least three consecutive days.

6 WATER LEVELS

Changes in the level of water in the Vasse and Wonnerup estuaries, as measured from the gauge boards upstream of the Vasse and Wonnerup floodgates, are presented in figure 4. The figure also briefly identifies management actions taken during the monitoring program (see section 12). The presented water levels have been calibrated and adjusted to true AHD to correct for inaccuracies in the height of the gauge boards (J. Lane, CALM, pers. comm.).

Generally, the water levels in both estuaries exhibit a declining trend over the course of the summer and early autumn due to evaporation of the upstream water body. On a day-to-day basis, water levels in the estuaries may fluctuate slightly for several reasons. Strong winds may cause water levels to rise or fall, because water is 'pushed' by the prevailing wind, either towards or away from the floodgate gauge boards. This phenomenon, known as seiching, may account for up to 10cm variation at times. Occasionally, water levels may rise due to runoff from rainfall, or may increase as a result of water leakage through the floodgates during periods of very high tides.

6.1 Vasse Estuary

At the commencement of the monitoring program, the water level in the Vasse Estuary (upstream of the floodgates) was +0.31m AHD, which is higher than in previous years due to the artificial closing of Wonnerup Inlet mouth during October (see section 4.0). The water level steadily decreased, with some minor fluctuations, to slightly above the target minimum level of –0.1m AHD on March 2nd (day 62), where it stabilised for the remainder of the monitoring period. The minimum level reached was –0.11m AHD on March 26th (day 86). The reduction in the apparent rate of evaporation after early March coincides with the period where daily maximum temperatures were cooler than the remainder of the monitoring period by around 4 - 8°C (see figure 3).

Four of the substantial rainfall events during the summer appear to have caused water levels to rise slightly in the estuary. On January 15th (day 15) a rise of 0.03m was recorded following 18mm of rainfall in the previous 24 hours. On January 23rd (day 23) the water level rose 0.015m following 12mm of rainfall over the previous two days. March 10th (day 70) the water level rose 0.035m after 22mm of rain in the previous 24 hours. March 22nd (day 82) the water level rose 0.02m after 9mm of rain fell during the previous two days. Rainfall within the catchment appears to cause estuary water levels to rise within 24 hours. Wonnerup Estuary water levels rose by slightly less than the Vasse water levels on the same dates (see section 6.2). Wonnerup Estuary receives flow from the Ludlow River only whereas the Vasse Estuary receives flow from three rivers (two of which have been partially diverted to direct agricultural runoff away from the estuary) and stormwater from urban areas of Busselton.

The Vasse floodgates were opened to allow the release of fish on only two occasions during the monitoring program. On February 3rd the floodgates were opened for approximately three hours, and on February 15th they were opened for exactly eight hours. Neither of these openings caused any measurable increase in water level.

At the commencement of monitoring, the lower portion of the upstream gauge plates were heavily fouled by a microalgal scum that dissolved and peeled the paint (along with the markings) when attempts were made to remove it. As a result, water levels upstream (and occasionally downstream) of the floodgates were measured from a calibrated point using a tape measure. Several anomalous rises in the water level during the end of December and first week of January are probably errors that occurred during the initial measurements using the tape measure.

A complete tabulation of weather conditions at the time of each inspection are tabulated in Appendix 2.

6.2 Wonnerup Estuary

At the commencement of the monitoring program, the water level in Wonnerup Estuary was +0.32m AHD. Water levels in the Wonnerup Estuary closely paralleled those in the Vasse Estuary. Wonnerup Estuary water levels were 0.10 - 0.30m lower than the Vasse Estuary during the summer of 1998/1999 (White, 1999). Wonnerup Estuary's water level declined steadily as occurred in the Vasse, but slightly faster during February to be around 0.03m lower than the Vasse from the middle of February onwards.

The minimum water level reached was -0.09m AHD on April 11th (day 102), although the level had declined to –0.085m by March 8th (day 68) already. The normal minimum water level attained in Wonnerup Estuary is –0.40m AHD, and was –0.51m AHD in early March 1999 (White, 1999). Consequently, the water level in Wonnerup Estuary during this summer was considerably higher than normal, primarily due to the artificial closing of Wonnerup Inlet mouth in October.

The rainfall event of January 15th (18mm to 9am) saw the Wonnerup water level rise 0.03m that day, exactly as occurred in the Vasse. The water level in Wonnerup also rose on January 23rd (0.01m compared to 0.015 in the Vasse) following 12mm of rain over the previous two days, and on March 10th (0.02m compared to 0.035m in the Vasse) after 22mm of rain in the previous 24 hours. The rainfall event of March 22nd and 23rd (9mm over two days) did not cause any rise in the Wonnerup Estuary water level.

The Wonnerup floodgates were opened for between 1-2.5 hours on three occasions (3/02, 21/02, 25/02) to allow the release of fish. The openings did not result in any measurable increase in water levels.

A complete tabulation of weather conditions at the time of each inspection is tabulated in Appendix 9.

7 RATE OF LEAKAGE AND DIRECTION OF FLOW

Neither set of floodgates form a complete barrier to water flow and, when Wonnerup Inlet mouth is open, seawater is able to leak into, and estuary water out of, the main estuary bodies. The direction of the leakage flow is dependent upon the head of water at the floodgates, which varies daily with the tidal height in Wonnerup Inlet. When the tidal height in Wonnerup Inlet exceeds the water level in the estuaries, water will leak in to the estuaries (upstream) through the floodgates, and leak out of the estuaries (downstream) when the tidal height is lower in the inlet. The rate of leakage is determined by the size of the head of water at the floodgates: when the head of water is small, the leakage is gentle, and as the head of water increases, the rate of leakage increases. As the water levels in both estuaries are not always the same, the rate of leakage and direction of flow is not always the same at each set of floodgates at the same time.

From a management perspective, knowledge of the direction and rate of flow is necessary to determine when a fish release can be physically accomplished. To easily open the floodgates, the head of water on the upstream side must be sufficiently small. For this purpose, a subjective assessment of leakage rate was adequate.

At times, it appeared that leakage of seawater upstream through the floodgates may have been a cue that caused large numbers of mullet to school above (upstream of) the floodgates (see section 9.2). This may be due to a number of factors. Seawater leaking in through the floodgates may be either cooler or warmer than the estuary water, although it is likely to be cooled on its passage through the floodgates on hot days, when the rate of leakage is moderate to fast, due to the effects of aeration and evaporation. The aeration caused by the leakage also serves to oxygenate the seawater. At times, the seawater leaking in may be more oxygenated than water in the estuary channel, particularly on calm mornings when algal blooms reduce dissolved oxygen to low concentrations through night-time respiration.

To more precisely describe the rate of leakage through the floodgates to examine its effect on fish behaviour, the head of water at the time of each day's inspection was calculated from the calibrated water levels. Generally, the subjectively judged direction of flow agrees well with the calculated head of water, given that accuracy of the measured water levels could not exceed 1cm at best. All of the discrepancies between the theoretical and actual direction of flow concern very small heads of water, or gentle leakage conditions. At times of very gentle leakage, the chop of a gentle breeze was enough to make it difficult to judge the direction of flow.

The subjectively allocated rates of flow do not clearly reflect the calculated water heads, and this is probably due to several factors. Firstly, during the first few weeks of monitoring, the actual head of water at the floodgates was very small, so little variations were probably judged to be relatively greater than they actually were, as the author had no previous experience of how great the leakage rate could be. Despite this, the observed rates of leakage were assessed on a three option scale (gentle – moderate – fast), which is possibly too simplistic to reflect the range of variation in the head of water over the season. The subjectively allocated flow rates more likely reflect the relative changes in flow rate on a day to day basis.

7.1 Vasse Floodgates

The calculated head of water at each day's inspection at the Vasse floodgates is shown in figure 5. Figure 6 displays the subjectively assessed rate of flow at each day's inspection. A complete tabulation of the observed flow directions and rates is included in Appendix 3.

At the commencement of the monitoring program, when the water level in the Vasse Estuary was around +0.30m AHD, the head of water and rate of leakage was low. The direction of the leakage flow reversed irregularly, every few days or each week, although the number of days where the leakage was downstream were more numerous during the first two months. As the monitoring program progressed, water levels in the estuary dropped, the head of water at the floodgates (at the time of inspections) increased, causing both the frequency and rate of leakage upstream to increase. Prior to February 20th, the head of water on the downstream side (causing leakage upstream) only exceeded 10cm (at the time of inspections) on three occasions. After February 20th, the head of water was regularly greater than 10cm, resulting in a moderate to high rate of leakage for two thirds (16 out of 24) of the remaining inspections. In addition, the direction of flow was upstream on all but eight of the remaining inspections (during four of which there was no flow at all). During the highest tides in April, when the estuaries' water levels were lowest, the head of water at both floodgates reached 0.5-0.6m for several days. This resulted in a very fast leakage of water upstream, such that the upstream side of the floodgates appeared to be a very fast waterfall.

7.2 Wonnerup Floodgates

The calculated head of water at each day's inspection at the Wonnerup floodgates is shown in figure 7. Figure 8 displays the subjectively assessed rate of flow at each day's inspection. A complete tabulation of the observed flow directions and rates is included in Appendix 10.

In contrast to the Vasse floodgates, the calculated head of water was on the downstream side of the Wonnerup floodgates (resulting in upstream leakage) for most of the inspections during the first three weeks of monitoring. As occurred in the Vasse, the water levels in the estuary steadily dropped, the head of water at the floodgates (at the time of inspections) increased, resulting in an increased rate of leakage upstream as the monitoring program progressed. After February 26th, the direction of leakage was upstream at every inspection. For the last three weeks of the monitoring program (March 21st to April 15th), the head of water on the downstream side was greater than 0.3m at every inspection, reaching 0.6m for 2 days, resulting in a gushing waterfall of seawater leaking into the estuary.

8 PHYTOPLANKTON AND PHYSICAL PARAMETERS

The Water and Rivers Commission Southwest Region (WRC Southwest) kindly provided the following data for the two floodgate sites from their routine sampling program. Sampling of physical parameters is undertaken directly from the floodgate access way, immediately in front of the floodgate bays where seawater leaks in from Wonnerup Inlet (see section 7). Due to the leakage of seawater through the floodgates at times, data collected in this dynamic position may possibly not always reflect the actual conditions that the fish are subject to along the length of the exit channel. To clearly understand the conditions that the fish are subject to upstream of the floodgates, a comparison of conditions at several sites along the exit channel is required. This would allow the effects of seawater leakage in the immediate vicinity of the floodgates to be estimated. The WRC Southwest have undertaken sampling at one further site in the Vasse Estuary exit channel, around 500m upstream, adjacent to Ballarat Road, and one site in the main estuary lagoon (Webster Road). In Wonnerup Estuary, the Water and Rivers Commission undertake sampling at the floodgates, and at two sites upstream in the main lagoon bodies. It is important to note that data from only one site in each estuary channel (immediately upstream of each set of floodgates) is included here.

8.1 Phytoplankton

At the time of writing this report, only preliminary results of the cyanobacteria monitoring of the estuaries were available, covering the period of December 31st to January 27th. Due to the severe Swan River *Microcystis* bloom during February, results of the remaining Vasse – Wonnerup samples by the Water and Rivers Commission's Phytoplankton Ecology Unit were temporarily delayed. The WRC Southwest will be reporting on the seasonal patterns in phytoplankton activity later this year. Relationships between seasonal patterns, water quality and floodgate openings will be considered. In light of this, only a very brief overview of the cyanobacterial status of the estuary channels upstream of both sets of floodgates during January is given.

8.1.1 VASSE ESTUARY

Between December 30th 1999, and January 21st 2000, the cyanobacteria in the Vasse Estuary (and the Vasse River also) underwent species changes, from *Microcystis aeruginosa* to *Nodularia spumigena* to

Anabaena circinalis. All of these species are gazetted as toxic to humans, and densities above 20,000 cells/mL exceed the Agriculture Resource Management Council of Australia and New Zealand's Recreational Guideline limit for cyanobacteria. Warning signs should be erected in areas where the density of cells is greater than this limit, as were at both sets of floodgates for most of the monitoring period.

The cyanobacterial cell density (does not include chlorophytes, diatoms and other phytoplankton) at the Vasse floodgates rose from around 22,000 cells/mL on December 30th 1999, to peak at over 140,000 cells/mL on January 12th 2000. The density of cyanobacteria then declined to 40,000 cells/mL by January 21st 2000, and further declined to a recreationally 'safe' 10,000 cells/mL on January 27th. At Ballarat Road, the density of cyanobacteria steadily increased from a comparable density to the floodgates on December 30th of 22,000 cells/mL, to just over 50,000 cells/mL on January 12th. On January 21st, the density of cyanobacteria at Ballarat Road peaked at in excess of 160,000 cells/mL. By January 27th, the cyanobacteria had declined to 'safe' levels of around 12,000 cells/mL, with *Nodularia spumigena* the dominant cyanobacterium at both the Vasse floodgates and Ballarat Road.

Integrated phytoplankton cell densities (including all species present) are only available for January 27th, when it appears that the algal bloom had finally declined. At the Vasse floodgates, the total phytoplankton density was just under 20,000 cells/mL, of which around two-thirds were cyanobacteria, with the remainder composed of diatom species. At Ballarat Road, the density of cyanobacteria was only marginally higher than at the floodgates, but the total phytoplankton density was greater (around 30,000 cells/mL) due to the presence of a greater number of diatoms.

8.1.2 WONNERUP ESTUARY

No cyanobacteria was recorded at the Wonnerup floodgates on December 30th or January 12th, however, by January 21st, Wonnerup Estuary was experiencing a *Nodularia spumigena* bloom of around 80–100,000 cells/mL, which is four to five times higher than safe recreational guidelines. One week later (January 27th), cyanobacterial cell densities had declined to 50,000 cells/mL at the Wonnerup floodgates.

An integrated phytoplankton sample from January 27th indicated that Wonnerup Estuary was still experiencing a bloom of *Nodularia spumigena* at densities of 35-70,000 cells/mL, with diatoms and chlorophytes contributing only a minor fraction.

8.1.3 WONNERUP INLET

No bloom of cyanobacteria was recorded in Wonnerup Inlet on the December 30th or January sampling occasions, although small numbers (well within 'safe' guidelines) of cyanobacteria were present. Integrated phytoplankton samples indicated that the phytoplankton community of Wonnerup Inlet was composed predominantly of diatoms (less than 20,000 cells/mL), although small numbers of dinoflagellates were recorded near Layman Road Bridge.

8.2 Salinity

8.2.1 VASSE FLOODGATES

A salinity profile of the Vasse Estuary exit channel immediately upstream of the Vasse floodgates is presented in figure 9. During the course of the monitoring program, the salinity ranged from fresh (2.7 parts per thousand) to highly saline (42.7ppt).

Prior to the opening of Wonnerup Inlet mouth (December 24th, 1999), the salinity at the Vasse floodgates was brackish, at around 3.0ppt. Six days after the opening of the inlet mouth, the water upstream of the floodgates was highly saline, with a gradual increase in salinity from the surface of the water to the bottom (16.4-24.3ppt respectively). Salinity gradually increased, with some minor fluctuations, to equal the salinity of seawater (35ppt) on February 9th, 2000, the first sampling occasion following the initial floodgate opening on February 3rd, 2000. Salinity ranged from 22.5-24.8ppt (from the surface to the bottom) on February 3rd, immediately prior to the opening of the floodgates. A further 3ppt increase in salinity followed the floodgate opening of February 15th, 2000. Salinity continued to rise for the course of monitoring program, with the maximum salinity of just under 43ppt recorded on April 6th, 2000. From week to week, salinity varied by up to 12ppt at the floodgates. A decrease in salinity of more than 13ppt on March 2nd, 2000, to 25.3-26.6ppt (surface to bottom) cannot be explained by rainfall events. The same decrease was recorded at Wonnerup floodgates also.

On February 9th 2000, the last sampling occasion prior to the fish kill event (February 15th, 2000 – see section 10.3), the salinity gradually increased from 33.3ppt on the surface to 36.0ppt at 1.0m deep. The morning following the fish kill (February 16th, 2000), after the floodgates were opened to a high head of water for 8 hours the previous day, salinity on the surface and at 0.5m was 36.9ppt, whilst salinity at 1.0m and 1.5m was 38.8 and 39.2ppt respectively. It appears that the water column may possibly have been stratified between 0.5-1.0m.

No *in situ* measurements of physical parameters were made on the morning of the fish kill as all the available WRC equipment was in Perth for the Swan River algal bloom that occurred at the same time.

8.2.2 WONNERUP FLOODGATES

A salinity profile of the Wonnerup Estuary exit channel immediately upstream of the Wonnerup floodgates is presented in figure 10. The salinity profile closely follows that of the Vasse floodgates (figure 10). During the course of the monitoring program, the salinity ranged from fresh (3.8ppt) to highly saline (42.0ppt), with week to week variance of up to 12ppt.

Following the floodgate opening on February 3rd, 2000, salinity rose more than 11 ppt, from 27.0-27.5ppt (surface to bottom) on February 3rd, to 38.6-39.5ppt on February 9th. The floodgate opening of February 21st did not affect salinity. An anomalous decrease in salinity of more than 12ppt had occurred by the next sampling occasion after the floodgate opening of February 25th. This cannot be explained by rainfall, however the same decrease was recorded at the Vasse floodgates.

8.3 Water Temperature

8.3.1 VASSE FLOODGATES

A temperature profile of the Vasse Estuary exit channel, immediately upstream of the Vasse floodgates is presented in figure 11. The maximum water temperature recorded was 26.9°C, on December 30th, 1999. The water temperature declined, with some large fluctuations, until March 10th, 2000 (23°C), after which the temperature declined to remain below 21°C for the remainder of the monitoring program. The minimum water temperature reached was 17.9°C on April 6th, 2000. Weekly fluctuations of up to 4°C were recorded.

The sampling occasion prior to the fish kill (February 9th, 2000), the water temperature of 21.6°C (consistent from the surface to the bottom – 1.0m) was the second lowest recorded for the monitoring period to that date. The morning following the fish kill (February 16th, 2000), after the floodgates were opened for 8 hours the previous day, the water temperature was around 24°C, with the bottom water (1.5m) 0.5° warmer than the surface.

8.3.2 WONNERUP FLOODGATES

A temperature profile of the Wonnerup Estuary exit channel immediately upstream of the Wonnerup floodgates is presented in figure 12. The maximum water temperature recorded was 25.5°C, on December 22nd, 1999, which is 1.5°C cooler than the maximum water temperature in the Vasse Estuary. The minimum water temperature reached was 18.7°C on April 6th, 2000, which is just under 2° warmer than the Vasse Estuary. Weekly fluctuations of up to 5°C were recorded.

Table 2. Times of weekly water sampling undertaken by Water and Rivers Commission Southwest together with the duration of time since sunrise.

DATE	TIME OF SUNRISE	VASSE FLOODGATES		WONNERUP FLOODGATES	
		SAMPLING TIME	HOURS SINCE SUNRISE	SAMPLING TIME	HOURS SINCE SUNRISE
16/12/99	5.02 am	9.28 am	4 hrs 26 min	10.36 am	5 hrs 34 min
22/12/99	5.05 am	9.35 am	4 hrs 30 min	10.41 am	5 hrs 36 min
30/12/99	5.10 am	9.20 am	4 hrs 10 min	10.20 am	5 hrs 10 min
6/01/00	5.15 am	9.24 am	4 hrs 9 min	10.24 am	5 hrs 9 min
12/01/00	5.20 am	9.24 am	4 hrs 4 min	10.26 am	5 hrs 6 min
21/01/00	5.28 am	10.07 am	4 hrs 39 min	11.27 am	5 hrs 59 min
27/01/00	5.34 am	10.05 am	4 hrs 31 min	11.35 am	6 hrs 1 min
3/02/00	5.41 am	9.15 am	3 hrs 34 min	10.05 am	4 hrs 24 min
9/02/00	5.47 am	8.25 am	2 hrs 38 min	9.53 am	4 hrs 5 min
16/02/00	5.54 am	8.47 am	2 hrs 53 min	11.00 am	5 hrs 6 min
25/02/00	6.02 am	12.10 pm	6 hrs 8 min	1.10 pm	7 hrs 8 min
2/03/00	6.07 am	12.30 pm	6 hrs 25 min	1.20 pm	7 hrs 13 min
10/03/00	6.14 am	11.20 am	5 hrs 6 min	12.15 pm	6 hrs 1 min
17/03/00	6.19 am	10.30 am	4 hrs 11 min	1.00 pm	6 hrs 41 min
23/03/00	6.24 am	9.10 am	2 hrs 46 min	10.15 am	3 hrs 51 min
31/03/00	6.30 am	8.50 am	2 hrs 20 min	9.55 am	3 hrs 25 min
6/04/00	6.34 am	9.40 am	3 hrs 6 min	10.45 am	4 hrs 11 min
12/04/00	6.38 am	10.10 am	3 hrs 32 min	12.00 pm	5 hrs 22 min

(Sampling times provided by Water and Rivers Commission Southwest)

8.4 Dissolved Oxygen

Dissolved oxygen profiles are presented here as line graphs, which do not indicate the significant level of fluctuation that occurs during each day (see section 1.2). Dissolved oxygen (DO) concentrations are variable, depending on the time of day, and also due to temperature and atmospheric pressure. These profiles represent the week to week variance in DO at the time of the

WRC Southwest sampling, which varied between 8.20am and 1.20pm over the course of the monitoring program. As a result, some of the week to week variance in the observed DO is a factor of the time of sampling and weather conditions. Profiles of DO are presented as both total amount present (mg/L), and as percentage saturation. Percentage saturation is the percentage of total DO that should be present at equilibrium for the given water temperature and atmospheric pressure. To assist interpretation of the DO profiles, the time of each weeks sampling together with the duration of time since sunrise is given in table 2.

8.4.1 VASSE FLOODGATES

DO profiles for the Vasse Estuary exit channel immediately upstream of the Vasse floodgates are shown as the total concentration present (mg/L) in figure 13, and as percentage saturation in figure 14.

DO concentrations during the sampling occasions varied from a high of 11.2mg/L (just over 150% saturation) at the surface on January 12th, 2000, to a low of 1.19mg/L at the surface (17% saturation) on February 16th, 2000 (the morning following the fish kill incident, after the floodgates had been opened for 8 hours the previous day). Immediately following the opening of Wonnerup Inlet mouth, and throughout January, DO was considerably higher on the surface than the bottom, with up to 9mg/L (or more than 125% saturation) difference between the surface and the bottom on January 12th, 2000. The surface DO, and the range between surface and bottom DO, declined after January 12th, to reach the minimum recorded DO of 1.17mg/L on the surface (17.6% saturation) to just 1.49mg/L (22.5% saturation) at 1.5m on February 16th, 2000 (the morning following the fish kill, after the floodgates were opened to a high incoming tide for 8 hours). DO was more than five times higher the following week (February 25th, 2000), however, it was measured three and a half hours later than the previous week. DO fluctuated for the remainder of the monitoring period, however it was not recorded below 41% saturation, and not above 81% saturation again. Over the course of the WRC Southwest monitoring, DO was measured at different times each week at the Vasse floodgates, from 8.25am to 12.30pm (see table 2).

On February 26th, 2000, Jim Lane (CALM) and Chris Webb (WRC Southwest) profiled the early morning DO, from 6.55am to 7.15am, at three locations along the Vasse Estuary exit channel, from the floodgates to the two strainer posts on the south bank of the channel, approximately 150m upstream (see paragraph 3 of section 8.4.2 for reason). Water was trickling out (downstream) through the floodgates, and consequently, there was little variance between the measured sites. Immediately in front of the floodgates, DO ranged from 5.21mg/L (72.6% saturation) on the surface, to 5.22mg/L (72.4% saturation) on the bottom, although DO was highest at 1.2m (5.57mg/L or 79.1% saturation). At the strainer posts, DO ranged from 5.72mg/L (80.4% saturation) on the surface, to 5.85mg/L (79.9% saturation) on the bottom. The water temperature was 0.5°C cooler at the floodgates than 150m upstream (20.9°C compared to 21.4°C).

8.4.2 WONNERUP FLOODGATES

DO profiles for the Wonnerup Estuary exit channel immediately upstream of the Wonnerup floodgates are shown as the total concentration present (mg/L) in figure 15, and as percentage saturation in figure 16.

DO concentrations during the sampling occasions varied from a high of 9.72mg/L (137.7% saturation) on the surface on April 12th, 2000, to a low of 3.82mg/L (53.7% saturation) on

March 31st, which was the earliest sample taken during the monitoring period (9.55am). Sampling for DO occurred at varying times, ranging from 9.55am to 1.20pm, so some of the week to week variance may be a factor of the time of day. It is interesting to note that on February 16th and 25th, 2000, the surface DO was lowest for almost the whole monitoring period (except March 31st), even though the sampling did not occur until midday, when DO is normally highest for the day (11.00am and 1.20pm respectively). Prior to the initial floodgate opening of February 3rd, 2000 (when the stopboards were also removed from one bay), DO was considerably higher at the surface than on the bottom, excepting January 21st, 2000. Following the increase in salinity that occurred after the floodgate opening, DO remained consistent throughout the water column for the remainder of the sampling occasions.

Following five consecutive days of apparently stressed fish behaviour (from February 21st to 25th, 2000 - see section 10.2.2), which culminated with a floodgate opening on February 25th, Jim Lane (CALM) and Chris Webb (WRC Southwest) profiled the DO upstream of the Wonnerup floodgates early on the morning of February 26th, 2000. From 6.01am to 6.26am, DO was profiled at five locations along the Wonnerup Estuary exit channel, from the floodgates to the overhead powerlines above the channel, approximately 150m upstream. Water was trickling out (downstream) through the floodgates at the time of sampling, and consequently, there was only minimal variance between the measured sites. Immediately in front of the floodgates, DO ranged from 2.56mg/L (33.6% saturation) on the surface, to 2.14mg/L (29.2% saturation). Approximately 100m further up the channel (alongside the metal pole), DO ranged from 3.31mg/L (44.7% saturation) on the surface, to 2.68mg/L (34.9% saturation) on the bottom. In the centre of the channel below the powerlines (about 150m upstream), DO ranged from 3.10mg/L at the surface to 2.68mg/L on the bottom. DO was marginally lower in the shallows alongside the bank, with the DO ranging from 2.36mg/L (31.7% saturation) at the surface to 2.31mg/L (30.0% saturation) on the bottom. The water temperature was 1.5°C warmer at the floodgates than 150m upstream (19.5°C from surface to the bottom at the floodgates compared to 18.05-17.7°C from the surface to the bottom, in the channel 150m upstream).

8.5 pH

pH is a measure of the acidity or alkalinity of a waterbody. Like DO, pH may fluctuate significantly over the course of the day, due to the amount of carbon dioxide in solution, and also biological activity (see section 1.2). A chart showing the weekly change in surface pH at the time of WRC Southwest sampling occasions, upstream of the Vasse and Wonnerup floodgates is presented in figure 17. This chart describes the week to week variance in surface pH immediately upstream of both floodgates only, and does not show the daily variation that will also have occurred. Some of the variance between pH from week to week may be a factor of the time of day, as sampling was not undertaken at the same time each week.

8.5.1 VASSE FLOODGATES

At the commencement of the monitoring program, pH upstream of the Vasse floodgates was 8.68. The highest pH recorded was 9.07 on January 21st, 2000. The minimum pH recorded was 7.67 on February 16th (the morning following the fish kill event, after the floodgates had been opened for 8 hours the previous day). The pH fluctuated around 8.00 for the remainder of the monitoring period.

8.5.2 WONNERUP FLOODGATES

Upstream of the Wonnerup floodgates, week to week changes in surface pH closely followed that in the Vasse, although the pH was usually around 0.5 units lower until March 2nd, 2000, after which the pH in Wonnerup remained marginally higher. The recorded pH varied from a high of 8.62 on December 22nd, 1999 to a low of 7.60 on February 16th, 2000.

8.6 Turbidity

Turbidity is a measure of the clarity of a waterbody. In both the Vasse and Wonnerup estuaries during the monitoring period, turbidity was probably most affected by phytoplankton densities. Turbidity immediately upstream of both floodgates (surface only), expressed as nephelometric turbidity units (NTU) is shown in figure 18. A high NTU reading indicates high turbidity (low clarity).

8.6.1 VASSE FLOODGATES

At the commencement of the monitoring program (December 16th, 1999), the turbidity of the water upstream of the Vasse floodgates was the second most turbid that was recorded for the entire monitoring period (56.0 NTU). Two days prior to the opening of Wonnerup Inlet mouth (December 22nd, 1999), the turbidity had already declined by almost half (to 28.3 NTU). Six days later (December 30th, 1999), turbidity had declined by half again (to 13.8 NTU). The turbidity then rapidly increased again to reach the maximum of 67.7 NTU on January 12th, 2000. Two weeks later (January 27th, 2000), turbidity had decreased to one third again (22.7 NTU). The turbidity decreased by less than 5 NTU in the week following the floodgate opening of February 3rd, 2000, and decreased by a further 5 NTU the morning following the fish kill event, after the floodgates had been opened for 8 hours the previous day. The turbidity rose slightly the week following the fish kill event and floodgate opening (to 18.6 NTU on February 25th, 2000), and then declined to fluctuate below 15 NTU for the remainder of the monitoring period.

8.6.2 WONNERUP FLOODGATES

At the commencement of the fish monitoring program, the turbidity in Wonnerup estuary was considerably lower than in the Vasse (14.2 NTU compared to 56.0 NTU on December 16th, 1999). Two days prior to the opening of Wonnerup Inlet mouth (December 22nd, 1999), the turbidity was 20.5 NTU. Following the opening of the inlet mouth, the turbidity declined only minimally, to reach 16.1 NTU by January 6th, 2000. The turbidity peaked at 42.9 NTU on January 21st, 2000. Turbidity then declined steadily for the remainder of the monitoring period, except for two minor rises, on February 9th, 2000, following the floodgate opening the previous week, and on February 25th, 2000, following the floodgate opening of February 21st. Both represent rises of less than 8 NTU, however the reason for these rises is not clear.

9 WATER QUALITY OBSERVATIONS

9.1 Observations Of Phytoplankton and Water Colour

Daily changes in the colour and clarity of water may potentially provide management with an indication that a toxic algal bloom, or algal decay situation is occurring. For instance, dinoflagellate species, some of which are toxic to fish, may rapidly turn the water a red-brown colour before fish deaths occur (J. Lane, CALM, pers. comm.). Similarly, when the water in the estuary rapidly clears following a period of high turbidity due to an algal bloom, it is probable that the bloom has collapsed and that benthic decay, which consumes oxygen, is occurring. For these reasons, a subjective assessment of water colour and clarity, together with observations of scum, were made at every inspection. Comparison of this information to the WRC Southwest's phytoplankton sampling results may provide management with an indication of the readily apparent visual signs (if any) of the different microalgae that dominate the blooms in the wetland system. Complete tabulations of the visible water quality observations made at each inspection are included in Appendix 4 (Vasse floodgates upstream), Appendix 5 (Vasse floodgates downstream), Appendix 11 (Wonnerup floodgates upstream), and Appendix 12 (Wonnerup floodgates downstream).

9.1.1 VASSE FLOODGATES

A summary of the visible changes in water quality upstream of the Vasse floodgates over the course of the monitoring program is shown in table 3. Visible changes in the quality of water downstream of the floodgates are given in table 4.

Table 3. Summary of visible changes in the quality of water upstream of the Vasse floodgates.

PERIOD	COLOUR	SCUM	CLARITY	COMMENTS
16/12/99 – 24/12/00	Bright pea-green	Golf-ball sized spongy green and black scum at floodgates	Poor to very poor	
26/12/99 – 4/01/00	Olive green – khaki – olive brown		Poor (cleared slightly on 3/01/00)	Bubbles rising at floodgates
5/01/00 – 12/01/00	Bright green with darker green (khaki) phytoplankton swirls or floccules visible in water column	Large patches of spongy khaki green and brown scum with white foam bubbles around the edge of the scums	Very poor to nil visibility	Water very thick and soupy looking, swirls of phytoplankton visible in the water column, bloom looks like light and dark green marbled paper
13/01/00 – 15/01/00	Bright green	No scum	Very poor to nil visibility	Water homogenous in colour and texture, very smelly on leeward shore
16/01/00 – 19/01/00	Bright green	Large khaki and brown spongy and crusty scum mats, surrounded by bubbles, floating on surface from floodgates to past 30m upstream	Very poor to nil visiblity	Nil visibility for most of this period, lots of bubbles on surface with scum mats
20/01/00 – 23/01/00	Bright green – olive green	No scum	Very poor	Homogenous looking, although slight phytoplankton swirls visible in the thick soupy water. Appeared to clear slightly on 23/01/00
24/01/00 – 25/01/00	Bright to khaki green mottled with lighter green phytoplankton flecks	Small patches (triangles) of spongy khaki scum at floodgates	Very poor	Thick and soupy looking bloom again – appears as if a thick colloid forming, looks darker than previous weeks

Table 3. Summary of visible changes in the quality of water upstream of the Vasse floodgates.

PERIOD	COLOUR	SCUM	CLARITY	COMMENTS
26/01/00 – 29/01/00	Khaki green to dark khaki	No scum (except for a small patch of crusty brown scum at floodgates on 29/01/00)	Poor	Looks to have improved in clarity, clearer than all of December
30/01/00 – 5/02/00	Dark khaki/green and bright/light olive green	Kaleidoscope coloured thick and chunky spongy scums from the floodgates to 100m upstream (see plate 1)	Very poor to nil visibility	Bloom again, thickest at floodgates to around 20m upstream – extended >100m upstream on 2/02/00 – appear to be the worst the bloom had been all summer – floodgates were opened for 4.5 hours to release fish on 3/02/00
6/02/00 – 11/02/00	Dark khaki to brown (pale brown by 11/02/00)	No scum	Poor	Bubbles and froth on surface at floodgates and along north bank – clarity improved over last two days
12/02/00 – 15/02/00	Olive brown	No scum	Poor-moderate and then moderate-good	Froth/bubbles on surface for 15m upstream, occasional bubbles rising, sulphur smell along north bank
16/02/00 – 17/02/00	Dark khaki – clear	No scum	Very good - moderate	Following the fish kill event (15/02/00), the floodgates were opened for 8 hours which cleared the water on 16/02/00
18/02/00	Dark khaki	Bright olive and pale green scum at floodgates	Poor	Froth all around scum
19/02/00 – 20/02/00	Olive brown/khaki	No scum	Moderate to good	Slightly clearer than previous few days – could see bottom along banks, bubbles for 120m upstream along banks
21/02/00 – 24/02/00	Dark khaki	Large chunks of patchy-coloured (pale to dark brown) spongy scum in patches on surface of water at FG and patchy for 200m upstream.	Moderate	Bubbles rising at floodgates and in patches for 200m upstream
25/02/00 – 28/02/00	Pale milky green to olive green	Small amount of spongy brown scum remaining	Moderate to poor and then to very poor	Notable colour change on 25/02/00 followed by a bloom that visibly thickened the water for 5m upstream of the floodgates, sulphurous smell along south bank for two days

Table 3. Summary of visible changes in the quality of water upstream of the Vasse floodgates.

PERIOD	COLOUR	SCUM	CLARITY	COMMENTS
29/02/00 – 8/03/00	Pea-green to milky green to khaki green	No scum	Moderate	Water column slowly clearing, bubbles rising along both banks and at floodgates, sediments look very black
10/03/00 – 28/03/00	Milky green to milky pea green	No scum	Moderate	Estuary very smelly on 10/03/00, bubbles on surface along N bank for most of the period
30/03/00 – 7/04/00	Dark khaki green	Oily film with a small amount of pale and dark brown thin scum on surface on 30/03	Moderate to poor (30/3 and 1/04) then moderate	Water quality noticeably deteriorated for two days then the water slowly cleared, few bubbles on 31/03 and 1/04 only
9/04/00 – 13/04/00	Khaki green		Good	Water was the clearest all summer due to very strong leakage of water upstream for several days due to exceptionally high tides – very smelly on 13/04/00
15/04/00	Pale green	Very small amount of pale brown scum at floodgates with some bubbles	Moderate	Colour and clarity change again

Table 4. Summary of visible changes in the quality of water downstream of the Vasse floodgates.

PERIOD	COLOUR	SCUM	CLARITY	COMMENTS
16/12/99 – 24/12/99	Olive green to pea green to coppery brown on 24/12	No scum	Poor	Water quality downstream was similar to upstream until the opening of the Wonnerup Inlet mouth on 24/12/00
26/12/99 – 27/02/00	Khaki green – dark khaki	No scum	Mostly moderate to good (although good to very good during 27/01/00 – 3/02/00)	Both the colour and clarity of water downstream of the floodgates vary, sometimes dramatically, from day to day due to the effects of tide and leakage from upstream
28/02/00 – 15/04/00	Khaki green to very clear	No scum	Mostly very good	Very clear on most days

9.1.2 WONNERUP FLOODGATES

A summary of the visible changes in water quality upstream of the Wonnerup floodgates, for the course of the monitoring program, is shown in table 5. Visible changes in water quality downstream of the floodgates are shown in table 6.

Table 5. Summary of visible changes in the quality of water upstream of the Wonnerup floodgates.

PERIOD	COLOUR	SCUM	CLARITY	COMMENTS
16/12/99 – 7/01/00	Brown to olive/brown or green/brown	No surface scum other than small amounts of *Ruppia* matting	Mostly poor (moderate-poor to poor-very poor)	Water homogenous looking, no surface scum, some submerged filamentous and spongy algae along banks – Wonnerup Inlet mouth was opened on 24/12/99
8/01/00 – 12/01/00	Olive brown to brown	Oily pale green surface film – looks like marbled paint	Very poor to nil visibility	Shiny surface film extended upstream from the floodgates for up to 20m upstream. Worst day was 10/01/00
13/01/00 – 15/01/00	Olive brown	No scum	Poor to very poor	Water all homogenous looking for 3 consecutive days
16/01/00 – 20/01/00	Olive brown/dark khaki	Swirls of pale green and brown oily surface film – very marbled and mottled looking	Very poor to nil visibility	Bloom worst on 17/01/00 – thick for at least 50m upstream – water smelly as well
21/01/00 – 23/01/00	Brown to olive brown to khaki	No scum	Very poor	Homogenous again due to 2 days of wind
24/01/00 – 25/01/00	Olive green – bright green	Phytoplankton visibly flocculating together (wind driven) to form a shiny green surface film at the floodgates	Very poor	Wind pushing up against floodgates is causing scum to form on surface right at floodgates again
26/01/00 – 30/01/00	Olive green	Small amounts of several types of scum – shiny green surface film, some long brown 'stringy' scum (>30cm long x 2mm wide), and also submerged green spongy scum along banks	Poor	Clarity improved slightly on previous weeks. Deteriorating again by the 30/01/00, when sediment surface (crusty brown scum) appears to have risen in small patches
31/01/00 – 3/02/00	Dark olive green – khaki with green phytoplankton swirls visible	Small amounts of pale green paint-like scum together with stringy scum	Poor – very poor	Bloom visibly confined to 20m upstream of the floodgates
4/02/00 – 9/02/00	Olive brown – khaki - brown	No scum	Moderate to good	Clearest the estuary has been yet, following the opening of the floodgates on 3/02/00 for 3hours, all stopboards remained out in release bay, resulting in increased seawater leakage upstream also
10/02/00 – 11/02/00	Olive brown – dark brown	Very small amount of brown stringy scum only	Poor	Water quality noticably deteriorated, residual bubbles on surface at floodgates

Table 5. Summary of visible changes in the quality of water upstream of the Wonnerup floodgates.

PERIOD	COLOUR	SCUM	CLARITY	COMMENTS
12/02/00 – 20/02/00	Olive brown – olive green – khaki green	Very small amount of stringy brown scum at floodgates only	Moderate - good	Bubbles on surface from floodgates upstream (40m upstream on 16/02/00)
21/02/00 – 25/02/00	Pale milky khaki green – very clear	No scum	Very good	Very clear – could see bottom for a long way upstream – many bubbles rising along banks and at the floodgates, following opening of the floodgates on 21/02/00 to release fish
26/02/00 – 10/03/00	Khaki to olive green	No scum	Moderate to good	Slightly cloudier than the previous week (milky green tinge), dense masses of bubbles and brown froth on surface along banks and at floodgates (see plate 2)
12/03/00 – 15/04/00	Very clear (light khaki tinge)	No scum (except for very occasional small amount of string brown scum right at floodgates only)	Very good	Very clear water – dense bubbles on surface along banks and at floodgates from 14/03/00 – 18/03/00, small amount of bubbles on surface for several days

Table 6. Summary of visible changes in the quality of water downstream of the Wonnerup floodgates.

PERIOD	COLOUR	SCUM	CLARITY	COMMENTS
16/12/99 – 26/12/99	Olive green - brown	Small amount of chocolate brown scum at floodgates	Moderate	Water quality downstream was similar to upstream prior to the opening of the Wonnerup Inlet sandbar on 24/12/99
26/12/99 – 26/01/00	Khaki green	No scum	Moderate-good to good	Water colour in the immediate vicinity is affected daily by the leakage flow from upstream
26/01/00 – 15/04/00	Very clear (occasional milky khaki tinge for a day or two)	No scum	Very good	Water very clear – could see bottom off the Forrest Road bridge on most days

9.2 Observations of Water Clarity

Visual observations of water clarity can provide management with an indication of whether an algal bloom, or algal bloom decay is occurring. At times, inspections were made close to dawn, and the angle of the sun was quite low, shading the water upstream of the Vasse floodgates, which made it difficult to judge the colour and clarity of the water. Similarly, overcast or cloudy conditions could dramatically alter the appearance of the water. To more clearly judge the clarity of the water, to note day by day changes, a secchi disc may be useful.

9.2.1 VASSE FLOODGATES

The subjective rating of water clarity, applied by visual assessment at each inspection, for both the upstream and downstream sides of the Vasse floodgates is given in figure 19.

Water clarity upstream of the floodgates was judged to be 'poor', and rapidly deteriorating prior to the opening of the Inlet mouth on December 24th, 1999, which slightly improved clarity until January 5th, 2000. From January 6th until February 3rd, 2000, when the floodgates were opened for the first time, clarity was 'very poor' (excepting a few days between January 26th and 29th, when the water cleared a little), and for many days the actual visibility into the water was zero. Following the initial floodgate opening on February 3rd, the clarity improved gradually to 'poor – moderate' on February 14th (the morning prior to the fish kill) and 'moderate to good' the next morning, when the fish kill occurred (February 15th, 2000). Following one very clear day (February 16th, 2000) after the floodgates were opened for 8 hours to a very high incoming tide, clarity then declined to reach 'poor' again by February 25th, 2000, when the floodgates were again opened to release fish. Water clarity then improved to 'moderate', except for 2 occasions when clarity deteriorated to 'poor' (March 16th and 31st, 2000), until April 7th, after which clarity further improved for the remainder of the monitoring period.

Downstream of the floodgates, water clarity was initially 'poor', although slightly better than upstream, until the opening of Wonnerup Inlet on December 24th, 1999. After the inlet became tidal again, water clarity downstream of the floodgates fluctuated dramatically due to the daily effects of leakage and tides, although it remained 'moderate' or better, except for two occasions (February 11th and 26th/27th, 2000), when the quality deteriorated to 'poor' again.

9.2.2 WONNERUP FLOODGATES

The subjective rating of water clarity, applied by visual assessment at each inspection, for both the upstream and downstream sides of the Wonnerup floodgates is given in figure 20.

Upstream of the Wonnerup floodgates, water clarity slowly deteriorated, despite the opening of Wonnerup Inlet mouth, to 'very poor' by January 7th, 2000. Water clarity remained 'very poor' until January 25th, after which it improved slightly (to 'poor'). Following the floodgate opening on February 3rd, the clarity steadily improved until February 20th, when the water cleared to 'very good' for the first time during the monitoring period. 'Very good' water clarity lasted for four consecutive days, which coincided with a period of five consecutive days where fish appeared to be very stressed (see section 10.2.2). Water quality subsequently declined slightly over the following week, and then fluctuated from 'good' to 'very good' for remainder of the monitoring program.

Downstream of the floodgates, water clarity was initially 'moderate', and was slightly better than upstream, until the opening of Wonnerup Inlet on December 24th, 1999. After the inlet became tidal again, water clarity downstream of the floodgates fluctuated dramatically due to the daily effects of leakage and tides, although it remained 'moderate' or better, except for two occasions

(January 11th and 26th, 2000), when the quality deteriorated to 'very poor'. After January 27th, 2000, water quality was almost always 'very good' downstream of the floodgates.

10 FISH BEHAVIOUR

10.1 Fish Species Observed

During the course of the monitoring program, a list of fish captured during the angling trials and fish clearly observed was generated for each estuary and Wonnerup Inlet (table 7). Only positively identified species have been included, so the list is not an exhaustive species list.

Interestingly, on February 3rd, 2000, an injured southern blue-fin tuna (approximately 1m long) was observed swimming back and forth parallel to the downstream side of the Vasse floodgates. The fish appeared to have been speared or harpooned in the top of the head, although the injury did not appear likely to kill the fish. It is probable that the fish was using the inlet to recover. This observation highlights how Wonnerup Inlet is used opportunistically by a wide variety of fish species, even large tuna.

Table 7. Fish species observed or captured in the various components of the wetland system.

COMMON NAME	SCIENTIFIC NAME	VASSE ESTUARY	WONNERUP ESTUARY	WONNERUP INLET
Sea mullet (flat-nosed mullet)	*Mugil cephalus*	√	√	√
Yellow-eye mullet (pilch)	*Aldrichetta forsteri*	√	√	√
Black bream	*Acanthopagrus butcheri*	√	√	√
Unidentified goby sp.		√		
Herring	*Arripis georgianus*			√
Tailor	*Pomatomus saltator*			√
Sand whiting	*Sillago* sp.			√
Flounder	*Pseudorhombus* sp.			√
Yellowtail trumpeter	*Amniataba caudavittatus*			√
Blue-fin tuna	*Thunnus maccoyii*			√

In addition to sea mullet, yellow-eye mullet and black bream, blue manna crabs *Portunus pelagicus* were observed in Wonnerup Inlet and in both estuaries upstream of the floodgates.

10.2 Daily Fish Activity

Throughout the monitoring program, the majority of the fish observed both upstream and downstream of the floodgates were mullet, due to their characteristic schooling and surface activity. Although both sea mullet *Mugil cephalus* and yellow-eye mullet *Aldrichetta forsteri* are present in the estuaries, on almost all occasions, it was not possible to tell one species from the other whilst rapidly swimming, so all observations refer simply to mullet.

Normal active mullet behaviour included activity both on the surface and below the surface, some of which could not be seen without polaroid sunglasses and an experienced eye. On the surface, small mullet (generally less than 30cm long) could frequently be seen schooling in tight circles, occasionally splashing at the surface or jumping completely out of the water (see plates 3 & 4). Alternately, schools of mullet (particularly the larger mullet) would swim very rapidly below the surface, back and forth, only very occasionally (often not at all) breaking the surface. These were all considered to be very active behaviours, yet not all were visible on the surface. At times, only the briefest flash of a school of fish was visible, yet it provided confirmation of the activity of fish. At other times, fish would swim more slowly below the surface, rolling sideways (often visible as flashes), and occasionally just break the surface, resulting in a gentle surface rise (visible as a surface ring). This was also considered to be active behaviour, but less vigourous than that described above.

On several occasions, mullet appeared to behave in stressed ways. On at least several days, schools of hundreds to thousands of large mullet were observed to be nosing hard up to the gaps in the floodgates where seawater was leaking in from downstream, such that the water appeared to be a seething mass of fish. Immediately prior to and following the fish kill event (0600-0715 hours on February 15th, 2000), mullet were seen to be gasping at the surface and swimming with their noses above water. These two behaviours were considered to be stressed fish behaviours, suggesting that the release of fish was necessary.

Perplexingly, similar behaviour was observed on at least several occasions in Wonnerup Inlet (downstream of the floodgates), when the water quality appeared to be fine. On several occasions, large schools of mullet and black bream were observed nosing hard up to the gaps in the floodgates in the murky leakage flow from upstream, although they were never seen in a 'seething mass' as was observed on the upstream side of the floodgates. At other times, particularly in December and towards the end of the monitoring program, large schools of mullet were observed swimming very slowly in dense schools with just the very tip of their noses at the surface. Occasionally one or two in the school would splash at the surface or jump completely from the water. Although it is unclear what the fish were actually doing (they may have been feeding on microalage), the behaviour is distinct from the stressed behaviour where fish gasp at the surface, as the mouth of the fish appeared to remain below the surface. Additionally, mullet both within the school and in other schools in the same area at the same time were observed to be vigorously splashing and jumping out of the water. As a result, these behaviours, although very similar, were not considered to constitute stressed behaviour.

On many of the mornings during the course of the monitoring program, the conditions were very calm at the time of the inspections (see Appendices 2 and 9 for a tabulation of weather conditions at the time of each inspection). On several occasions, the wind rapidly freshened during the inspection, thereby oxygenating the water upstream of the floodgates, and the activity of mullet rapidly increased, particularly the frequency of small fish jumping above the water.

While a very high level of fish activity obviously indicates the presence of a large number of fish in the area, a low level of observable activity does not necessarily indicate that fish were not present in the area at the time. At times, particularly when severe algal blooms and surface scums were present, the visibility into the water column reduced to just centimetres (down to zero visibility at times), and only fish activity at the surface could be observed. Also, activity below the surface was only visible for around 25m upstream. When the sun was at very low angles to the water surface in the morning, it was also difficult to see into the water column, particularly in shaded areas and when the sky was overcast.

Although the daily observations of fish behaviour made during the course of this monitoring did describe the distance that fish activity was from the floodgates, the subjective activity rating was applied to describe the total activity observed between the floodgates and 250-300m upstream. This approach to summarise the observed fish activity was taken due to the limited budget for reporting and analysis of the monitoring program results. The activity rating does not discriminate between fish activity immediately at the floodgates, and that which occurred 250m upstream. Consequently, the activity rating does not, at times, accurately describe the activity and behaviour of fish in the area affected by the leakage flow (which is also the limit of the WRC Southwest data on physical parameters described in this report). As a result, the fish activity ratings may not correlate closely with the leakage data here. It would be better to examine each day's activity observations in terms of distance from the floodgates in relation to the leakage rate and direction data, however the available time did not allow this to be done. A complete tabulation of the daily fish behaviour observations at the Vasse floodgates is included in Appendix 6, and at the Wonnerup floodgates in Appendix 13.

To accurately determine the effects of seawater leakage on mullet behaviour in the estuary exit channels, appropriate statistical correlation of the observed fish behaviour both at the floodgates and further upstream (such as Ballarat Road) together with the direction and rate of leakage is required. Additionally, statistical correlation of the effects of leakage on physical parameters along the length of the exit channel is required. This may require the collection of more rigorous data to describe mullet behaviour and activity, such as the number of rises per minute per area, and log abundance of fish per area.

Although black bream are present in all areas of the system, they never feed or swim at the surface, so observations of bream were only made when the water was very clear, and they were in close proximity to the floodgates. Therefore, the bulk of the observations made refer to both species of mullet.

10.2.1 VASSE FLOODGATES

A chart of daily fish activity ratings upstream and downstream of the floodgates is presented in figure 21.

For the first three weeks of monitoring, low levels of fish activity (either individual fish or very small schools only) were recorded upstream of the floodgates, when the leakage was downstream and very gentle at most inspections. For the next three weeks, from January 6th to 26th, when water quality was lowest, no fish activity was observed at all. This is not surprising given the extent of surface scum and water clarity during this period. Hosja and Deeley (1994) suggest that fish and crabs will avoid areas affected by dense blue-green algal blooms, however they were observed on at least several occasions swimming actively and surfacing right on the edge of dense mats of scums when seawater had been leaking upstream (see plate 5). This did not occur during this period however, when estuary water was observed to be leaking downstream on almost every occasion.

A comparison of daily activity ratings to leakage direction and rate revealed that over the course of the monitoring program, as the amount of seawater leaking through the floodgates increased, the observed activity upstream of the floodgates increased. Prior to February 20th, 2000, the number of days where seawater was leaking upstream was considerably less than later in the monitoring program. Additionally, for the first two months of monitoring, when seawater did leak in, upstream through the floodgates, it was rarely more than a very gentle trickle, which is less likely to alter conditions directly upstream of the floodgates than a fast leakage of water. The level of observed activity was consistently greater after February 20th, when the head of water was regularly above 20cm on the downstream side, resulting in a moderate to fast rate of leakage upstream through the floodgates. Following the fish kill (February 15th, 2000), fish activity was moderate to high, with hundreds of active schooling mullet observed on all but three days, which were days where the leakage of seawater was downstream.

10.2.2 WONNERUP FLOODGATES

A chart of daily fish activity ratings upstream and downstream of the Wonnerup floodgates is presented in figure 22.

At the Wonnerup floodgates, the direction of water leakage was upstream more frequently than at the Vasse. Water quality was also better. As a result, for most of the monitoring period, activity was considerably greater at the Wonnerup Floodgates than at the Vasse.

During the week of February 21st to 25th, 2000, thousands of very large mullet were seen schooling hard up against the floodgates where seawater was rapidly leaking in from Wonnerup Inlet, such that the water looked like a seething mass of fish. When this was observed, the water was very clear, so fish could be seen below the surface. There was very little (or no) surface activity on most of these days, so if the water was not clear, this behaviour may not have been observed. In addition to the fish seething at the floodgates, many thousands more mullet were swimming and rolling very slowly along the bottom, a little distance back from the floodgates, few were breaking the surface at all. At 7.00 am on February 25th, after exhibiting the same behaviour again, a large school of medium sized mullet began swimming with their noses above the water, although not violently gasping or thrashing at the surface. This was considered to be very stressed fish behaviour. In summary, it appeared that when fish were first becoming stressed, most of the surface activity ceased, and only when the fish became severely stressed did they begin to return to the surface again. Thus, early indications of stressed behaviour may not be visible on the surface at times. Following these observations, the floodgates were opened for around 2 hours to release more than 6000 mullet on February 21st and for another four hours on February 25th to release more than 3400 mullet.

In an attempt to better define the tolerance limits of these fish, Jim Lane (CALM) and Chris Webb (WRC Southwest) profiled the DO upstream of the floodgates early on the morning of February 26th (see section 8.2.2). Unfortunately, this work could not be done until after the floodgates had been opened for over four hours (fully open for only 1.5 hours) the day before, which seemed to improve conditions for the fish. Observations of the fish behaviour made whilst the DO profiling was occurring indicated that the fish were no longer stressed, and were displaying normal, active behaviour for the first time in six days. DO concentrations in the channel upsream of the floodgates ranged from 2.14mg/L (29.2% saturation) to 3.31mg/L (44.7% saturation). The water temperature ranged from 17.7° - 19.5°C. These levels of DO and temperature were apparently adequate for the mullet in the estuary.

On one of the days that stressed fish were observed (February 23rd) a recreational fisherman was fishing from the floodgates. He assisted by attempting to catch one of the mullet on the upstream side, but only very small black bream would take the bait from between the seething mass of fish. Three small black bream that were caught all displayed dark red gills, similar to those observed during the Vasse fish kill a week earlier. It is interesting to note that, when the seething mass of fish were observed, it was always the largest mullet (some in excess of 40cm long) that were nosing hard up against the boards, and smaller mullet that were schooling behind them. Meyer and Barclay (1990) note that low DO conditions will affect larger fish first.

10.3 Vasse Estuary Fish Kill – 15th February 2000

On the morning of February 15th, 2000, the author arrived at the Vasse floodgates at 6.25am (32 minutes after sunrise – 5.53am) to find fish already dying and thousands more fish thrashing at the surface and throwing their heads above water to gasp at the air. A regular fisherman at the floodgates, Jim Black, was there when I arrived. He noted that the fish activity had only commenced less than half an hour before I arrived, and one hour earlier, there was no visible fish or bird activity whatsoever. So, sometime around 6.00am, fish had approached the floodgates, swimming slowly with their heads above the water at first, obviously gasping at the air. The activity became louder and more violent, and less than half an hour later, fish were thrashing at the surface, then floating belly-up, sinking and dying. Thousands and thousands of fish noses were visible above the water surface, from the floodgates to around 150m upstream.

By 7.10am, fewer fish were thrashing at the surface, and few were jumping above the surface any more. Many fish could be seen lying on the bottom, still kicking. Shortly after, a light south-easterly wind (about 5 to 10 knots) began to ripple the surface of the water. The number of fish gasping at the surface and swimming with their nose above the water gradually reduced, and the fish moved further away from the floodgates. No further fish deaths appeared to occur after this stage.

At 8.00am, the floodgates were opened by the Water Corporation, although mullet did not recommence schooling at the floodgates until around 9.30am. The first few mullet began to emigrate through the floodgates at 10.40am. In the intervening time, a fish kill kit had been obtained from GeoCatch and samples of the fish, sediment and water were taken. Dead fish were observed as far upstream as Ballarat Road.

A complete report of all observations and actions taken during and following the fish kill event is included in Appendix I.

In the two weeks leading up to the fish kill, the level of fish activity observed was very high. From February 1st until February 10th, hundreds to thousands of mullet were present upstream of the floodgates, and were extremely active, jumping vigorously and splashing along the length of the estuary channel. Between February 11th, 12th and 13th, the level of fish activity gradually declined each day, until the day prior to the fish kill, when an apparent frenzy of activity was observed.

The fish kill incident was somewhat unexpected, given that the day prior, the fish were extremely active and apparently healthy. In fact, the previous morning was the greatest level of activity that had been observed since the commencement of monitoring. Many schools of tiny fish (pinheads) had been breaking the surface and jumping en masse, resembling a fast spray of water drops across the water surface. At least seven or eight of these 'sprays' were visible at any time from the floodgates to at least 250m upstream. It appeared as if a very active feeding frenzy was going on, with small fish being predated everywhere. Mullet were regularly jumping from the water along the length of the exit channel. Water was gently leaking upstream at the time of that inspection. Meyer and Barclay (1990) note that low pH (or high levels of ammonia) may cause fish to become hyperexcitable, as would be expected when benthic decay is occurring and carbon dioxide levels are high. In hindsight, it appears that this apparently very active behaviour may have been an indication that that the fish were experiencing very low pH caused by benthic decay. It would appear that, on occasions, this may be a precursor to DO declining to lethal levels.

Section 8 describes the physical conditions at the floodgates leading up to the fish kill event. No *in situ* measurements of physical parameters were made on the morning of the fish kill as all the available WRC equipment was in Perth for the Swan River algal bloom that occurred at the same time.

10.3.1 NUMBERS AND SPECIES OF FISH KILLED

Interestingly, although sea mullet are also present in large numbers upstream of the floodgates, only yellow-eye mullet and black bream were killed in substantial numbers. In excess of 366 black bream and 1097 yellow-eye mullet died. Two small unidentifed gobies, one small unidentified fish (possibly a juvenile samson fish approx 10cm long), and two very large (in excess of 70cm long!) sea mullet were also killed. Some (not all) *Palaemonetes* sp. shrimp also died.

When the fish were being laid out for sampling, it was noticed that not all year classes of fish present in the estuary were affected. Plate 6 shows a representative sample of the size and species killed that was collected by Jim Lane from an area 5-10m wide, from the floodgates to around 150m upstream along the south bank. The following sizes were represented: black bream, 68% were 86 – 135 mm lower jaw-fork length (LJFL), 26% were 165 - 195 mm LJFL, and 6% were 265 – 295 mm LJFL; yellow-eye mullet, 62% were 95 – 145 mm LJFL, 22% were 220 – 260 mm LJFL, and 16% were 275 – 345 mm LJFL. Many of the fish appeared to have burst blood vessels along the outside of the gill plate and around the viscera. All displayed very red gills, indicating that the fish were deprived of dissolved oxygen.

10.3.2 FISH PATHOLOGY AND WATER SAMPLE RESULTS

The Animal Health Laboratory of Agriculture WA undertook a histological examination of two of the fish specimens submitted (Chadwick, 2000).

The gills of both fish showed evidence of fouling associated with algae and bacterial proliferation, as would be expected with an algal bloom. There was moderate irritation caused by the fouling.

Both fish were not healthy prior to the bloom. One fish was infested with liver flukes, and there were indications that the fish had been diseased for some time. The second fish showed signs of ongoing severe chronic bacterial peritonitis, followed by acute gill disease associated with the algal bloom. The combination of those diseases resulted in full-blown bacterial septicaemia, which led to death for this fish.

It was concluded that: "Overall, the indications are that these deaths represent the weaker members of the populations of both species succumbing to the additional environmental stress caused by the algal bloom. There were no indications that the bloom was directly toxic to the fish, or that it caused disease in any other way other than fouling of gills and possibly oxygen deprivation." (Chadwick, 2000).

Only two fish, of approximately eighteen yellow-eye mullet, black bream and gobies submitted, were examined. From the pathology report, it is not clear which species these were.

Other than the fish, only sulphide and phytoplankton samples were analysed. Sulphide concentrations were less than 0.1mg/L, however sulphide is very volatile and concentrations at the time of collection may have been higher.

The total phytoplankton density on the morning following the fish kill (February 16th, after the floodgates had been opened for 8 hours the previous day) was 11,649 cells/mL, with blue-green algae contributing only a minor fraction (Water and Rivers Commission, Phytoplankton Ecology Unit, unpublished data). The previous week (February 9th), the total phytoplankton density exceeded 155,000 cells/mL (blue-green algae – 6,759 cells/mL). Therefore, the Vasse Estuary experienced a significant algal bloom crash in the week prior to the fish kill, which can rapidly deplete DO as benthic decay of the algal bloom occurs (see section 1.2). In addition, the phytoplankton cell density on February 16th was probably still high enough to cause diurnal fluctuations in DO due to photosynthesis and respiration.

Biochemical oxygen demand (BOD), nutrient levels, and physical parameters on the morning of the fish kill were not determined.

10.3.3 LIKELY CAUSE OF THE DEATHS

The fish kill, which extended from the Vasse floodgates upstream to Ballarat Road, was most likely due to low dissolved oxygen levels, which occurred during the decay following an algal bloom crash. As the water clarity had greatly improved since the fish release conducted on February 3rd, it is likely that the deoxygenation was caused by benthic decay in conjunction with night-time respiration of phytoplankton. The Water and Rivers Commission's phytoplankton data support this (see section 10.3.2). Respiration by the tens of thousands of fish present early on the morning of the kill would also have contributed to the lowering of oxygen levels.

Observations made by Jim Lane (CALM) at 4.15pm the previous afternoon indicate that fish were already oxygen stressed during the afternoon (see Appendix 1). Leakage in of water from downstream was very rapid during the afternoon, due to the high head of water in the Inlet. This would have oxygenated the water in the immediate vicinity of the floodgates. As DO levels are rarely observed to fall below 50% saturation during the day (due to phytoplankton photosynthesis – often causing supersaturation upstream of the floodgates), it is likely that the rate of benthic decay, and thus BOD, was extremely high the previous afternoon. The BOD alone may not have been sufficient to deoxygenate the water to critical levels however, when combined with night-time respiration of phytoplankton, the DO appears to have declined to critical levels early on the morning of February 15th.

When critical conditions were reached, there was no wind at all (it was calm), and leakage into the estuary from upstream (which also oxygenates the water) had ceased several hours earlier. The fish deaths occurred in a very short space of time and had ended by the time the floodgates were opened. Those fish that had not already died appeared to rapidly recover as the sun rose (photosynthetic oxygenation of the water was occurring), and the breeze freshened (oxygenates the water). It appeared that critical levels of DO were overcome, and the fish were recovering, before the floodgates were opened. It is likely that the number of deaths were not reduced by the opening of the floodgates at 8.00am.

The pathology report indicated that it was the already weak and diseased fish amongst the population that were killed (Chadwick 2000, see section 10.3.2). As conditions in the Vasse Estuary had been very poor during December and January, with severe algal blooms lasting for weeks at a time, it is not surprising that many fish were not in a healthy condition at the time of the incident. While the algal blooms experienced in the Estuary were not directly toxic to the fish, they caused gill fouling and increased the susceptibility of the fish to critical low DO conditions.

Although the monitoring program did not prevent the fish kill from occurring, it did prevent the possible death of thousands more fish on subsequent mornings by allowing the release of the survivors. Whilst in excess of 1500 fish died, it was estimated that more than 35,000 mullet were released during the 8 hours that the floodgate was opened that day. The fish kill incident was well documented, and this will allow the VETWG to better understand and recognise indications (such as exceptionally high activity) that mean a fish kill is likely in the near future.

11 WATERBIRDS

11.1 Waterbird Species Observed

A list of all waterbird species in the various components of the wetland system, identified by the author during each day's monitoring, is shown in table 8. The table does not include several species of waders that were observed but not identified to species level. During the course of the monitoring program, waterbird diversity was highest upstream of the Vasse floodgates (Vasse Estuary), with a total of 19 different species recorded (excluding small waders), including three ducks, two cormorants, and several large waders. Five species observed in the Vasse Estuary were not recorded elsewhere within the study area: hardhead duck *Aythya australis*, purple swamphen *Porphyrio porphyrio*, dusky moorhen *Gallinula tenebrosa*, crested tern *Sterna bergii*, and the white-bellied sea-eagle *Haliaeetus leucogaster*.

Table 8 Waterbird species identified in the Vasse and Wonnerup Estuaries, and Wonnerup Inlet from December 1999 to April 2000.

WATERBIRD	SCIENTIFIC NAME	VASSE ESTUARY	WONNERUP ESTUARY	WONNERUP INLET
Black swan	*Cygnus atratus*	√	√	√
Pacific black duck	*Anas superciliosa*	√	√	√
Musk duck	*Biziura lobata*	√	√	√
Hardhead duck	*Aythya australis*	√		
Darter	*Anhinga melanogaster*	√	√	√
Little pied cormorant	*Phalacrocorax melanoleucos*	√	√	√
Little black cormorant	*Phalacrocorax sulcirostris*	√	√	√
Pied cormorant	*Phalacrocorax varius*		√	√
Australian pelican	*Pelecanus conspicillatus*	√	√	√
Nankeen night heron	*Nycticorax caledonicus*	√	√	√
White-faced heron	*Egretta novaehollandiae*	√	√	√
Great egret	*Ardea alba*	√	√	√
Little egret	*Egretta garzetta*			√
Eastern reef egret	*Egretta sacra*			√
Australian white ibis	*Threskiornis molucca*	√	√	√
Yellow-billed spoonbill	*Platalea flavipes*	√	√	√
Silver gull	*Larus novaehollandiae*	√	√	√
Pied oystercatcher	*Haematopus longirostris*			√
Purple swamphen	*Porphyrio porphyrio*	√		
Dusky moorhen	*Gallinula tenebrosa*	√		
Caspian tern	*Sterna caspia*	√		√
Crested tern	*Sterna bergii*	√		
White-bellied sea eagle	*Haliaeetus leucogaster*	√		
TOTAL	23	19	14	18

Fourteen species of waterbirds were observed upstream of the Wonnerup floodgates (Wonnerup Estuary), including two ducks, three cormorants, and several heron-types. A large number of waders (stilt, avocet and smaller species) were observed in Wonnerup Estuary and, although these were not counted or identified, it is important to note that they were not present in such numbers elsewhere in the study area, although small numbers were recorded in Wonnerup Inlet. No waders were observed at the Vasse floodgates.

A total of 18 waterbird species were identified in Wonnerup Inlet (downstream of both sets of floodgates). These included two ducks, three cormorants, and a greater diversity of heron-types than was observed elsewhere. Three species recorded in Wonnerup Inlet (downstream of the Wonnerup floodgates) were not recorded elsewhere: little egret *Egretta garzetta,* eastern reef egret *Egretta sacra,* and pied oystercatcher *Haematopus longirostris.*

11.2 Waterbird Abundance

11.2.1 VASSE FLOODGATES

A chart of the total abundance of waterbirds, with breakdown by the main groups, upstream of the Vasse floodgates is shown in figure 23. For most of the duration of the monitoring program between five to fifteen waterbirds were regularly recorded upstream of the floodgates. The most commonly observed birds throughout the monitoring program were little black and little pied cormorants, followed by pacific black ducks and musk ducks. Small numbers of white-faced heron, great egret, Australian white ibis and yellow-billed spoonbill were also regularly observed.

In the week prior to the fish kill, 20-30 waterbirds were observed on 3 days. Both Australian pelicans and cormorants increased in numbers. On the morning of the fish kill (February 15th, 2000), and the following morning, waterbird numbers increased significantly, with pelicans and silver gulls the most numerous birds present.

A chart of the total abundance of waterbirds, with breakdown by the main groups, downstream of the Vasse floodgates is shown in figure 24. Downstream of the Vasse floodgates, few waterbirds were observed. For the duration of monitoring, less than 4 birds were observed on almost every occasion, and no more than 10 were observed together at all. Most of the birds observed on the downstream side of the Vasse floodgates were roosting on the old bridge several metres downstream of the floodgates.

11.2.2 WONNERUP FLOODGATES

A chart of the total abundance of waterbirds, with breakdown by the main groups, upstream of the Wonnerup floodgates is shown in figure 25. Waterbirds were considerably more abundant in the Wonnerup Estuary than in the Vasse, with large numbers (in excess of 200) cormorants, pelicans, silver gulls and large waders observed on several occasions.

It is interesting to note that, as occurred during the Vasse fish kill (February 15th, 2000), when stressed fish were observed in Wonnerup Estuary between February 21st to 25th, there was a significant increase in the abundance of silver gulls, which were rarely observed at other times. Although numbers of cormorants and pelicans also increased when stressed fish were observed, silver gulls only appeared in large numbers during these events, whereas large numbers of cormorants and pelicans were observed at other times also.

A chart of the total abundance of waterbirds, with breakdown by the main groups, downstream of the Wonnerup floodgates is shown in figure 26. Few waterbirds were observed downstream of the Wonnerup floodgates, except on one occasion (February 26th, 2000) when large numbers moved downstream after they were disturbed by Jim Lane and Chris Webb who were DO profiling upstream of the floodgates. On most other occasions, a variety of ducks, cormorants and heron-types were observed in low numbers.

12 MANAGEMENT ACTIONS TAKEN

In December 1999, at a meeting of the Vasse Estuary Technical Working Group it was decided that during summer-autumn of 1999/2000 consideration would be given to opening the Vasse or Wonnerup estuary floodgates if one or more of the following occurred:

- fish upstream were showing signs of stress (e.g. "gasping" with noses above the surface);
- the Water & Rivers Commission water quality monitoring program indicated that DO on the upstream side of the gates had declined to near-critical levels (or, in the absence of data, visual monitoring indicated a severe decline in water quality)
- medium to large sized fish were schooling in large numbers (several thousands or more) immediately upstream of the gates, particularly if they were swimming hard up against the floodgates and attempting to pass through the structure.

In practice, the floodgates were opened on relatively few (compared with 1998-99) occasions (table 9). This was because of concern about the structural integrity of the Wonnerup estuary floodgates (a large structural member came adrift during the opening of 21 February and hampered closure) and a desire not to "over-manage" the fish death problem (J. Lane, pers. comm.).

Table 9. Summary of management actions taken at both floodgates during the course of the monitoring program.

DATE	VASSE FLOODGATES	WONNERUP FLOODGATES
16/12/99	Floodgates open to outflow only, no seawater inflow, all stopboards in place.	From the south end of the floodgate, stopboards were missing in bays 1,3 and 9.
22/12/99		Floodgates repaired, all stopboards in place.
3/02/00	Floodgate opened for 4.5 hours (11.42am – 4.12pm) – in excess of 1900 mullet released. The reverse flap valve was opened and remained open for the remainder of the monitoring period (except for two occasions where it accidentally closed).	Floodgate opened for less than 2.5 hours (12.20pm – 2.45pm) – no movement of fish.
15/02/00	Fish kill incident – in excess of 1500 fish died – floodgates were opened for 8 hours (8.00am – 4.05pm) – in excess of 35,000 mullet were released	
16/02/00	The lower sill of the reverse flap (through which the fish escape) was found to be 1cm above the water level in the estuary, so the entire reverse flap valve assembly was lowered by two stopboards (around 30cm) to facilitate further fish releases.	
21/2/00		Floodgates were opened for 1.5 hours (8.55am – 10.25am) – more than 6000 mullet were released. Difficulties arose when attempts were made to close the floodgates at 10.25am, and they remained partially open for a further 2.5 hours (until around 1.00pm), when Water Corporation technicians closed the floodgates.
25/2/00		Floodgates were opened from 9.45am – 10.55am, more than 3400 mullet were released

13 RECOLLECTIONS OF FIVE LOCAL FISHERMEN ON THE USE OF THE WETLAND SYSTEM BY FISH

Prior to the preparation of this report, little had been documented about the wider use of the wetland system by fish. The VETWG reviewed the history of mass fish deaths in the system and the factors that cause them (Lane *et al.* 1997), however the information on daily and seasonal movement of fish within the system was scant. In a preliminary attempt to identify new information about the ecology of fish within the estuary, five local people (recreational fishermen, commercial fishermen and elders of the local Aboriginal community) who possess considerable historical knowledge of the movement of fish within the estuary were personally interviewed. Notes were taken during each interview (interviews were not recorded). Each person rechecked the drafts of their interviews for accuracy at least twice and all of their comments and requests were included. Therefore, the interviews reflect the stories each person wished to tell about their experience and knowledge of fish within the system. Unfortunately, due to illness, Mr Oldfield was unable to recheck his interview personally however his wife rechecked the draft and thought that the information was correct to the best of her knowledge. Finally, the stories have been summarised to provide an insight into the wider use of the estuary by the major fish species (yellow-eye mullet, sea mullet and black bream).

13.1 Recollections of Mr Alf Reynolds

11 Finlayson St
Dunsborough WA 6281

Interviews: March 23rd and 27th, 2000

Mr Reynolds was born in 1922 at the Reynolds family farm 'The Island', which was approximately 520 acres along the NW shore of Wonnerup Estuary (between the estuary and the Deadwater). The Reynolds mostly grew oaten hay for race horses and cattle that were run on the property. The old farmhouse was adjacent to the Wonnerup floodgates and Forrest Beach Road bridge, which was known is those days as Tom's bridge, after Mr Reynolds father. Mr Reynolds lived and worked continuously on the Island, except for a short spell at Lockeville, until 1970 when he moved to Dunsborough.

Mr Reynolds fished occasionally over the years, although he was generally busy working and too tired to fish after 9 or 10 hours a day in the saddle. He was a keen naturalist and wildlife warden for over 30 years (to police out-of season duck shooting), and this led him to make many observations about the Vasse-Wonnerup Estuary, Wonnerup Inlet and the Deadwater over the years. Most of the fishing Mr Reynolds did do was from his dinghy, in the Deadwater or Geographe Bay. What follows is Mr Reynolds recollections of the estuary and its life. Some of these memories are from many years ago, and are correct to the best of his memory.

The only fish in the estuaries were flat-nosed mullet (sea mullet), yellow-eye mullet and black bream. The Forrest family, who owned the farm to the north of the Island, used to net the upper Wonnerup Estuary regularly. They almost always set their net near the mouth of the Ludlow River. Their catch was mostly composed of flat-nosed mullet, with the occasional yellow-eye mullet, although the flat-nosed mullet were far more common. Mr Reynolds didn't recall bream being in the catches. The Vasse Estuary channel near Ballarat Road was the only place that bream were numerous (in the Estuary upstream of the floodgates), and along there is where the fishermen always caught them. On the whole, there were more fish in the Vasse Estuary than in Wonnerup Estuary.

Mr Reynolds never saw fish going in to the estuary through the floodgates when they opened during winter as the water was always too turbid and muddy. He assumed that was when they swam in. During spring, large numbers of mullet and bream would appear on the downstream side of Wonnerup floodgates. They would school in numbers at the floodgates and under the bridge, and appeared as if they wanted to swim upstream. They were often feeding. He thought that they would come up to the floodgates when there was water leaking and flowing out from upstream to feed on the algae and other food coming out. In spring, large numbers of bream would come in under Tom's bridge to feed on the tubeworms, which Mr Reynolds distinctly recalled were not present in the estuary or inlet during his childhood (the 1920's and early 1930's).

Mr Reynolds only saw mullet jumping and splashing at the surface during the summertime, never in winter. He used to see the mullet school in large numbers above the Wonnerup floodgates during very hot weather when the fish were stressed and he did not notice them at other times. He thought that the fish were dispersed widely within the estuary at some times of the year (when he did not see them) and that they would school at other times. He thought that the fish moved further downstream and into the channels as the estuary dried up each year. The fish only ever died after hot spells.

The PWD drag-line dredged the Wonnerup Estuary channel sometime during the late 1950's or early 1960's (Mr Reynolds could not recall the exact year). The channel just upstream of the floodgates was dredged to increase the flood flow. The dredged material was piled alongside the main channel to form a levee, as very high tides had breached the land immediately to the east of the floodgates (from the deadwater mouth to the backwater on the upstream side) on several occasions in the past.

Ilmenite Pty. Ltd. undertook dredging for ilmenite along some sections of the Deadwater during the 1950's. One section of the Deadwater that was dredged created a pool of about 15 foot depth which was rapidly colonised by King George whiting to the delight of many of the critics of the dredging.

During about five out of every six summers, Wonnerup Inlet mouth closed naturally with sand. Sometimes the bar would naturally open itself during the course of the summer when very high tides breached the low sand bar, otherwise it would be opened by hand when the first rains came, usually around April. Some years the bar would be low enough for the first real flood flow to breach it, but if that did not occur, Mr Reynolds, with the assistance of several of his neighbours, would dig the bar when water levels in the estuary began to rise. Their policy was to let nature take its course where possible, and only open the bar when needed.

Every winter the mouth of Wonnerup Inlet used to block with seagrass and algal wrack. The outflowing water was never strong enough to move the wrack on and eventually, when the highest tides came, the wrack would breach inwards, and great quantities were washed into the inlet. The wrack often blocked off the Deadwater and the Wonnerup Estuary channel completely, and only the Vasse Estuary channel flow was great enough to cause a small channel to form around the huge wrack that built up along the northeast shores of the Inlet. At times, the wrack would completely block the lower Wonnerup Inlet channel, and cause water levels to rise in the estuary. When this happened, Mr Reynolds and his neighbours would get hay forks (pitchforks) and try to dig the channel open.

The success of the operation (and also opening the sand bar in summer) was entirely dependent on the tides and prevailing winds. Onshore winds would cause masses of seagrass to be washed inshore and into the Inlet. To remove the wrack, there had to be low tides and offshore breezes. On one occasion in 1971, the Island's paddocks flooded because the Inlet channel had completely blocked with seagrass wrack which could not be moved on despite all attempts because onshore winds prevailed for several weeks. The amount of maintenance that the Inlet mouth needed varied from year to year, in some years requiring work two or three times each month, and in other years none at all.

Sometime during the 1950's, the Deadwater channel was blocked by wrack for many weeks and a large number of fish died subsequently. Fish were killed along the entire length of the Deadwater, but Mr Reynolds could not recall many other details about the event.

Mr Reynolds remembered that there used to be much more seagrass wrack along the coast than there is these days. In the early 1940's, the wrack used to be continuous from Dunsborough to Bunbury. He believes that the amount of seagrass washed ashore each year declined heavily around the time that farmers commenced large-scale use of herbicides such as 2,4-D and 2,4-D Estone 80, during the early 1950's.

Mr Reynolds described the extent of flooding caused by Cyclone Alby in April 1978 when seawater breached the dunes upstream of the Vasse floodgates near the old boat ramp. The storm surge caused seawater to flow over the lowest part of the foredunes, around the location of a former mouth to the Vasse Estuary that was present (in addition to the present Wonnerup Inlet mouth), in 1829 [described by Lt. Preston and Dr. Collie – see Appendix I of Lane *et al.* 1997]. The following day there were great pools of water in the carpark and along the base of the dunes opposite the Vasse floodgates that were filled with many large bream. There were lots of people fishing for big bream in the boat ramp carpark. The rising seawater damaged the Wonnerup Estuary floodgates, and flowed around the structure on the east side. Old Tom's bridge and part of the road was also washed away. The Vasse Estuary water level remained high for a week afterwards because the seawater had breached the dunes but not damaged the floodgates, so the floodgates slowed the drainage of the floodwaters afterwards. Unlike the Vasse, the Wonnerup Estuary water levels subsided quickly the next day because the floodgates were damaged and the bridge washed away.

Mr Reynolds believes the best solution to both the fish death and flooding problems is to construct a system of levees between the farmland and the estuary shores that exclude estuarine water from the farmland. The farmland could be drained into the estuary via a series of concrete culverts through the levee walls, and then the floodgates could be removed completely, allowing the system to return to a completely estuarine state. Mr Reynolds suggests that islands be created and vegetated to provide aesthetically pleasing waterbird habitat.

Mr Reynolds suggested that Peter and Mabel Bell, longtime Wonnerup residents, may also be able to provide information on the use of the estuary by fish. Mr Bell worked for many years on the Deadwater dredging, and both are keen wildlife carers who know the system well.

13.2 Recollections of Mr and Mrs George and Vilma Webb

33 Moylan Way
East Busselton WA 6280

Interview: April 3rd, 2000

George and Vilma Webb are respected Wardandi Nyungar elders who have lived for over 60 years in the Busselton area. They founded the Bibbulmun Mia Aboriginal Corporation and the Wardandi Cultural Centre 1990. Mr Webb is a direct descendent of Sam Isaacs, the local Nyungar man famous for his rescue efforts with Grace Bussell when the Georgette sank off Calgardup in 1876. Mr Webb was born in Bunbury on May 3rd, 1930. He attended school at Roelands and then returned to Busselton, where he has lived ever since. Mr Webb worked for 16 years (1966-1982) for the Public Works Department, maintaining the drainage network from Vasse-Wonnerup to Dunsborough during which time he made many observations about fish activity in all of the drains of the area. Mr Webb also worked for 18 years as a professional fisherman on net, line and longline boats working the waters from Augusta to Busselton, catching everything from mullet to salmon and groper. Mrs Webb was born in Northam on January 23rd, 1932 and came to Busselton at seven years of age. She camped and lived along the coast for many years and has regularly fished all of the waters from Dunsborough to Busselton for more than sixty years. Both Mr and Mrs Webb have a very good knowledge of the movement of fish within the waters of the Busselton – Cape Naturaliste region, including the changes that have occurred over many decades.

Mrs Webb said that over the years, they always fished in either the Wonnerup River (Vasse Estuary Channel), upstream and downstream of the floodgates, in Wonnerup Inlet, and in the Deadwater. Mrs Webb recalled that, upstream of the floodgates along the estuary channel they caught mullet (sea mullet), pilch (yellow-eye mullet) and bream (black bream). In the Inlet and the Deadwater they caught all sorts of fish, including sand whiting, King George whiting, tailor, bream (black bream), cobbler, flounder, and large kingies (mulloway). Mr Webb never professionally netted in the estuary or the Inlet as those waters were always closed to professional fishermen in the days when he fished for a living.

Mrs Webb's great grandmother lived and camped around Wonnerup and told her many stories about the place when she was a young girl. The Nyungars used to fish with kylies (like a boomerang to throw at fish) in all the shallows of the estuary. They caught mullet, whiting, and cobbler. There were also mussels, marron, turtles and frogs in the lower reaches of the rivers and fresh parts of the estuary. Along where Layman Road is now, there used to be a large mound of land that separated the estuary from the sea, and that is where they would bury their dead. In amongst all the reeds and sedges along that mound, the swans and ducks used to nest and breed. There was a place across the Vasse Estuary that they would walk across from the Ludlow Forest to go fishing and collect the swan and duck eggs. They would only ever take one egg from each nest so as not to disturb the birds breeding.

Mr Webb believed that large numbers of mullet and pilch would migrate upstream to spawn, although he could not recall at exactly what time of year that happened in the estuary here. Mr Webb knew that mullet, pilch and bream move far upstream into the drains and the rivers that feed the estuary during winter when the rivers begin their winter freshwater flows. They move upstream to feed on algae and other things in the water. Mr Webb recalled that at the eight-mile drain (the Carbunup River Diversion Drain), 'stacks and stacks' of pilch would come right up the drain and congregate below the weir where they would feed. He said that they would go and fish there regularly, once every two or three weeks, and the pilch would be there again and again for a couple of months, and then one day they would just be gone. Mr Webb did not know what made the mullet leave the rivers (or the drains). Mr Webb said that mullet and pilch will tolerate very shallow water, as shallow as they can physically swim through. The rivers (drains) were always deeper than that, and water was still flowing over the weir when the pilch went back to sea.

Mr Webb thought that the tide was what made the mullet and pilch move on a daily basis. On the flooding tide, mullet will move as far upstream as they can. When the tide turns and ebbs out, the mullet will move back downstream again. Mr Webb recalled how the Nyungars would use the tide to help trap fish along the rivers (estuary and Deadwater channels) when he was young. They would get the Devil's Web, which is a thick native creeper that grows high up in the paperbark trees, and put it across a shallow part of the river in a thick mat, densely packed from the bottom to the water surface to form a long net or trap. They would build the trap right across the river each day when the tide had come in and the fish had moved up the river. When the trap was made, some of the people would go on upstream and scare the schools of fish back down the river and into the trap of Devil's Web where the others waiting would collect the struggling fish. Sometimes they would just kylie the fish when they moved into the shallows during the high tide.

Mr Webb recalled that he had seen fish moving through the Vasse floodgates when he has been fishing from them. Although he could not remember what time of year it was, the floodgates were open due to the pressure of floodwaters flowing out of the estuary. He said that he saw them go through one or two at a time, then a dozen would dart through, moving upstream, for two or three hours. Then when the tide changed, the fish began to move back downstream. When the floodgates are not opened by floodwater flows, they form an impediment to the regular, daily movement of mullet and this is one of the reasons why Mr Webb believes that the floodgates should be removed altogether.

Mrs Webb believes that the floodgates no longer open as freely as they used to when there is more water on the upstream side, and so there is now less opportunity for the fish to escape. She believes that the fish school in great numbers upstream of the floodgates when the water quality deteriorates, as they will try to seek "fresher" water (the salt water of the Inlet). When the fish die in the estuary channel, even though conditions further upstream appear to be not as bad, Mrs Webb believes they do not swim away upstream because they will always try to return to the sea, where they have traditionally come from. The Nyungars believe that this is also true for dolphins and whales, which is why these mammals, which have evolved from land animals, will try to strand on the seashore when they die. When the water quality deteriorates in the estuary, the fish will congregate in great numbers when they reach the floodgates as they will always try to reach the sea and escape the estuary altogether.

Mrs Webb described how the sediments changed as the water quality deteriorated in the estuary every year. She said that the sediments appeared to go a dark purply grey colour, and would go all slimy. As it gets hotter, the crusty dark stuff comes off the bottom and floats up to the surface. Mrs Webb said that that was when you knew that the fish deaths were not far off. When they go fishing in the Wonnerup River (Vasse Estuary channel) during the summer, they look at the fish's gills to see if they are alright to eat. When the sediments start to go bad and turn that purple colour, the gills of the fish go a blackish dark colour. When they catch fish that look like that they know not to fish there any more and they don't go back there for a couple of months.

Mrs Webb knew that at times, large numbers of mullet and pilch move upstream to spawn in the estuary, although she was not sure of exactly when that happened. They would spawn in the estuary on any of the sandy areas. She believes that the sandy areas of the Deadwater are an important spawning area for many fish species, including whiting and King George Whiting.

Both Mr and Mrs Webb had witnessed fish deaths in the local area. Around 50 years ago, Mr Webb had seen fish dying in the nine mile drain (Anniebrook drain) on three or four occasions. It was always after a hot spell and they would be kicking, thrashing and gasping at the surface before going belly-up and dying. He didn't recall what the water looked like, but mentioned that the mouth of the drain always became blocked with seagrass and algal wrack in winter.

A few years ago, Mrs Webb saw fish dying in the Vasse Estuary channel, along the Captain Baudin Reserve. It was very shallow all the way across the channel there, and she said that she could see the bottom, and the sediment was that purple black colour. She said that fish, mullet and bream, were thrashing and kicking, then just going belly-up and dying. She did not go and look at the extent of the kill, and did not go back there to fish for a while either.

Mrs Webb has also witnessed a fish kill in the ten mile drain (Station Gully) around 1993. She said that the mouth had closed and the water was very green and smelly with scum all over the surface. Mullet, pilch, yellowtail, and bream were all dying. Mrs Webb and her sister Frances attempted to dig the bar by hand that day.

Both Mr and Mrs Webb feel that the only solution to the fish death problem is to remove the floodgates altogether and return the system to its estuarine condition. They said that waterbirds traditionally bred in great numbers around the estuary and would do so if the fringing vegetation returned. The floodgates form an impediment to the movement of the fish, which is not good. The water quality in the estuary is so bad that complete flushing and a return to tidal conditions would be best for the health of the estuary and its animals.

Mr and Mrs Webb both suggested that Peter and Mabel Bell are very knowledgeable on the ecology of the estuary. They lived for many years in the Wonnerup townisite, and Mr Bell worked as a caretaker for the ilmenite mine in the Deadwater. They also camped for some time at the old Ballarat Road bridge campsite.

13.3 Recollections of Mr Fred Oldfield

5b Talga Court
Busselton WA 6281

Interview: March 24th, 2000.

Mr Oldfield was born in England on the 12th of February 1918. He came to Busselton with his family in 1922. He lived for many years at Yalyallup, between Yoongarillup and Wonnerup and worked on nearly all of the farms surrounding the estuaries at different times over the years. For most of his life, Mr Oldfield worked as a professional fisherman, netting mullet, herring and tailor inshore from Quindalup to the Capel River mouth each day. He moored his net boat in Wonnerup Inlet from 1945 until 1995. Mr Oldfield assisted CSIRO fishery scientists with research in Geographe Bay on several occasions in the past, including a study on the spawning of herring in the 1950's.

During most of the years Mr Oldfield was a fisherman, the entire Vasse-Wonnerup Estuary and Wonnerup Inlet was closed to net fishing. He said that if you were caught fishing in any of those areas, your boat and all your gear was confiscated, so he never netted anywhere within the estuary or the Inlet waters. He often used to line fish in the Deadwater, and there were many King George whiting, sand whiting, skipjack trevally and bream in there. In the estuaries there were only mullet, bream and yelloweye, and they used to school in thousands up behind the old butter factory, which was a very popular recreational fishing spot.

Mr Oldfield believes there used to be many more fish in the estuary than now. He recalls that the mullet used to often school upstream of the Vasse floodgates in such large numbers that they could drop bricks from the floodgates to kill mullet for bait when they wanted to catch bream.

Mr Oldfield believed that both sea mullet and yelloweye mullet entered the Inlet to spawn. He often saw large schools of them waiting in the shallows outside of the Inlet mouth for the tide to rise and put enough water in the channel for them to enter the estuary, as the adult mullet don't like the shallow water. Mr Oldfield thought that sea mullet travelled into the estuary to spawn twice yearly, in December and February, whereas yelloweye came in to spawn around April. Mr Oldfield thought that adult mullet, those longer than about ten to twelve inches, would find the estuary too shallow and they would always try to leave the estuary to go to sea once they had spawned.

During winter, Mr Oldfield recalled that the sea mullet would migrate from the estuary up into the lower reaches of the rivers that entered the estuary when they began to flow. He thought that they travelled about five or six mile up the Sabina River, and recalled that there was a large, deep pool (9 or 10 foot deep) near the mouth of the Abba River on the old Layman's property that was 'chocka block' with mullet during the winter months. Mr Oldfield thought that there were few fish left in the main estuary bodies or the estuary channels during winter, and that they only entered the estuaries again as the river flows subsided in spring.

Mr Oldfield remembered that he frequently saw fish with their noses out of the water upstream of the Vasse Floodgates during summer when the weather was hot. It was always in the afternoons on hot days that he saw them like that, not in the mornings. Although Mr Oldfield never witnessed a fish death incident in the estuary, he knew that they always happened after a hot spell.

Mr Oldfield recalled that, during the 1950's and 1960's, to reduce the incidence of fish deaths, fisheries officers from Bunbury used to conduct fish releases over the summer period. Jim and Jack Goodlad (both deceased) were the officers who used to inspect the Vasse floodgates every second day when the weather was hot and fish deaths likely. If they felt it was necessary to release fish, they would wedge one the floodgates open a small amount on the rising tide to allow water to trickle in upstream. The oxygenated salt water would cause the mullet to school in large numbers upstream of the floodgates. When the tide had turned and was flowing out, one floodgate would be thrown open so that the fish could escape into the Inlet.

In the 1960's the ban on professional netting in the estuary was lifted and a few professionals would camp at the old Ballarat Road Bridge [at the Vasse floodgates] and net the mullet in the channel when they schooled in large numbers to remove them before they died.

Mr Oldfield recalled that, sometime during the 1950's, there was a mass death of mulies (*Sardinops neopilchardus*) on the west coast here. He said that all the mulies from Cape Naturaliste to Fremantle died but no one took any notice because no one fished for them in those days. Fishermen only commenced using mulies as bait during the 1970's.

13.4 Recollections of Mr Emanuel Soulos

48 Austral Parade
Bunbury WA 6230
Ph: 9721 2405

Interview: April 8th, 2000.

Mr Soulos was born in Bunbury in 1926, the son of a local net fisherman. He began fishing with his father almost as soon as he could walk and, although he attended primary school, he spent most of his time outside of school (including late nights) fishing. When he was a young boy, he used to camp with his father on the banks of the Vasse Estuary. They would set their nets throughout the estuary, but they often fished right up near the old butter factory, and even up behind the Council Chambers in the Vasse River. Mr Soulos has fished for almost all his life in the Leschenault Inlet, the Vasse-Wonnerup Estuaries and nearshore Geographe Bay. He gave fishing away to work on a dredge for 18 months once, but soon returned to fishing as he missed the lifestyle so much. Mr Soulos still regularly nets both the Vasse and Wonnerup estuaries (upstream of the floodgates), although he never fished in either the Deadwater or Wonnerup Inlet as they were always closed to professional fishermen.

Over the years, Mr Soulos has caught mostly mullet (sea mullet), yellow-eye mullet, and black bream in the Vasse Estuary, with small numbers of yellow-fin whiting, juvenile mulloway, salmon trout (juvenile Australian salmon), and blue-manna crabs. Mr Soulos recalls that, as a young boy, he and his father used to catch lots of King George whiting in the Vasse Estuary up near the old butter factory, but he hasn't caught any in the estuary for many years now. In Wonnerup Estuary, Mr Soulos mostly catches mullet (sea mullet), with small numbers of yellow-eye mullet and a few black bream. Mr Soulos believes that black bream are far more numerous in the Vasse Estuary than in Wonnerup Estuary, although Wonnerup Inlet and the Deadwater are far more important for bream than either estuary. The numbers of straggler, or opportunistic fish (fish other than mullet, yellow-eye mullet and bream), that use the estuaries are higher in the Vasse, which has always had a greater variety of fish. Mr Soulos has also noticed that the Vasse Estuary contains large numbers of small shrimp [probably palaemonid shrimp].

Mr Soulos regularly fishes in the estuaries, usually twice a week, for at least nine months of the year. In 1999, he fished for almost the full twelve months, although he rarely fishes during the height of summer, when the days are hot and the water quality gets very bad, as the fish are of poor quality and fetch a very low price. He will only bother to net the estuary in hot weather when the mullet are very easy to catch, when they are stressed and they school in great numbers just upstream of the floodgates.

In winter, Mr Soulos fishes in both of the main estuary bodies, although he concentrates his effort on the Vasse. In the past, he used to fish much further upstream in the Vasse Estuary than he does now, setting nets right up behind the old butter factory. These days he tends to only fish as far up the estuary body as the first fence lines. In summer, when the main estuary bodies get too hot and the fish move into the channels, Mr Soulos begins fishing the estuary channels. In the Vasse Estuary, he fishes from the floodgates up to the big houses just past Ballarat Road. In Wonnerup Estuary, he sets his nets anywhere from the floodgates to as far upstream as he can go (about 500 m), but there are fences that prevent him from going further.

At the start of the season, after the first winter floods, Mr Soulos fishes with large mesh net, of 3" to 3 ½" mesh (stretched) to catch the largest mullet first. As the season goes on, he moves down to 2 ½" mesh, which is the smallest mesh size he is allowed to use. In the wide part of the estuary, he usually sets two or three nets with each net set from the surface of the water to the bottom (the nets are 3 or 4 foot deep), for a length of 250 metres. He soaks the nets (which are tended at all times in the water) for variable amounts of time, and he pulls the nets when he thinks he has enough fish. These days, he usually sets his nets in the afternoons.

Mr Soulos takes his biggest catches during winter, when the river flows are greatest. His biggest catch in one day in the Vasse was 80 boxes (average weight of 23 kg), which equates to a catch of 1840 kg of mullet. His best season was a year of big floods. Mr Soulos estimates that he would sometimes (not always) take between 10 and 20 boxes of mullet each fishing trip (25 on a good night), which equates to between 230 and 460 kg a night. On average, Mr Soulos has caught a total of about 15 tonnes a season, from both estuaries combined (based on 9 months fishing). Mr Soulos commented that the Vasse Estuary is extremely productive, and always continues to produce more and more fish. Mr Soulos knows 4 other professional fishermen who also regularly net the system through the winter, so the total mullet catch in both estuaries may be around 15 to 20 tonnes each year.

Mr Soulos estimates that sea mullet comprise about 90% of his total catch in the estuaries, with yellow-eye mullet making up another 8%. He catches very few black bream (2% or less) because he doesn't target them, as black bream require different nets and different ways of fishing. Mr Soulos believes that black bream are a fish sought after by recreational fishermen, so he prefers to leave them for the amateurs, so as not to create any animosity between the professional and recreational fishermen. Stragglers such as yellowfin whiting are also uncommon in the catch because of the types of net and mesh size used.

The mullet that Mr Soulos catches is marketed both locally (Bunbury) and in Perth. During winter, prices are best and some of the fish are sold for human consumption. About 50% of the catch is sold as angling bait. When the quality of the fish is low, it is sold for crayfish bait. The markets for mullet are fairly variable, and Mr Soulos explained how sometimes he could sell much more than he could catch, and sometimes, there is no room for more fish at all. Last year, he couldn't sell all the mullet he caught, and now this year, they want mullet and don't want herring, just when herring are really plentiful off the coast.

Mr Soulos believes that the first freshwater runoff into the estuaries each year causes large numbers of mullet (both sea mullet and yelloweye) to migrate upstream into the estuaries from the sea. As soon as there is some freshwater coming in from the rivers, they begin to move upstream. During the winter flows, Mr Soulos gets his biggest catches, and they are always 'clean' fish. Mr Soulos explained that it is easy to tell the difference between mullet that have been in the estuary for a while (their body is slimy and they are full of mud), and those which have just come in from the sea ('clean' fish which have little food and no mud in them). Mr Soulos has observed that he catches 'clean' fish at all times of the year in the estuary (including summer). Mr Soulos believes that both sea mullet and yelloweye regularly recruit to both estuaries from Geographe Bay, particularly from late January to April, when there is a northward run of both species along this coast.

Mr Soulos thought that the mullet moved out of the main estuary bodies and into the estuary channels during summer, when the shallows of the main estuary bodies became too hot. Mr Soulos said that even large mullet will swim in very shallow water so, it is not the decreasing depth of water in the main estuary that drives them into the channels. Mr Soulos believes that the mullet do not tolerate the warm water well.

Mr Soulos thought that the incoming tide caused mullet to school in great numbers upstream of the floodgates. When the tide is high in Wonnerup Inlet, and the water level rises above that in the estuary, seawater leaks into the estuary through the floodgates. It is the leakage of seawater that makes the mullet school there, as they are seeking the cooler and cleaner oceanic water.

Mr Soulos recalled that he had never caught any sea mullet with spawn or roe in them in either estuary. Even in Geographe Bay, he very rarely caught them with any roe. Mr Soulos commented that mullet roe is worth more than the mullet, if you can get it. Mr Soulos thought that sea mullet migrated northward along this coast to spawn further north, maybe around Shark Bay. Mr Soulos often caught yellow-eye with spawn in them, and he thought that they may spawn in either the estuary or along this coast for most of the year.

Over the years, Mr Soulos has seen at least a dozen fish kills in the estuary. He said that they always happened in summer, from January onwards, on hot days when the water had been green. He thought that the water usually got too hot for them, that it's the heat that kills them. Mr Soulos recalled that, many years ago, the mouth of Wonnerup Inlet blocked and many fish died. He said that, years ago when estuary mouths blocked over the summer, it was a common thing for the water to heat up and all the fish to die.

About two or three years ago, Mr Soulos saw many fish, including whiting, cobbler, bream, kingfish (mulloway), and yellow-eye mullet, dying at the far northern end of the Deadwater. Mr Soulos recalled that the water was crystal clear, and that it had rained very heavily the night before.

Mr Soulos recalled that the tubeworms now common in both estuaries, but more numerous in the Vasse, were not there 20 years ago. Mr Soulos has also observed that the numbers of waterbirds on the estuaries has noticeably increased over the last ten years. He has noted that the Wonnerup Estuary is used by more birds than the Vasse Estuary, although musk duck are more numerous in the Vasse Estuary.

Mr Soulos, reflecting on a lifetime of fishing in the estuary, commented that the Vasse-Wonnerup Estuary was a beautiful expanse of water that had given him much of his income over the years, and allowed him and his family to survive. It is a big part of his life.

13.5 Summary

All of those interviewed suggested that both Wonnerup Inlet and the Deadwater were far more important to recreational fishermen than either of the main estuary lagoons, although the lower Vasse Estuary channel (particularly from the floodgates to around Ballarat Road) is regularly used by recreational fishermen to target black bream. The floodgates are also considered important to recreational fishers, who regularly fish on both sides of them. Other areas of the estuary are probably not popular because of their lack of access, and also because they are dry for much of the year. In the past, the lower Vasse Estuary and river behind the old butter factory was a very popular fishing spot for both commercial and recreational fishermen, and regularly produced large black bream, mullet, pilch (yellow-eye mullet), and even King George whiting on occasion. These days, severe algal blooms and occasional mass fish deaths discourage people from fishing there.

In light of this, most of the knowledge about fish within the estuary system held by recreational fishermen concerns Wonnerup Inlet, the Deadwater, the lower Vasse Estuary exit channel and the floodgate structures. The lowest reaches of the Vasse River and its confluence with the main estuary body were also important recreational areas in the past, however they have seen little use for more than a decade. There is little known about the wide expanse of the estuary lagoons, and also the eastern shores where the Ludlow, Abba and Sabina Rivers discharge into the estuary, which have always been relatively inaccessible to recreational fishermen.

For many years, all the areas of the estuary and inlet were closed to the commercial fishermen who used net and line in Geographe Bay. According to Mr Oldfield, a former net fisherman who moored his boat in Wonnerup Inlet, the commercial fishermen never fished anywhere in the estuary or inlet or they risked losing their boat and all their gear. At times over the years (during the 1920s and 1930s, and after 1960), the main estuary bodies were opened to commercial net fishermen. Only a few fishermen have ever commercially fished the estuary waters, and these include Mr Emanuel Soulos, whose father also fished in the estuary, and several generations of the Smith family (Mike Smith is the current operator). These fishermen represent only a handful of people who have had substantial contact with fish in the waters of the Vasse and Wonnerup main estuary bodies. Mr Soulos was the only commercial fisherman with extensive experience and knowledge of fish in most of the areas of the wetland system (upstream of the floodgates) who was interviewed. As such, information on the seasonal use of the estuary by fish was limited.

It appears that both yellow-eye mullet (*Aldrichetta forsteri*) and sea mullet (*Mugil cephalus*) attempt to move upstream through the floodgates in large numbers during the winter months, when the freshwater flow from the rivers begins. In South Africa, sea mullet (*Mugil cephalus*) have been recorded up to 120km up rivers (Whitfield 1996). Indeed, sea mullet are tolerant of and found in any salinity water, from 0-90ppt salinity (Whitfield 1996). It is not clear why the mullet move so far upstream, but it is likely that they are feeding.

Mullet are able to enter the estuaries from the Inlet at times during the year (see Section 1.1). Mr Soulos, a professional fisherman who has netted the estuary for over 50 years, has noticed that he catches 'clean' fish, those which have just entered the estuary from the sea, at all times of year in both estuaries. He can distinguish the fish which have been in the estuary for some time by the "slime" on their skin and within their viscera. Because Mr Soulos regularly catches 'clean' fish upstream of the floodgates (including during February 2000), he believes that mullet continue to move into the estuaries from Geographe Bay at most times of the year.

Although several of the fishermen believed that some of the sea mullet may spawn in the estuary, the fact that Mr Soulos never catches them with roe in them is an indication that they do not spawn in the estuary, but rather recruit as young-of-the-year (pinheads), which were observed in large schools in Wonnerup Inlet on many occasions during the monitoring period.

Both the movement of the tide, and seawater leakage in through the floodgates (which is closely related to the tide) were postulated to effect the daily movement of fish. Seawater leaking in to the estuary was known to cause mullet to school in large numbers on the upstream side of the floodgates.

Variance in water temperature was also suggested to determine the distribution of the fish within the estuary at times. As the water warms, the amount of DO is reduced, whilst the respiratory needs of fish increase (see section 1.2), so it is possible that fish may attempt to avoid areas of warm water, or seek refuge in cooler areas. Changes in water temperature at both sides of the floodgates and along the length of the exit channel, and its effect on fish behaviour, may be worth investigating.

Apparently, very small volumes of seawater have been allowed back into the Vasse Estuary periodically during the summer months for possibly many years during the late 1950's (and also possibly during the mid 1930's – based on a conversation between Mr Jim Lane and Mr Oldfield in 1998 – J. Lane, CALM, pers. comm.). Mr Oldfield said that Jim and Jack Goodlad were the Fisheries Department officers who periodically opened the floodgates. Presumably they must have kept some records of their operations. These may still be held by the Fisheries Department and would be worth investigating.

14 CONCLUSION AND RECOMMENDATIONS

Due to the extremely eutrophied nature of the Vasse-Wonnerup wetland system, the effects of the current "streamlining" (river bank revegetating), rehabilitation and nutrient reduction projects within the estuaries' catchment may take several years to be felt. As a result, conditions conducive to the sudden, mass deaths of fish may continue for some time. The floodgates perform several vital functions, including saving the Town of Busselton from flooding, which require careful management of water levels and quality. The current floodgate structures also restrict the free movement of fish into and out of the estuaries for much of the year, so it is inevitable that the fish population will be affected. To continue to reduce the incidence of sudden, mass fish deaths by strategic fish releases, the VETWG will need to continue with some form of monitoring at each set of floodgates over the summer period to determine the most appropriate timing for the release of fish.

Although this monitoring program did not prevent the fish kill of February 15th, 2000, from occurring, it did prevent the deaths of thousands more fish by allowing the release of the survivors. Whilst in excess of 1500 fish died, it was estimated that more than 35,000 mullet were released during the 8 hours that the floodgate was opened that day. The fish kill incident was well documented, and this will allow the VETWG to better understand and recognise the conditions that mean a fish kill is imminent in future. Additionally, the monitoring program allowed the successful release of another 1900 mullet from the Vasse Estuary on February 3rd, 2000, and more than 9400 mullet from Wonnerup Estuary over two releases (February 21st and 25th, 2000), which is the highest number of fish released from Wonnerup Estuary to date.

Continued daily monitoring of the floodgates will require ongoing funding. To reduce the costs of monitoring, several remote applications may have potential. Remote video monitoring of fish behaviour has been suggested as an alternative to a physical inspection each day. Given the poor water quality in the estuaries, video monitoring of fish behaviour upstream of the floodgates for most of the period critical to fish survival is likely to be difficult. Very low water clarity means that often, only surface activity can be seen. Whilst fish may possibly be seen when gasping at the surface, it is also possible that this behaviour only occurs a matter of minutes before death.

Additionally, at times, extensive surface scums may make it difficult for fish to be seen by video at all. Despite this, a remotely operated video directed at the water immediately upstream of the floodgates structure (covering the area from the floodgate boards to around 1-2m upstream) may be useful. On several occasions during the monitoring program, large numbers of very large mullet were seen swimming in seething masses immediately upstream of the floodgate boards, swimming slowly in the seawater leakage from downstream and nosing hard up against the floodgate structure as if they wanted to swim downstream. This appeared to occur when the fish were stressed and may be a useful indicator that can be monitored by video when the water in the estuary clears, as happens following an algal bloom crash (which can cause potentially lethal deoxygenation).

To be aware of impending critical low oxygen conditions likely to cause fish deaths, some indication of the daily fluctuation in dissolved oxygen concentrations is required. In recognition of this, an *in situ* dissolved oxygen probe was installed in the Vasse Estuary exit channel (immediately upstream of the floodgates) in 1997, however there have been considerable problems with encrusting organisms fouling the probe, and since its installation, few accurate data have been generated. Monitoring of pH several times per day, rather than dissolved oxygen, may possibly be a cheaper and more reliable indicator of impending critical low DO conditions when they are caused by algal bloom respiration. pH metres are considerably cheaper, more robust and reliable than DO metres, so the viability of *in situ* pH monitoring as indicator of daily fluctuations in dissolved oxygen may be worth investigating.

During the course of this monitoring program, precautionary fish releases were conducted in response to the presence of large numbers of fish schooling at the floodgates. The author inspected the floodgates on a total of 90 occasions, yet fish were released on only five occasions after it was observed that fish were present and a release able to be conducted. It appears that Bunbury Fisheries Department officers may have conducted similar releases to reduce the incidence of mass fish deaths over 40 years ago (see section 13.3). In contrast to today's releases where we wait for fish to school in numbers at the floodgates, the fisheries officers of the 1950's and 60's used the incoming tide to cause the mullet to school at the floodgates by wedging a gate open to allow the seawater to leak in. When sufficient numbers of fish had gathered at the floodgates, the floodgates were apparently opened to release the fish.

It may be possible to reduce the number of inspection days required to sufficiently reduce mass fish deaths by commencing a series of regular precautionary fish releases using the method described above, which may also allow for flushing of the lower estuary channel when conditions deteriorate. Jim and Jack Goodlad were the Fisheries and Wildlife officers who conducted the releases, presumably the Fisheries Department must contain some records pertaining to the Vasse Estuary which may be worth investigating.

As the leakage of seawater through the floodgates appears, at times, to attract large numbers of fish to school above the floodgates, knowledge of the rate of leakage and how it affects fish behaviour may assist the VETWG to determine the appropriate timing for successful releases on a remote basis. As the head of water and resulting relative rates of leakage can be determined by remote monitoring of water levels (on both sides of the floodgates), further research to clearly determine the effect of leakage may be justified, given the potential for ongoing remote monitoring. Knowledge of the effects of leakage flow on schooling behaviour may also assist the VETWG in the design of a 'fishway' mechanism that allows the passage of fish through floodgates whilst still maintaining the structure's flood mitigation functions.

The current floodgate structures are due for replacement over the next few years. To improve on the current design, some sort of fish release mechanism or 'fishway' that enables the free passage of fish through the floodgate structure should be incorporated. Until the free passage of fish through the floodgate can be ensured, or until conditions within the wetland system improve, sudden-mass fish deaths are likely to be an infrequent, but recurring event. Continued efforts by the VETWG may help to reduce their incidence.

15 ACKNOWLEDGEMENTS

The author would like to thank Mr and Mrs Alf Reynolds, Dunsborough, Mr and Mrs Fred Oldfield, Mr George Webb and Mrs Vilma Webb, Busselton, and Mr and Mrs Emanuel Soulos, Bunbury, for telling me their wonderful stories about fish in the Vasse-Wonnerup wetland system. The author would also like to thank Mr Jim Lane (CALM) for management of the fish monitoring program, preparation of the water level graph contained within the report, useful editorial advice, and for invaluable guidance and assistance during the project. Many thanks are also due to several people who provided kind assistance: Robyn Paice (WRC) for help when the fish kill occurred on 15/2/00, and for providing plates 3 & 6; to Anthony Sutton, Claire Thorstensen and Shelley Voight (GeoCatch Network Centre) for their thoughtfulness and assistance during several long days in the field; to the Water and Rivers Commission for the kind provision of phytoplankton and water quality data to assist interpretation of the monitoring program observations; to the ever helpful librarians Lisa Wright (CALM) and Vicki Gouteff (Fisheries WA) for assistance to find and obtain relevant literature; to Charlie Broadbent (CALM) for a period of project management in Jim Lane's absence; and lastly to Graham Holtfreiter, John Moon and Clive Piggott (Water Corporation) for their prompt action when floodgate openings were required.

16 REFERENCES

ANCA (1996). *A Directory of Important Wetlands in Australia (2nd Edition).* Australian Nature Conservation Agency, Canberra.

Chadwick, B. (2000). *Final Report on fish pathology from the Vasse Estuary Fish Kill – February 15, 2000.* Unpublished laboratory report from the Agriculture Western Australia Animal Health Laboratories, South Perth. Report dated 23/02/00, Case number P-00-581, Submission number 39119.

Crawshaw, L.I. (1977). Physiological and behavioural reactions of fishes to temperature change. *Journal of the Fisheries Research Board of Canada* 34: 730-734.

Hosja, W. and Deeley, D. (1994). *Harmful Phytoplankton Surveillance in Western Australia.* Waterways Commision, Perth. Report No. 43.

Hutchins, B. and Swainston, R. (1986). *Sea Fishes of Southern Australia.* Swainston Publishing, Perth.

Lane, J.A.K., Hardcastle, K.A., Tregonning, R.J. and Holtfreter, G.J. (1997). *Management of the Vasse-Wonnerup Wetland System in Relation to Sudden, Mass Fish Deaths.* Unpublished technical report prepared for the Vasse Estuary Technical Working Group, Busselton.

Meyer, F.P. and Barclay, L.A. (1990). *Field Manual for the Investigation of Fish Kills.* United States Department of the Interior, Fish and Wildlife Service, Washington. Resource Publication 177.

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

Simpson, K. and Day, N. (1996). *Field Guide to the Birds of Australia (5th Edition).* Viking, Melbourne.

White, K.S. (1999). *Monitoring of Fish Behaviour in the Lower Vasse – Wonnerup Wetlands During the Summer of 1998/1999.* Unpublished report prepared for the Vasse Estuary Technical Working Group, Busselton.

Whitfield, A. (1996). A review of factors influencing fish utilisation of South African estuaries. *Transactions of the Royal Society of South Africa* 51:115-137.

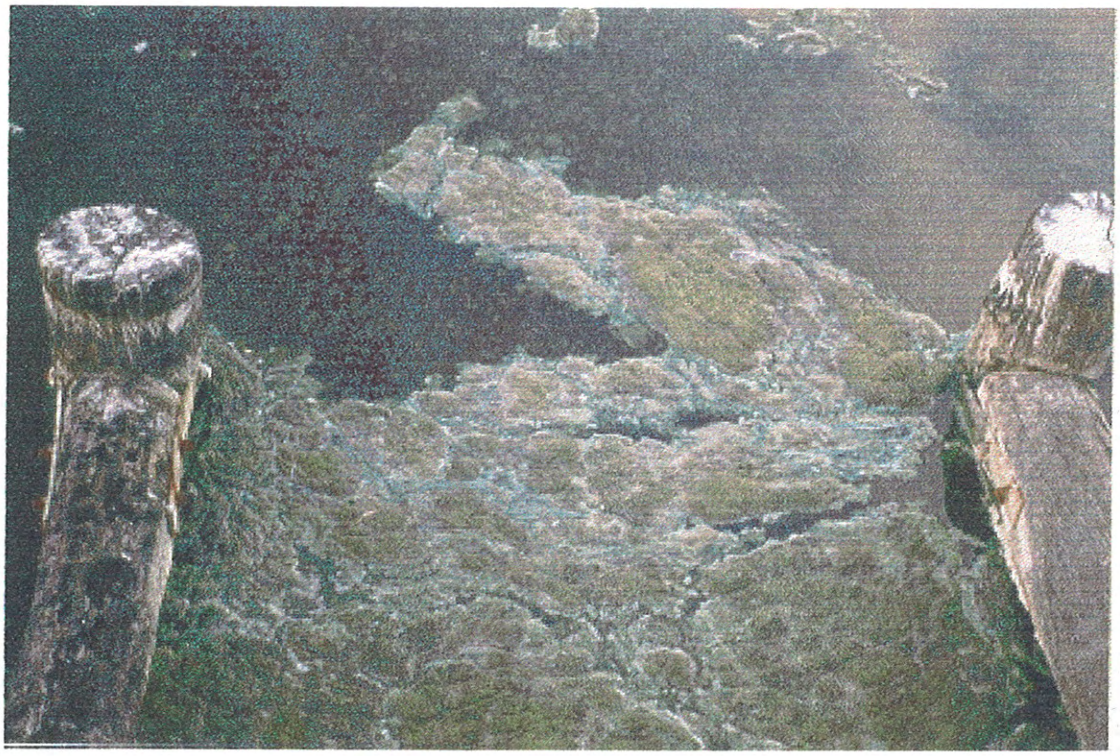


Plate 1. Algal scum upstream of the Vasse floodgates – February 2nd, 2000.

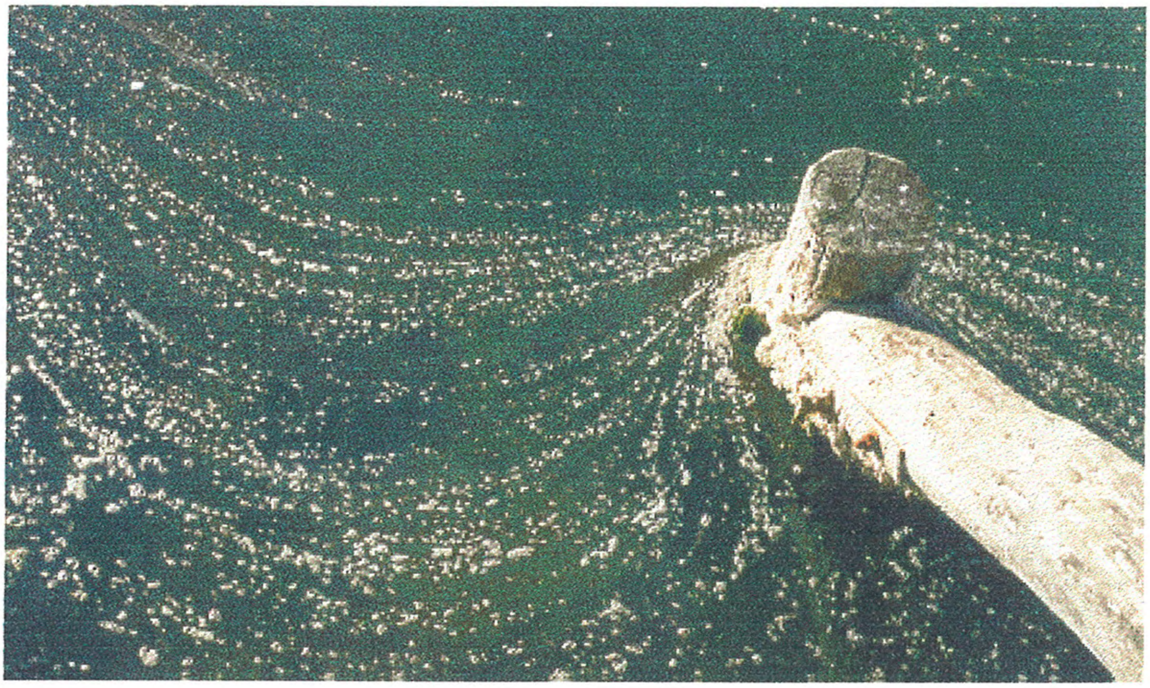


Plate 2. Bubbles and frothy scum upstream of the Wonnerup floodgates – February 29th, 2000.

Plate 3. Mullet schooling actively in tight circles on the downstream side (Wonnerup Inlet) of the Vasse floodgates.

Plate 4. Mullet surfacing actively on the downstream side (Wonnerup Inlet) of the Vasse floodgates.

Plate 5. Mullet activity on the edge of dense algal scum upstream of the Vasse floodgates – February 3rd, 2000.

Plate 6. Representative sample of size and species killed in the Vasse Estuary fish kill – February 15th, 2000.

S

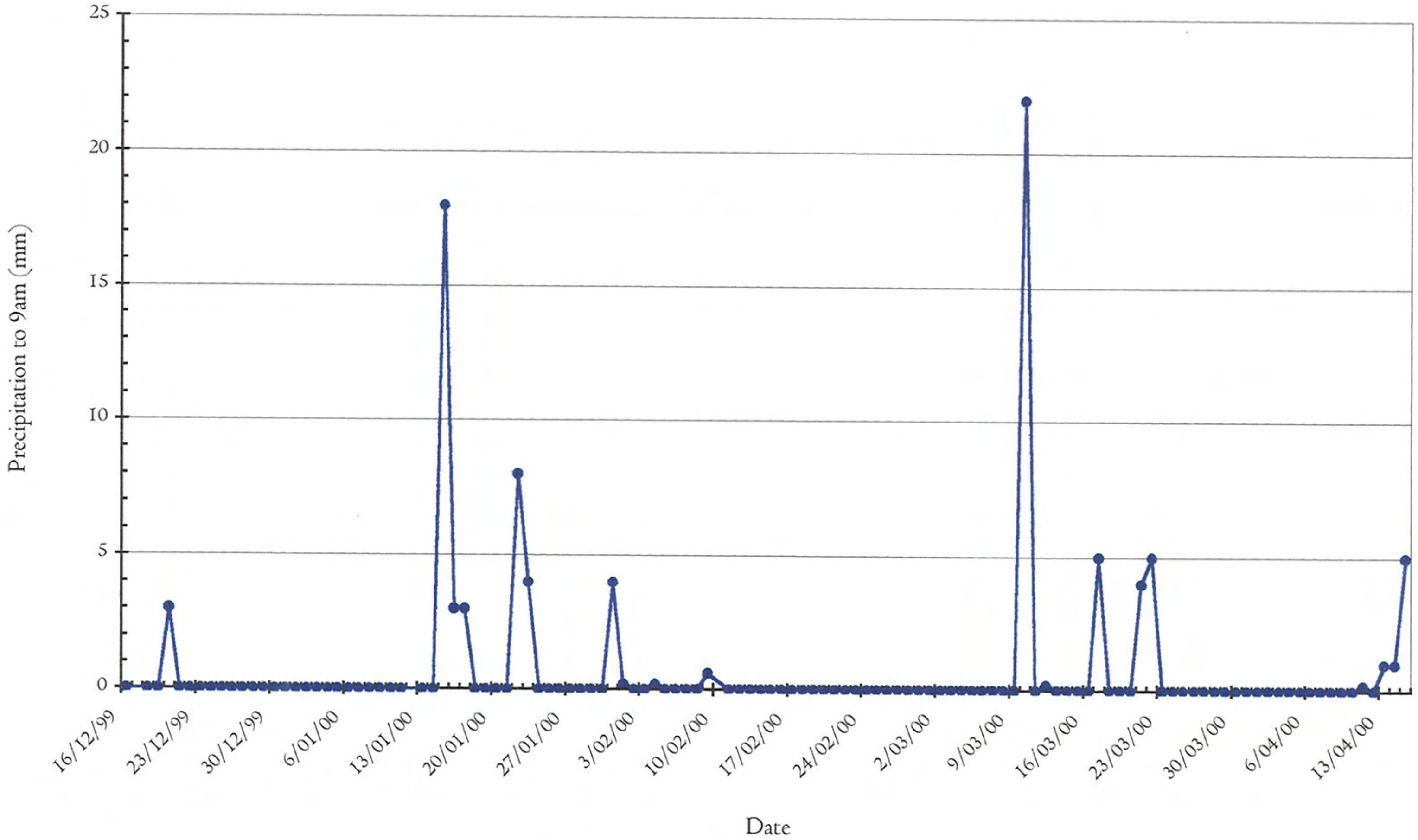


Figure 2. Daily precipitation for the Busselton Shire

(Data provided by the Bureau of Meteorology)

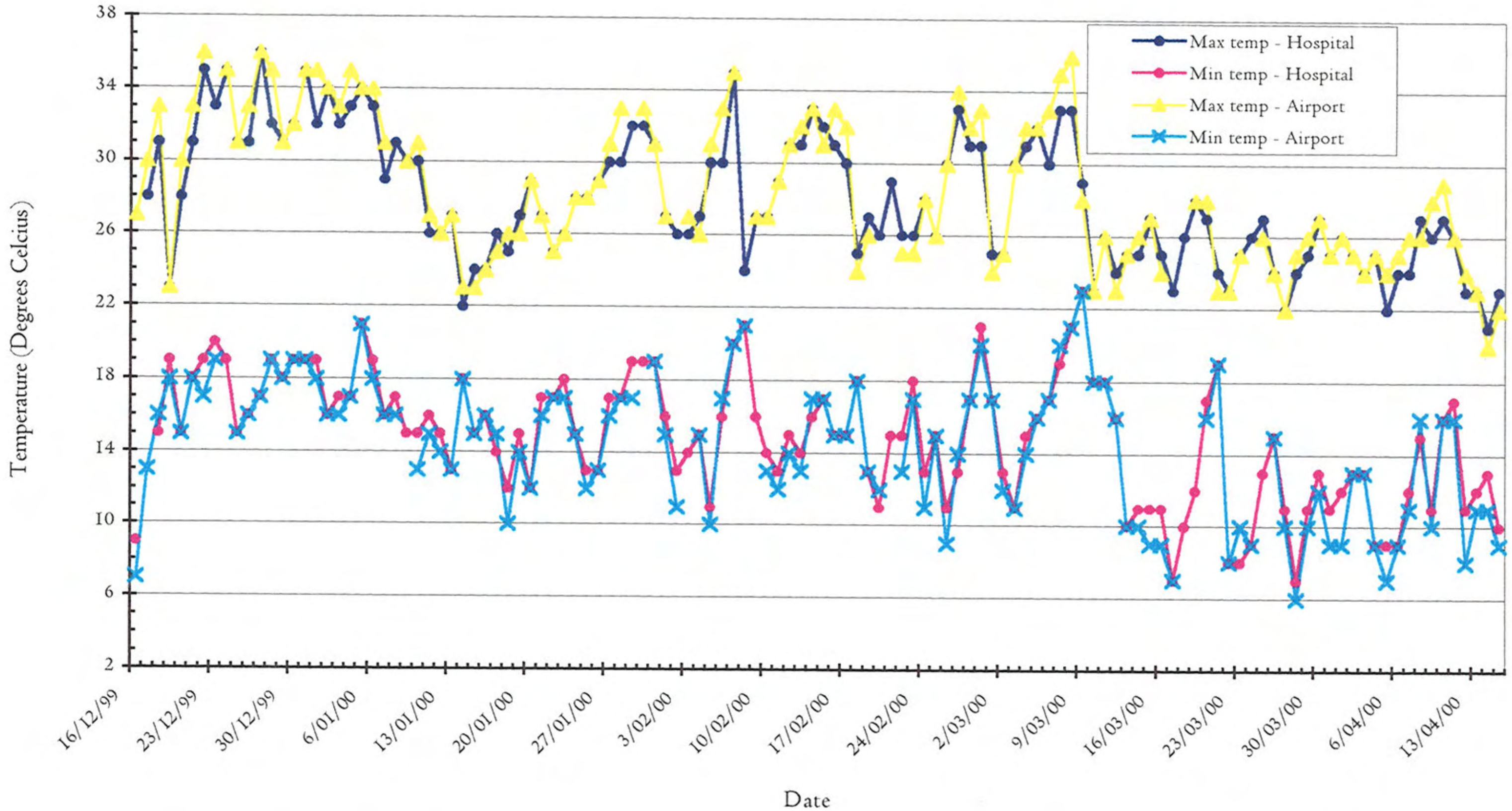


Figure 3. Maximum and minimum temperatures at the Busselton Airport and Busselton Hospital weather stations

(Data provided by the Bureau of Meteorology)

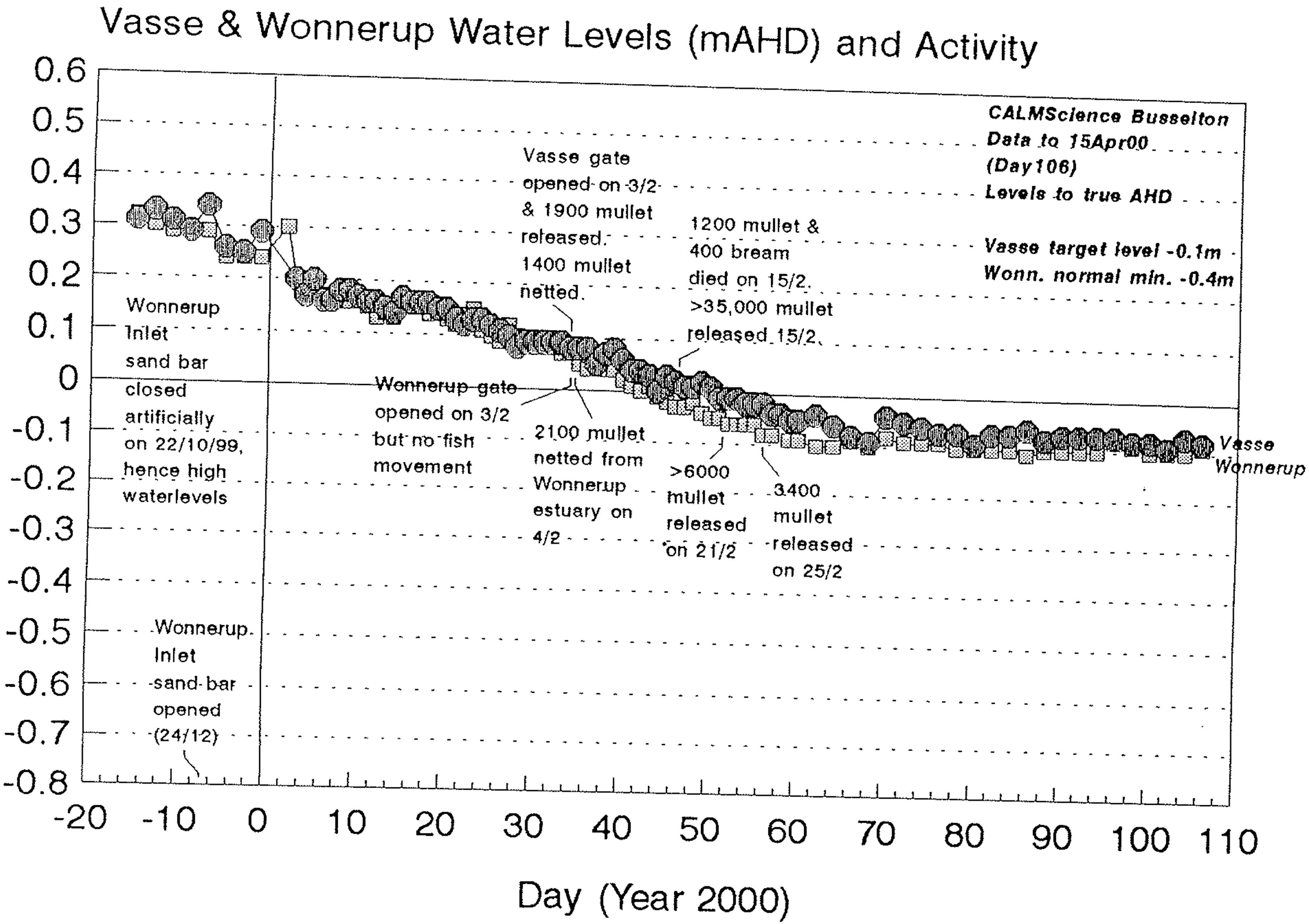


Figure 4. Water levels (in AHD) in the Vasse and Wonnerup Estuaries over the summer of 1999/2000.

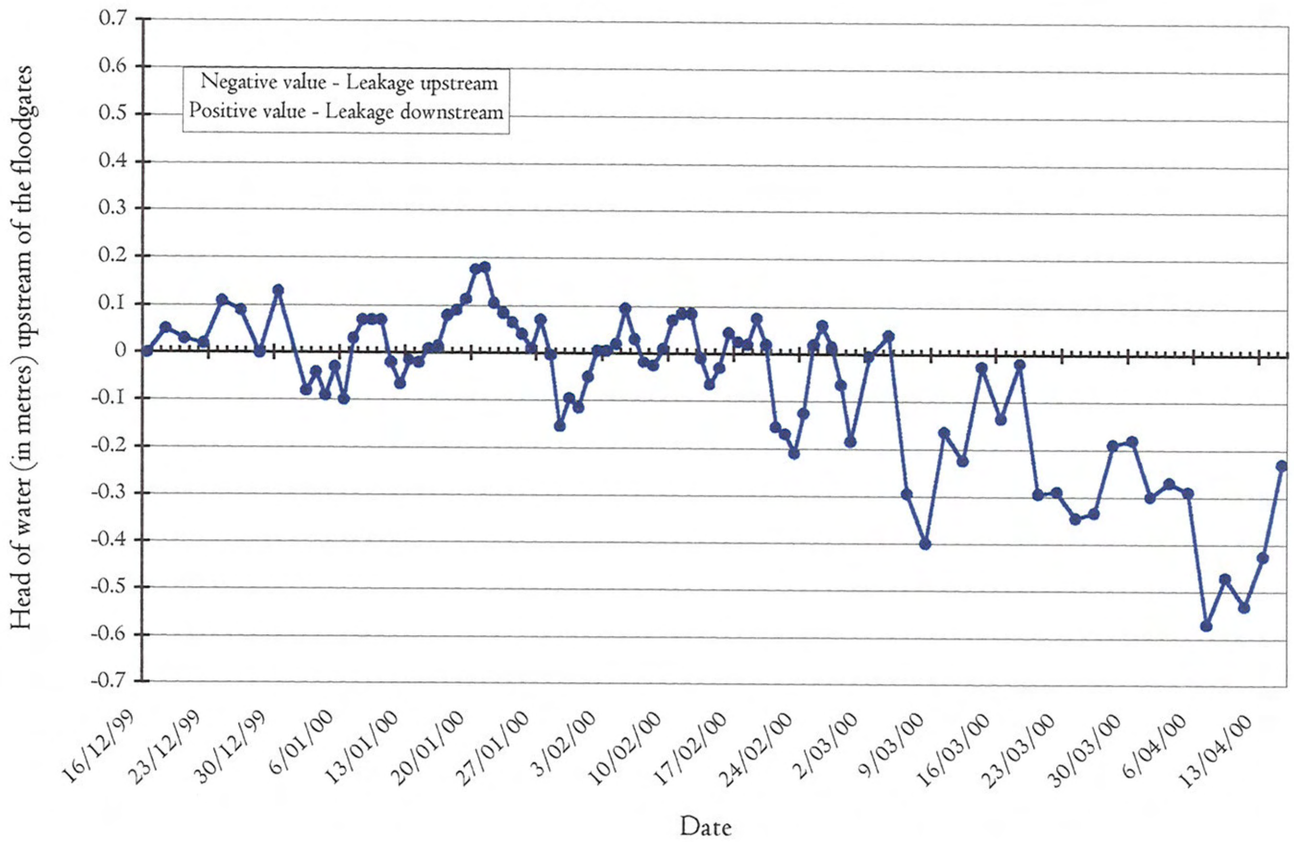


Figure 5. Head of water at the Vasse floodgates.

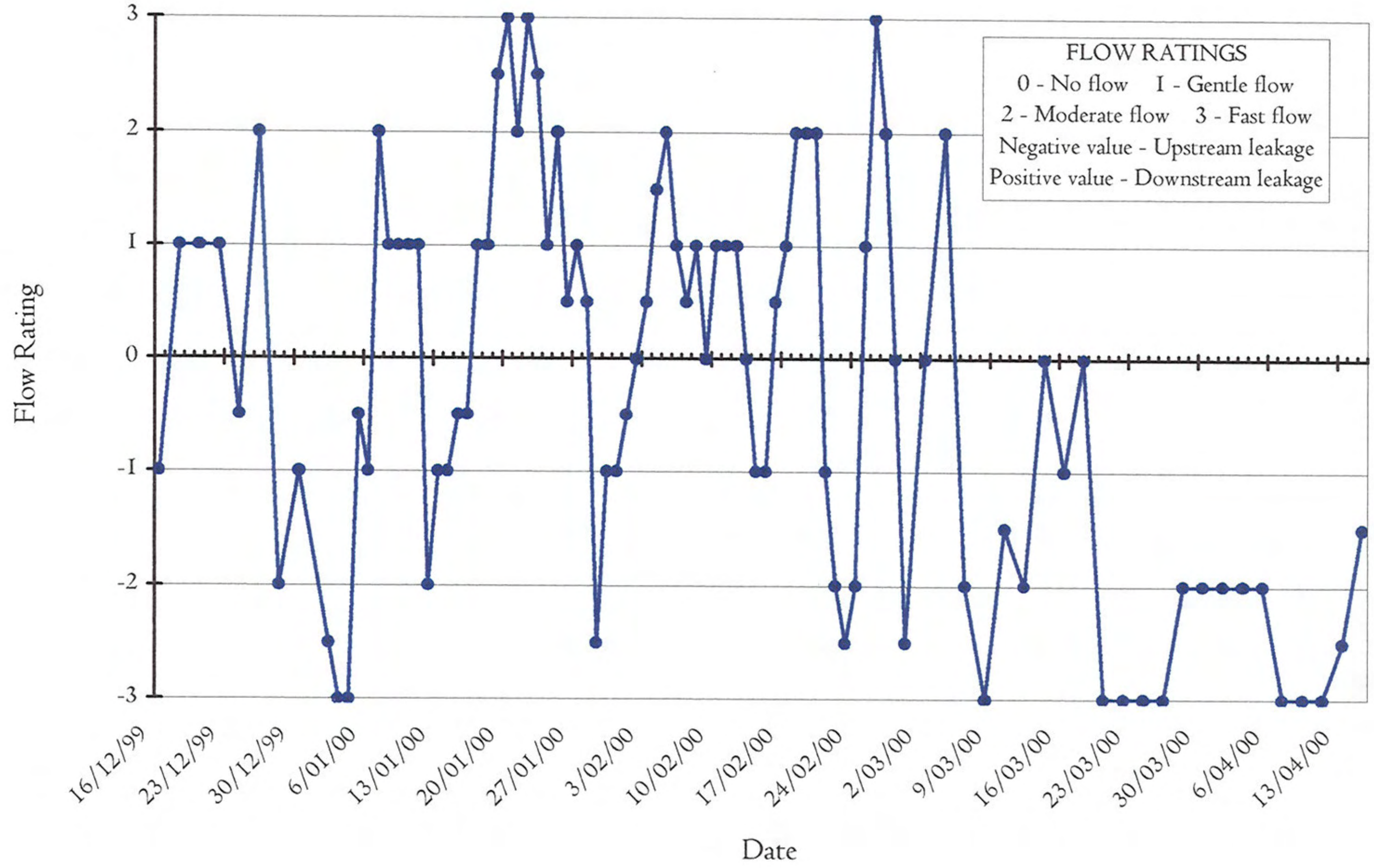


Figure 6. Subjective rating of water leakage at the Vasse floodgates.

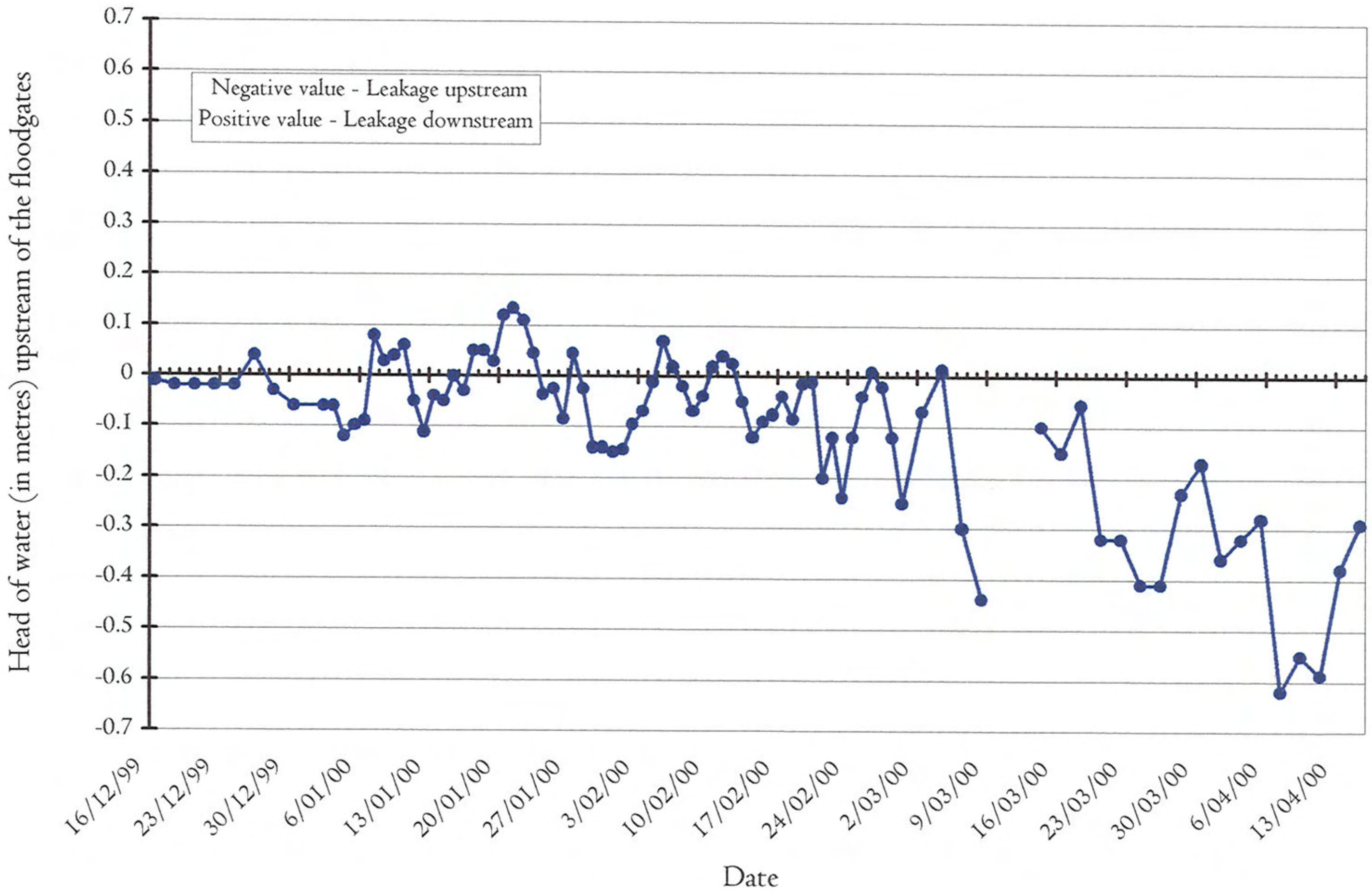


Figure 7. Head of water at the Wonnerup floodgates.

(Data provided by CALM)

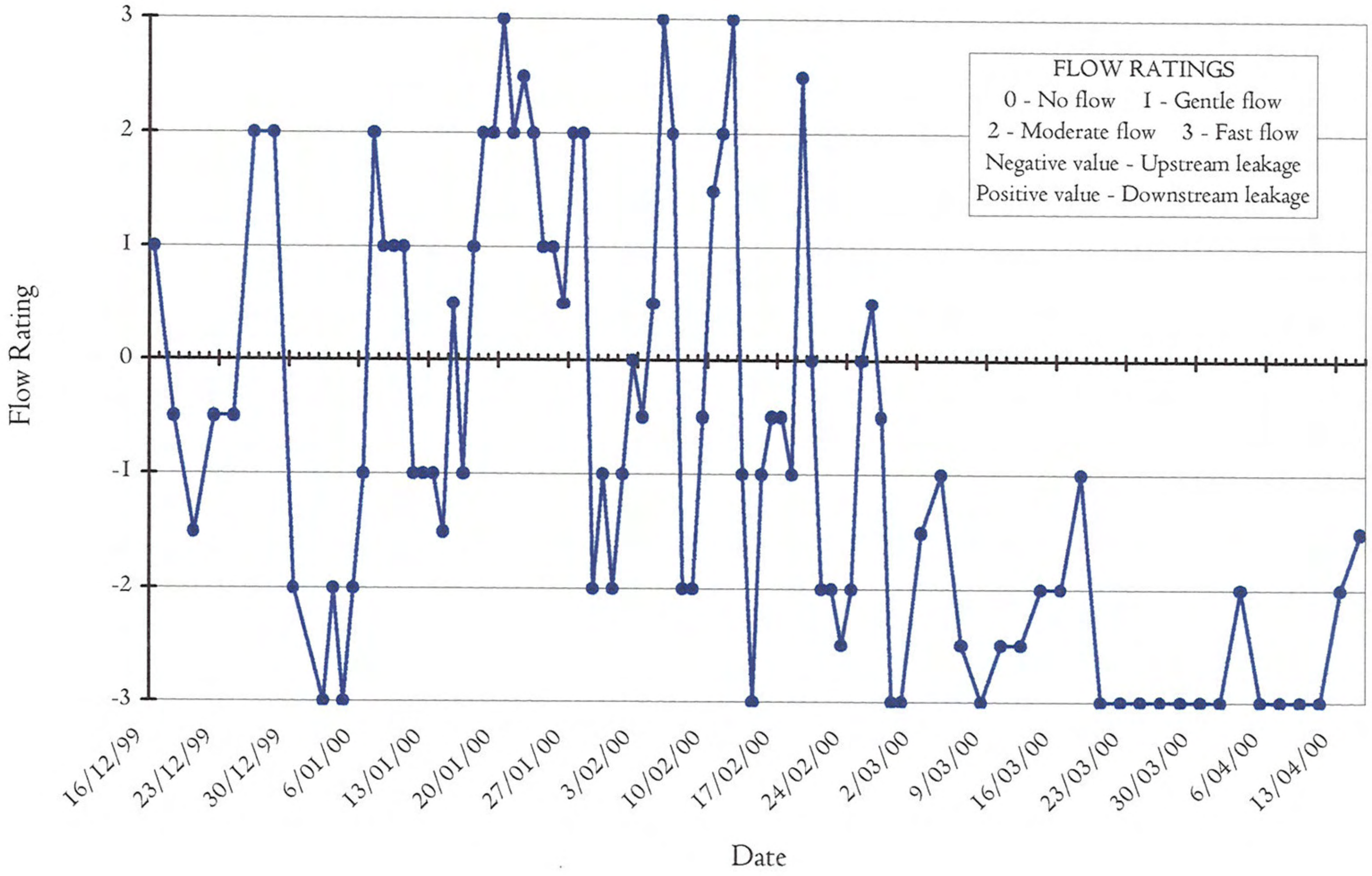


Figure 8. Subjective rating of water leakage at the Wonnerup floodgates.

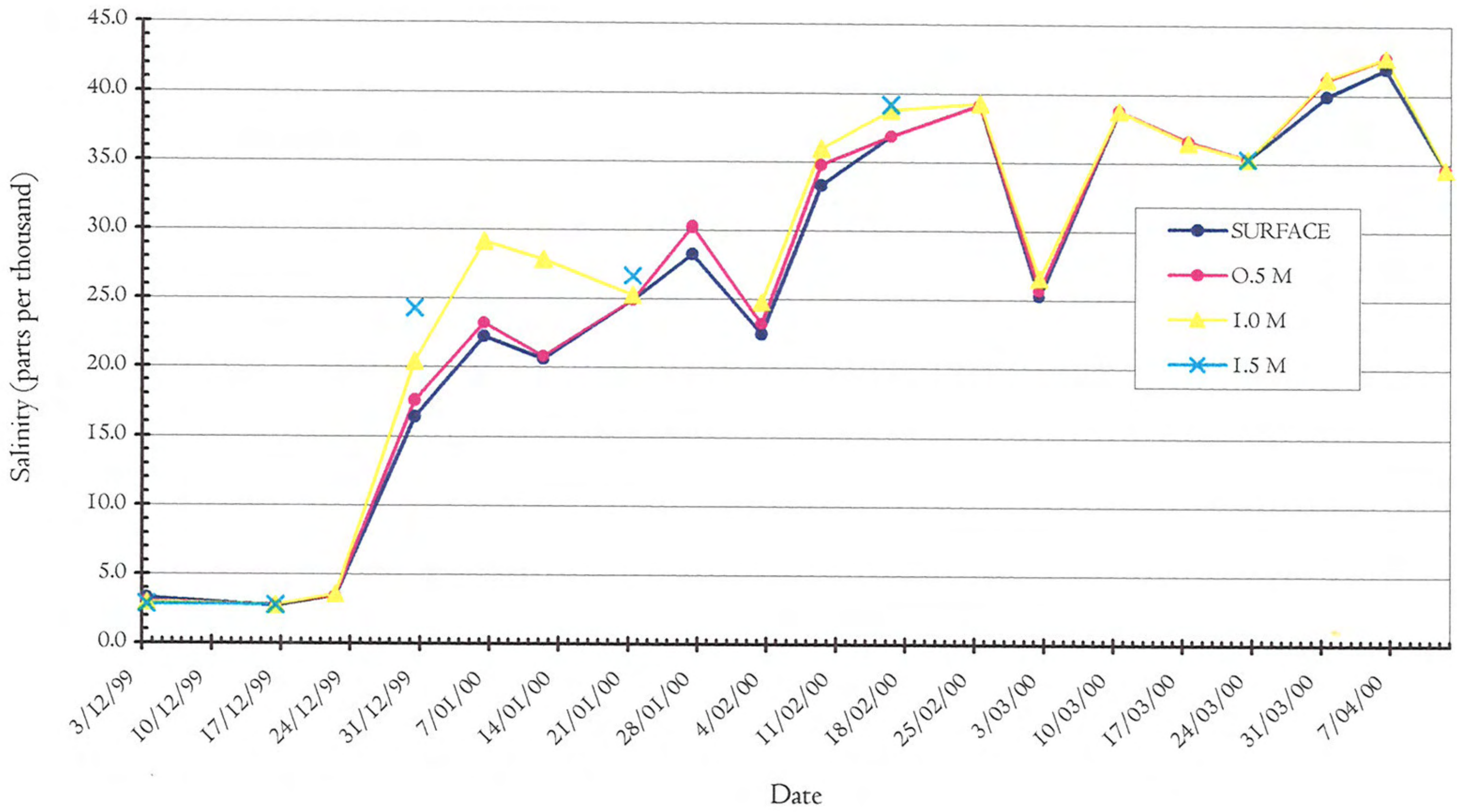


Figure 9. Salinity upstream of the Vasse floodgates

(Data provided by the Water and Rivers Commission Southwest)

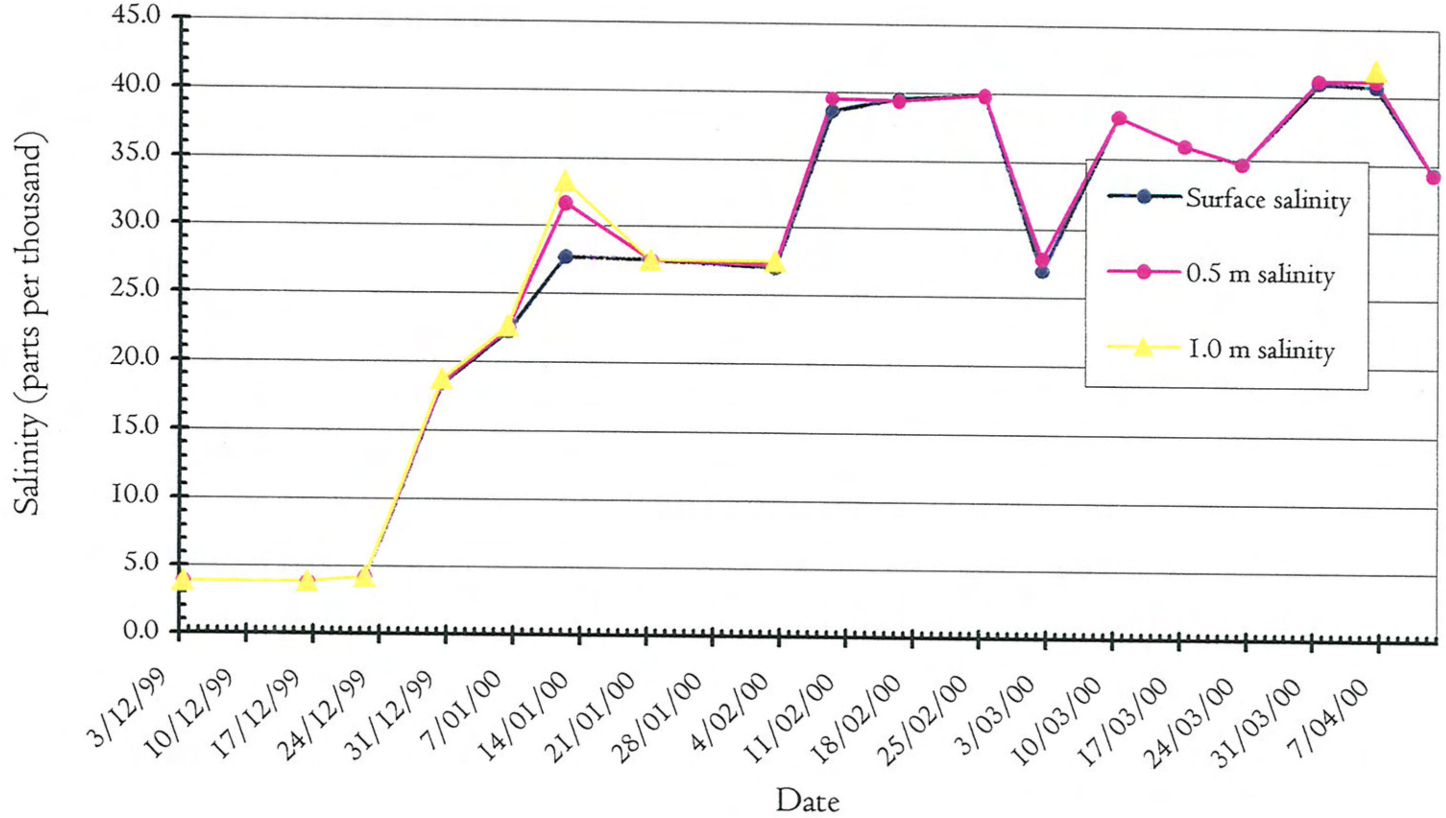


Figure 10. Salinity upstream of the Wonnerup floodgates.

(Data provided by the Water and Rivers Commission Southwest)

Figure 11. Water temperature upstream of the Vasse floodgates.

(Data provided by the Water and Rivers Commission Southwest)

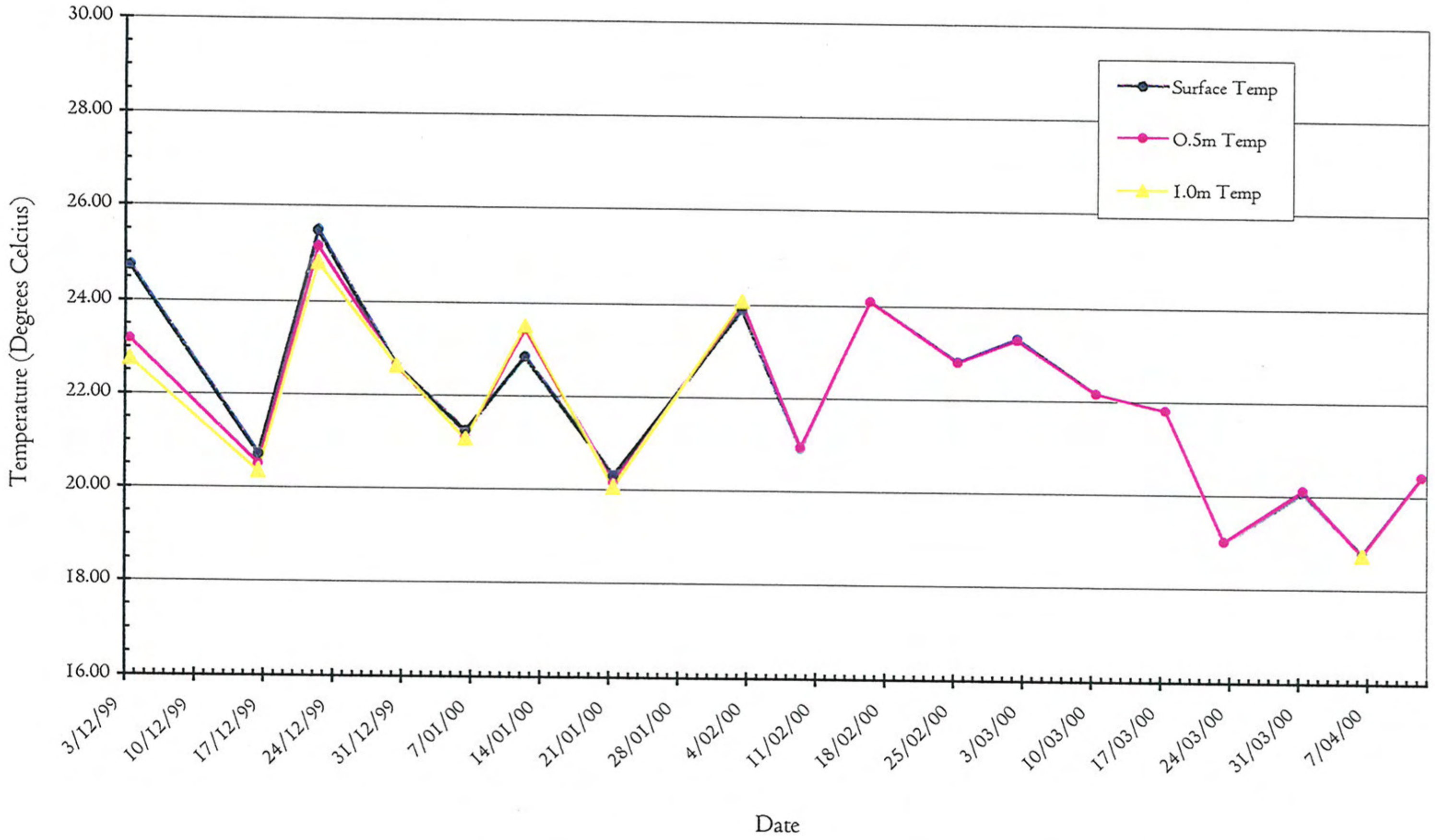


Figure 12. Water temperature upstream of the Wonnerup floodgates.

(Data provided by the Water and Rivers Commission Southwest)

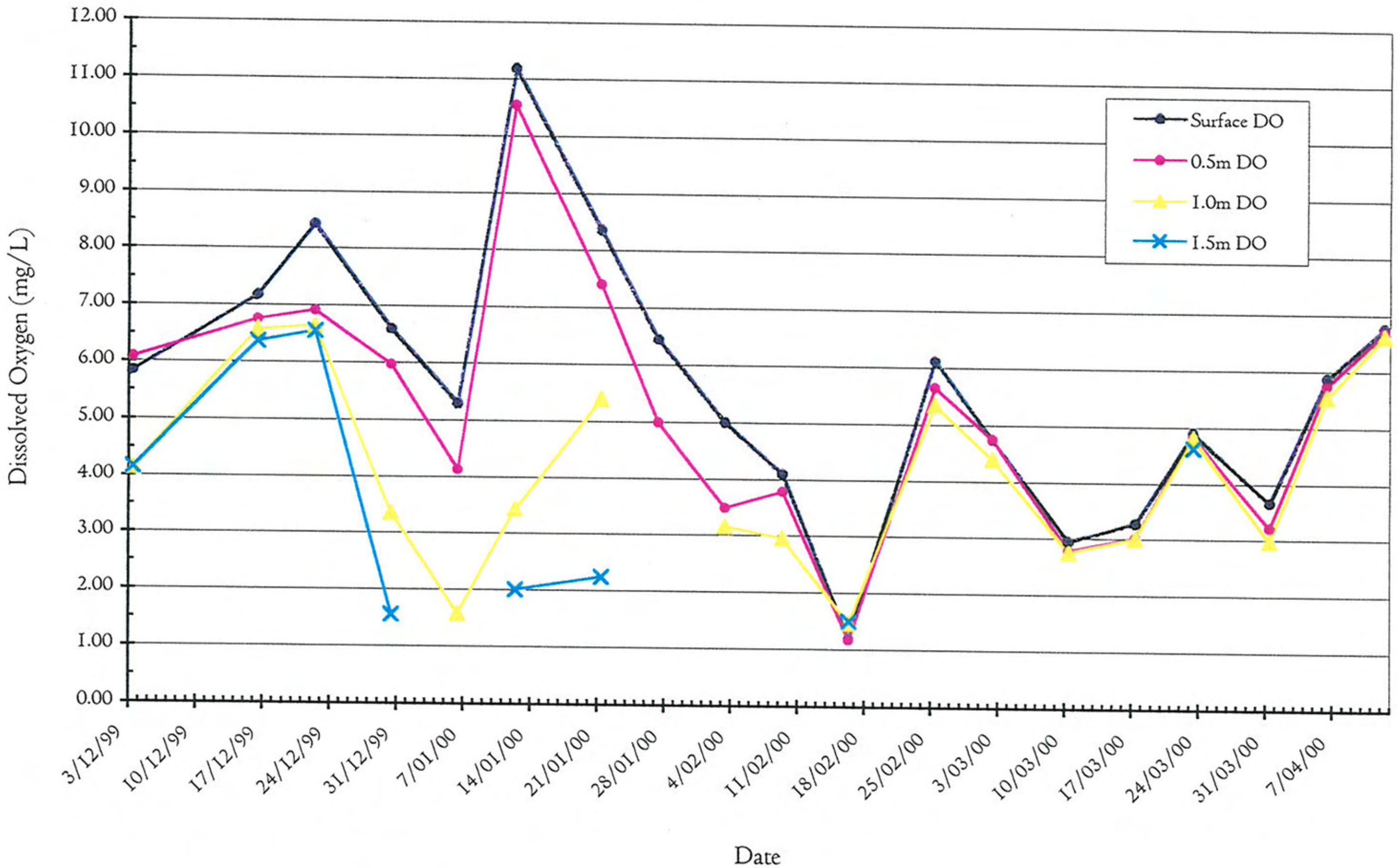


Figure 13. Dissolved oxygen upstream of the Vasse floodgates.

(Data provided by the Water and Rivers Commission Southwest)

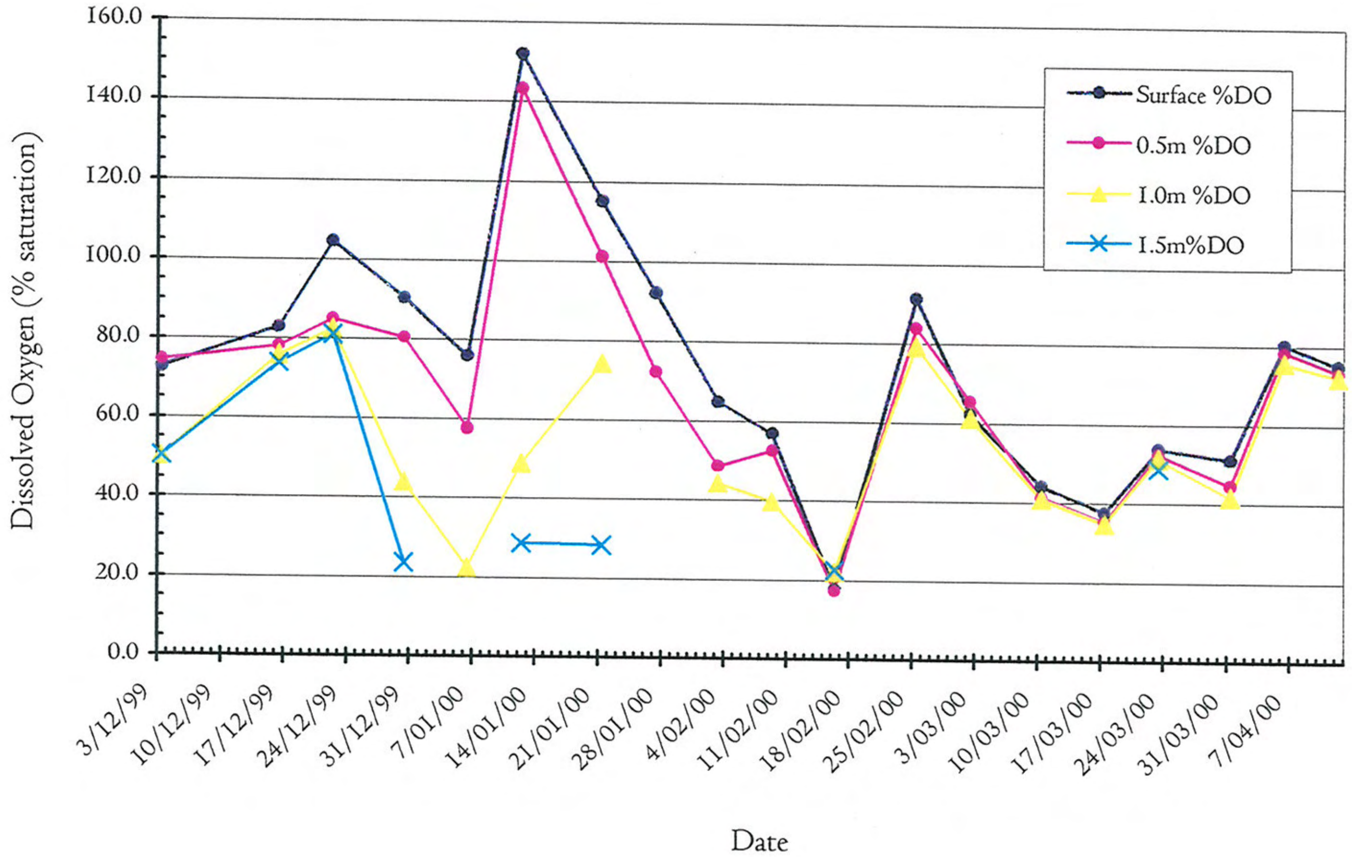


Figure 14. Dissolved oxygen saturation upstream of the Vasse floodgates.

(Data provided by the Water and Rivers Commission Southwest)

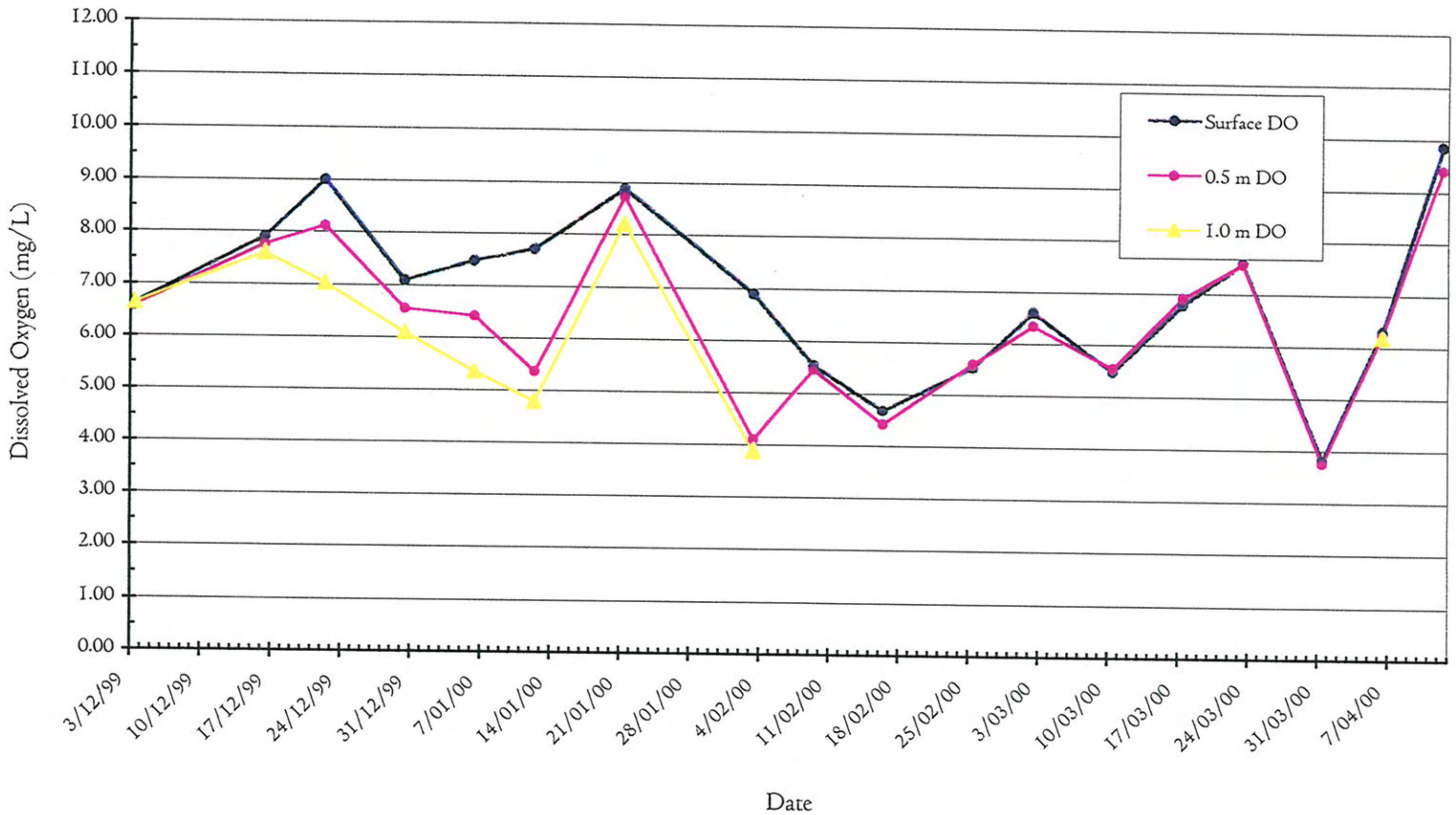


Figure 15. Dissolved oxygen upstream of the Wonnerup floodgates.

(Data provided by the Water and Rivers Commission Southwest)

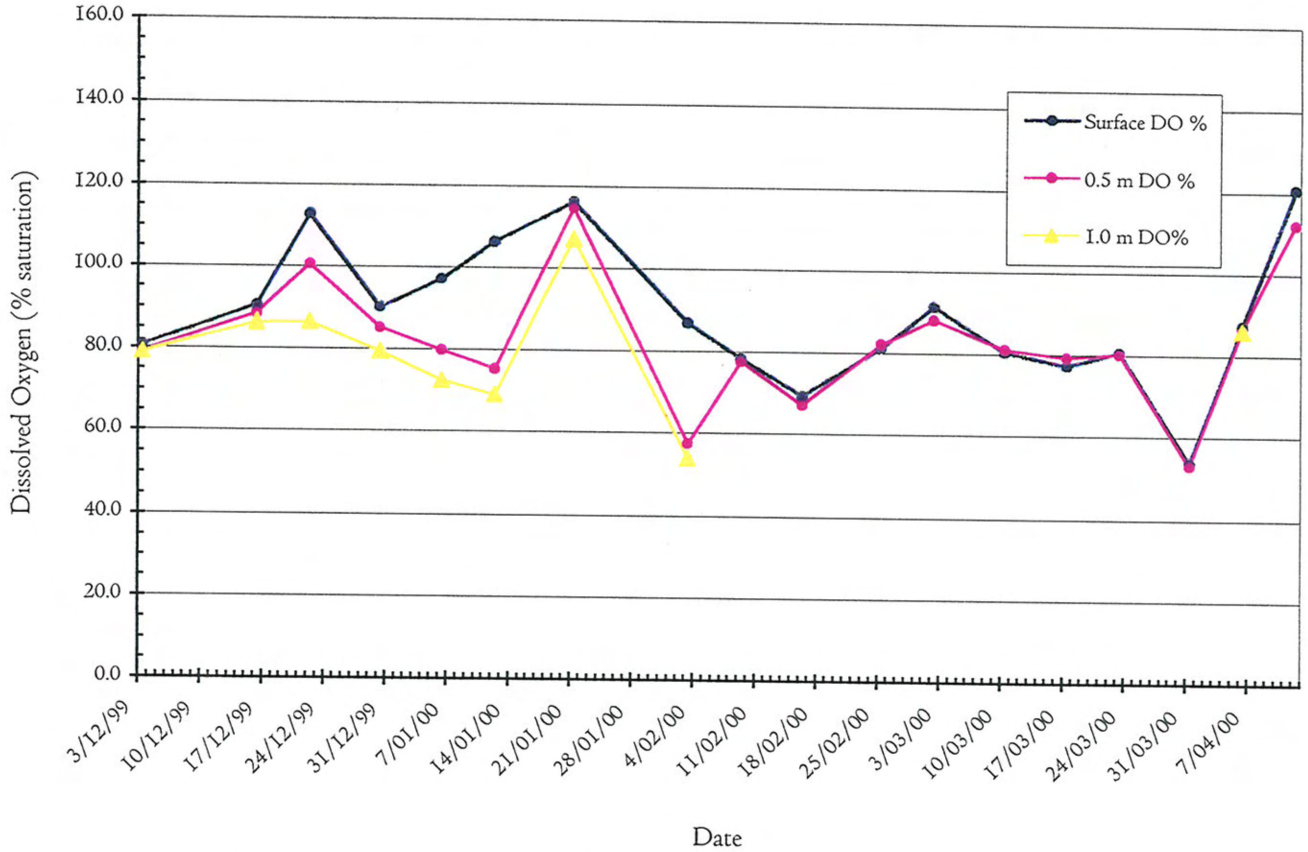


Figure 16. Dissolved oxygen saturation upstream of the Wonnerup floodgates.

(Data provided by the Water and Rivers Commission Southwest)

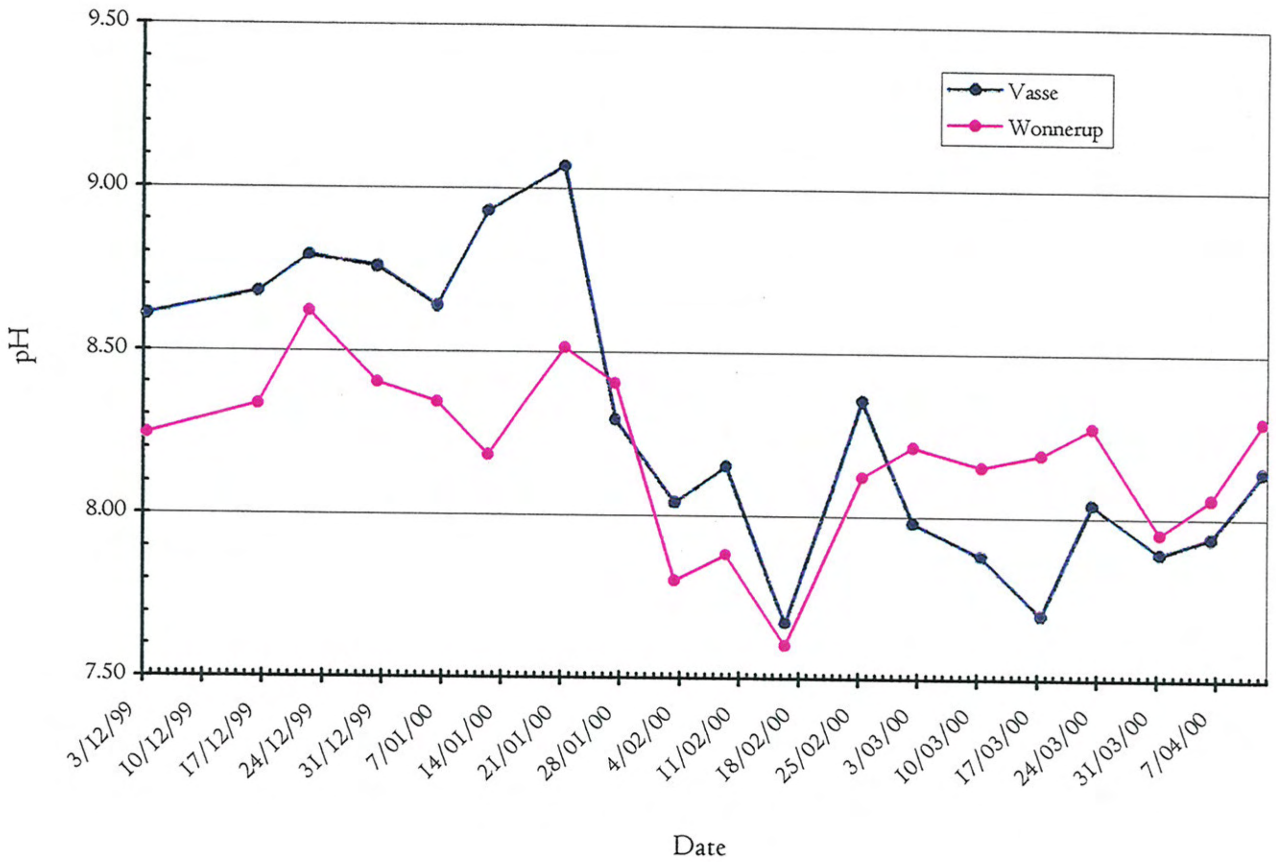


Figure 17. pH upstream of the Vasse and Wonnerup floodgates.

(Data provided by the Water and Rivers Commission)

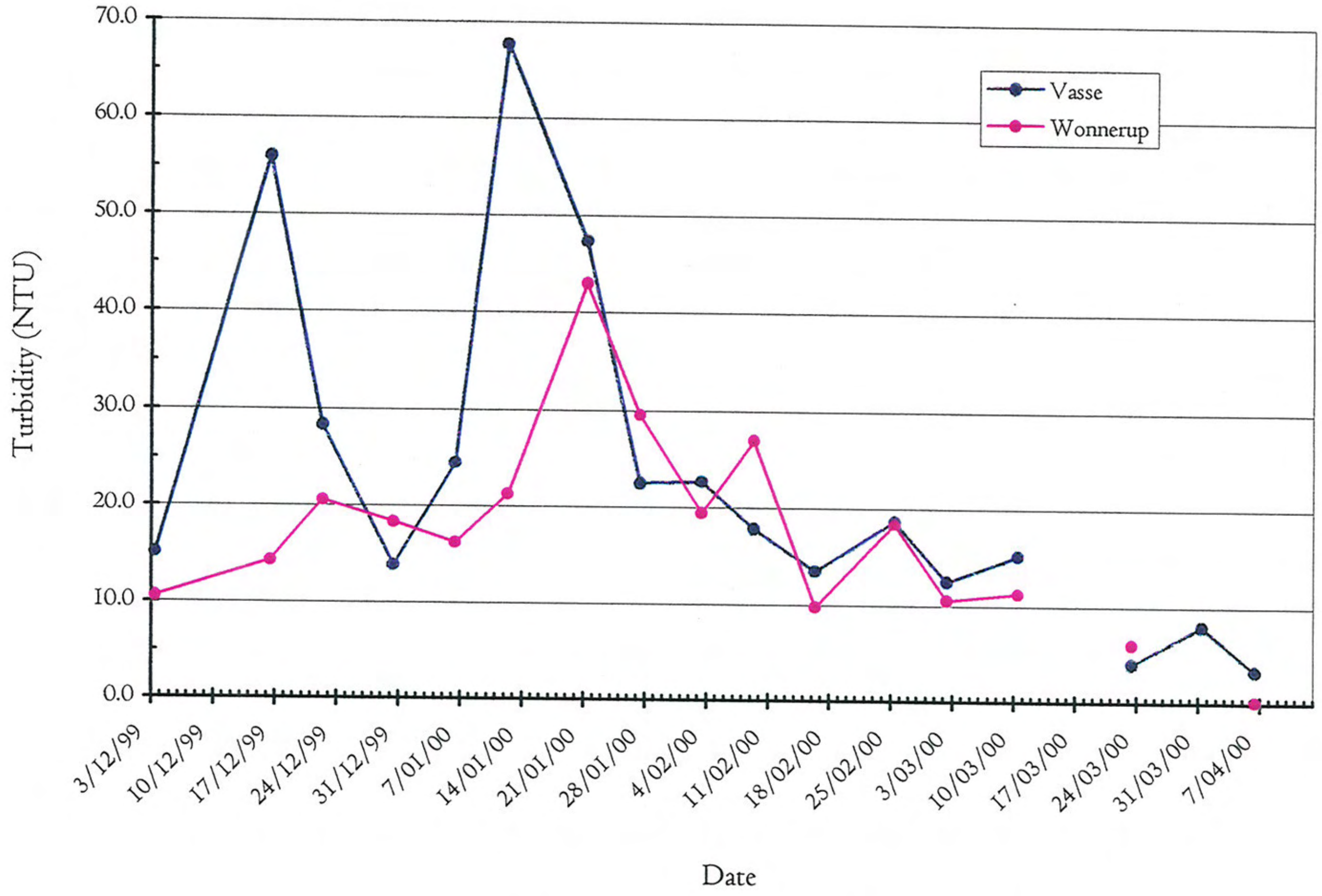


Figure 18. Turbidity upstream of the Vasse and Wonnerup floodgates.

(Data provided by the Water and Rivers Commission Southwest)

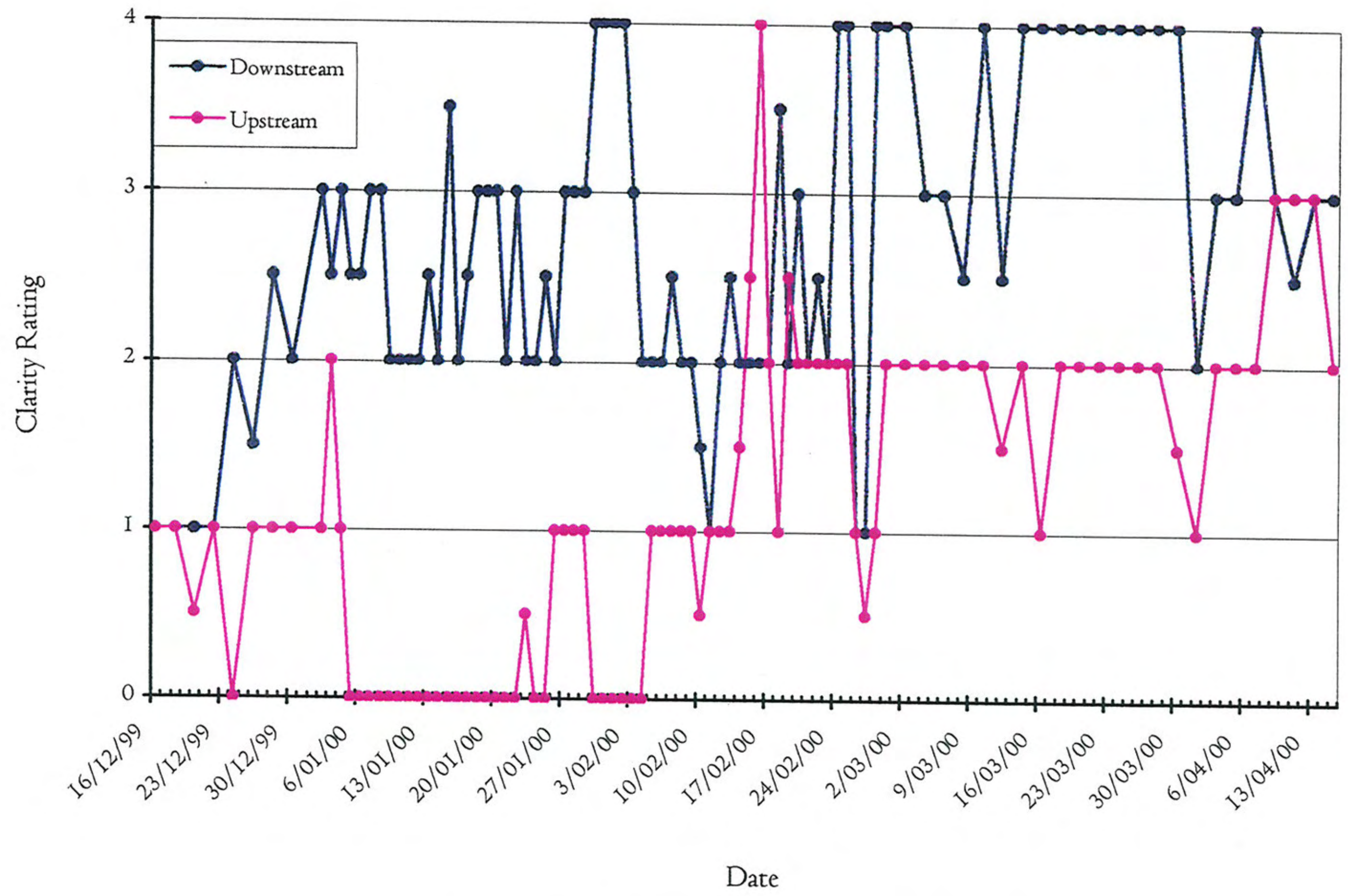


Figure 19. Subjective rating of water clarity at the Vasse floodgates.

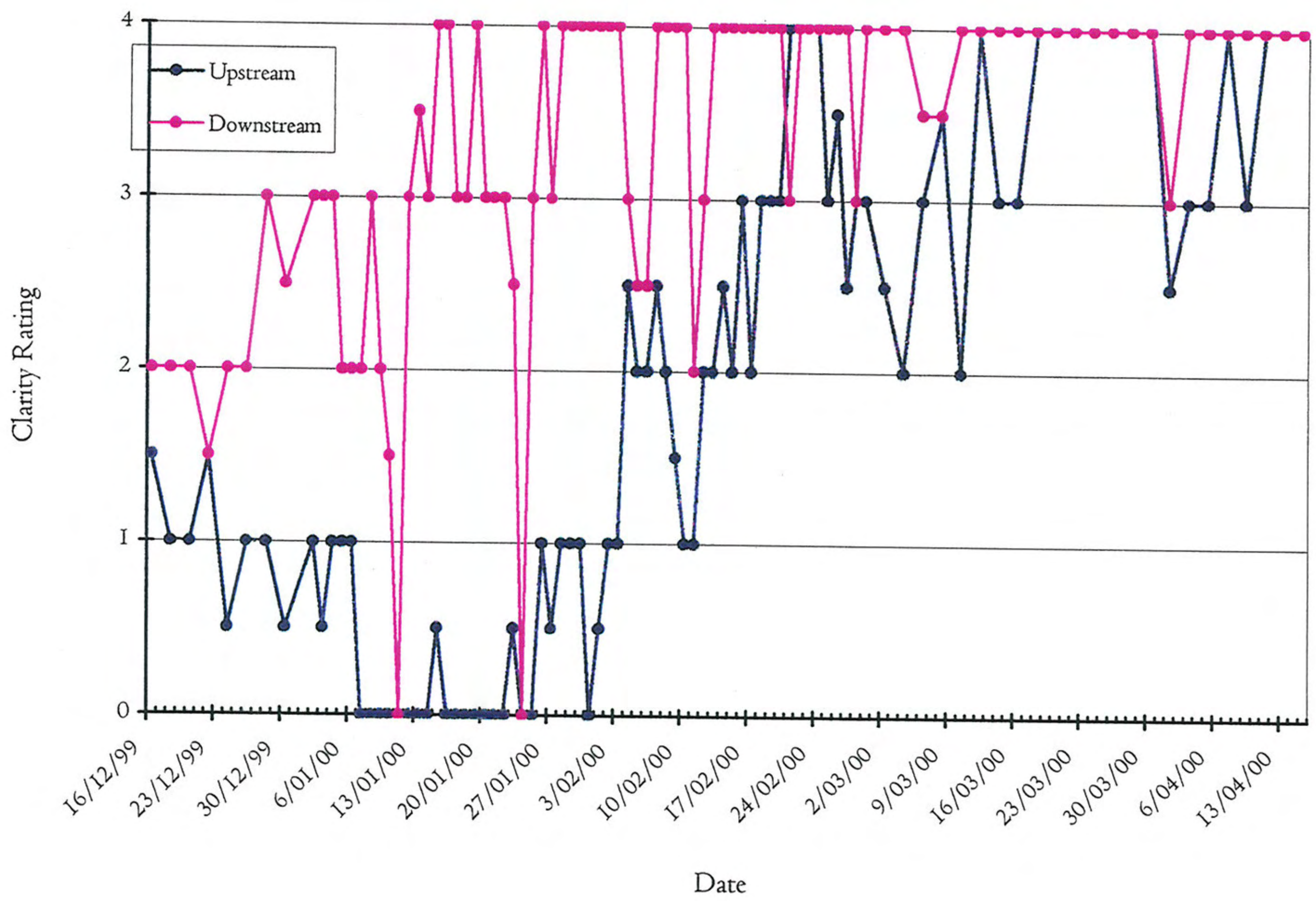


Figure 20. Subjective rating of water clarity at the Wonnerup floodgates.

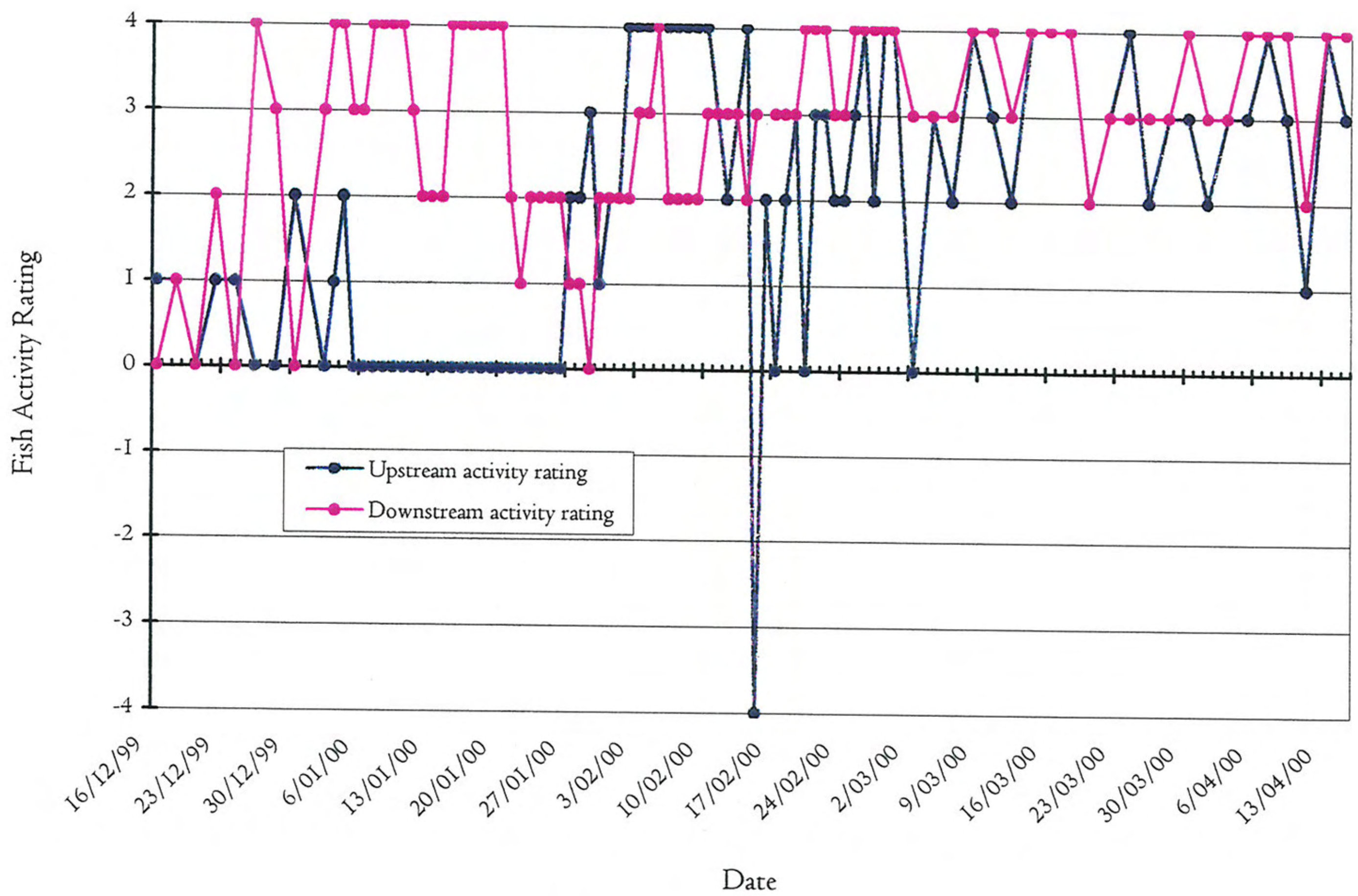


Figure 21. Fish activity at the Vasse floodgates.

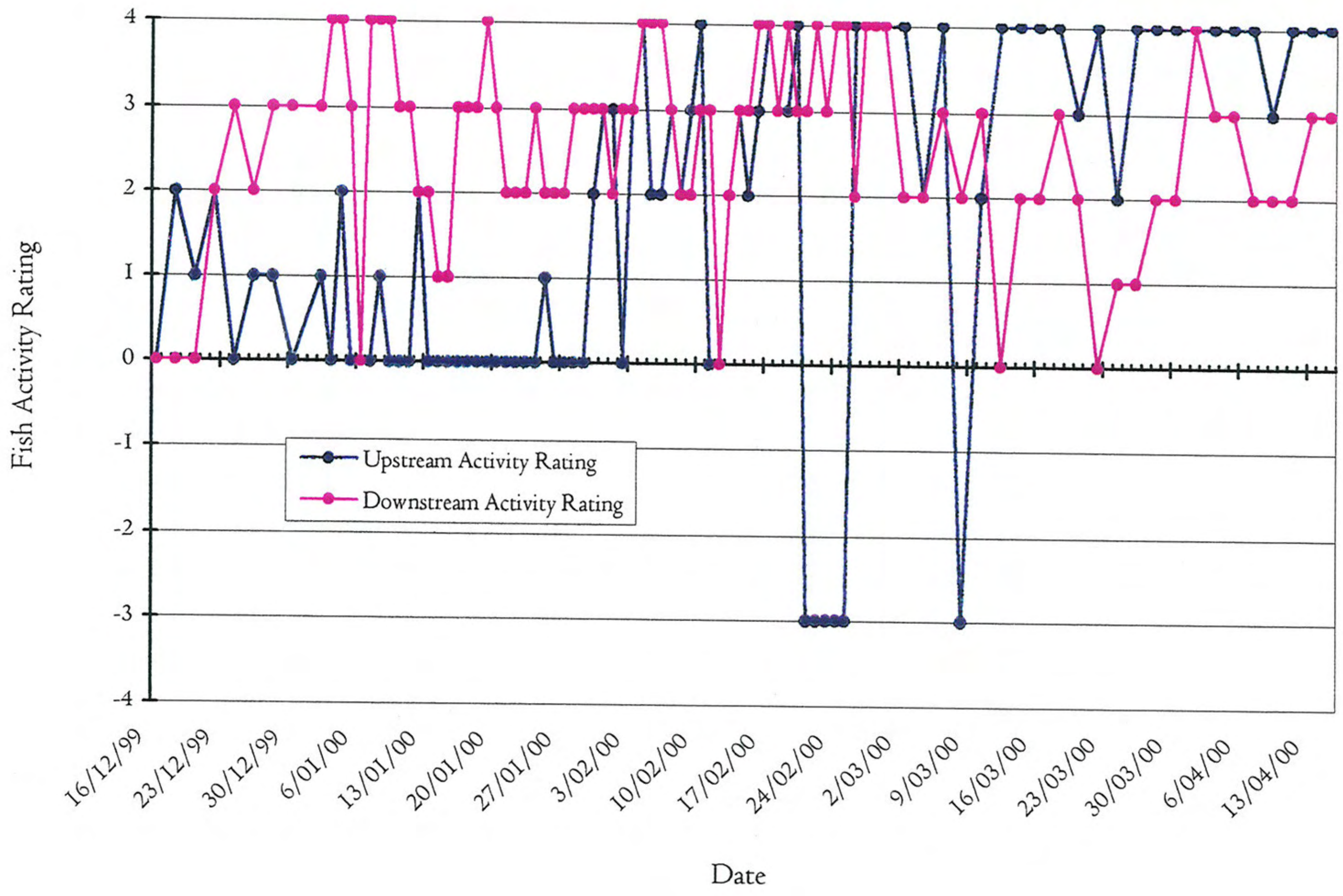


Figure 22. Fish activity at the Wonnerup floodgates.

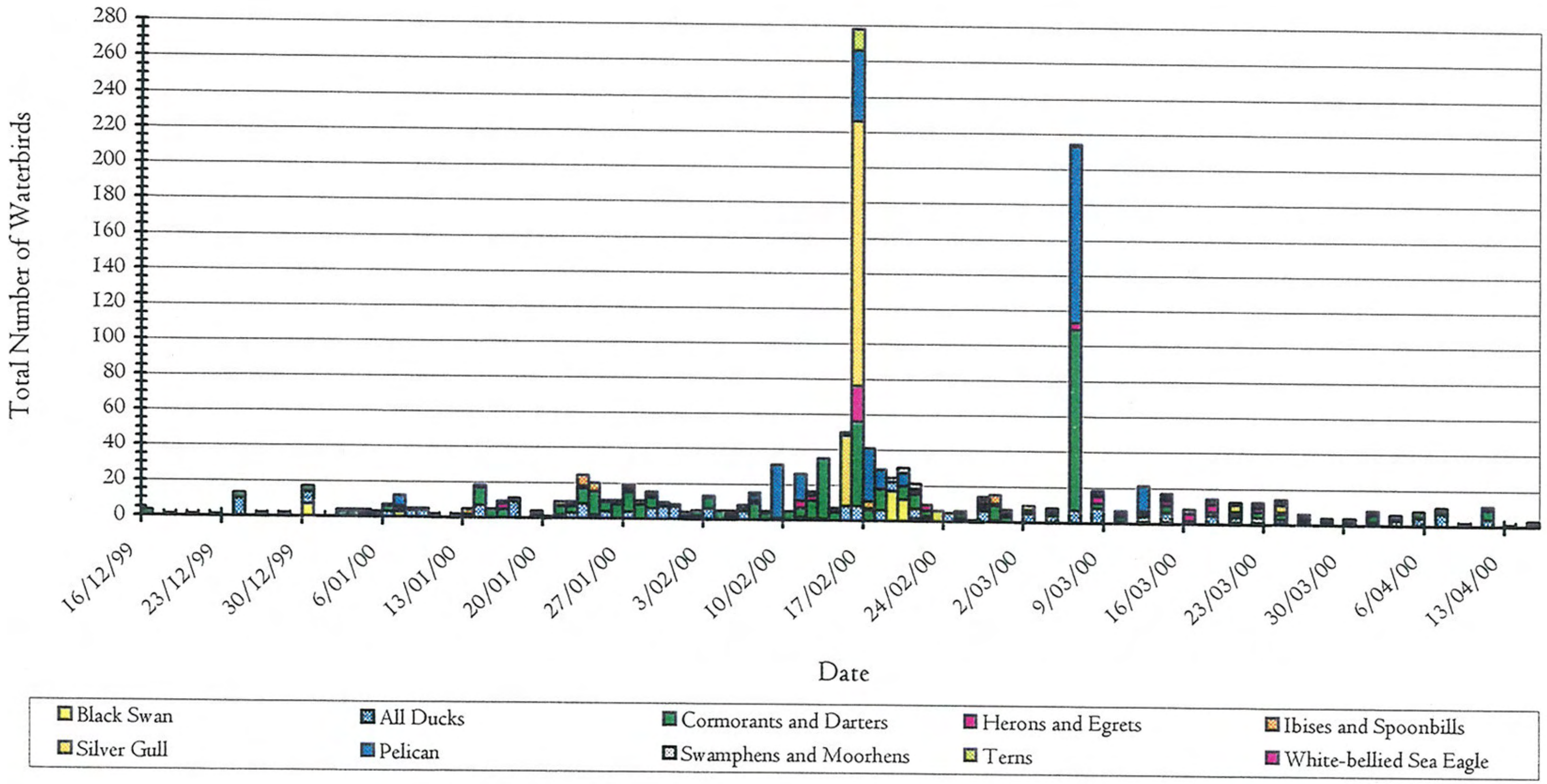


Figure 23. Waterbird abundance upstream of the Vasse floodgates.

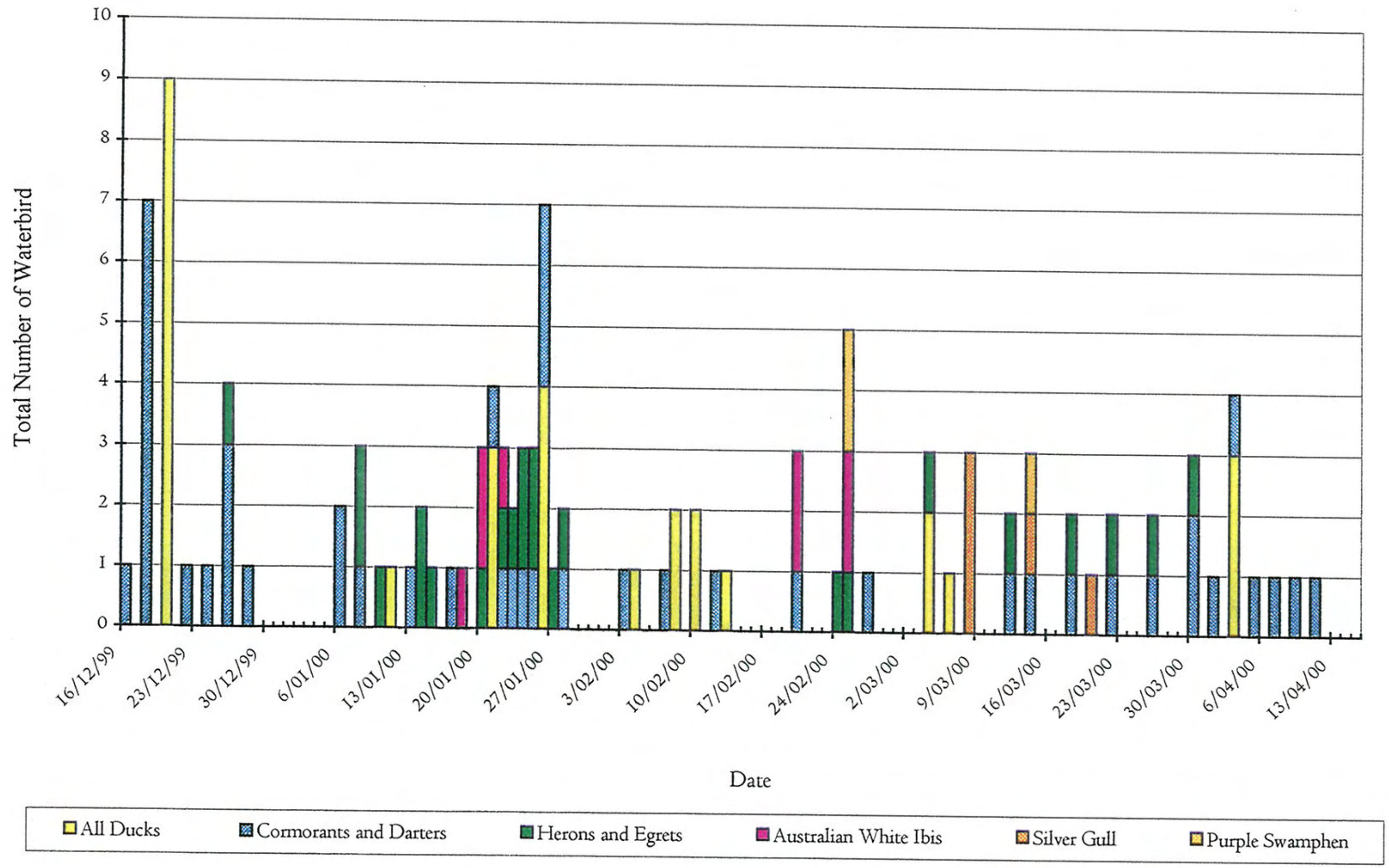


Figure 24. Waterbird abundance downstream of the Vasse floodgates.

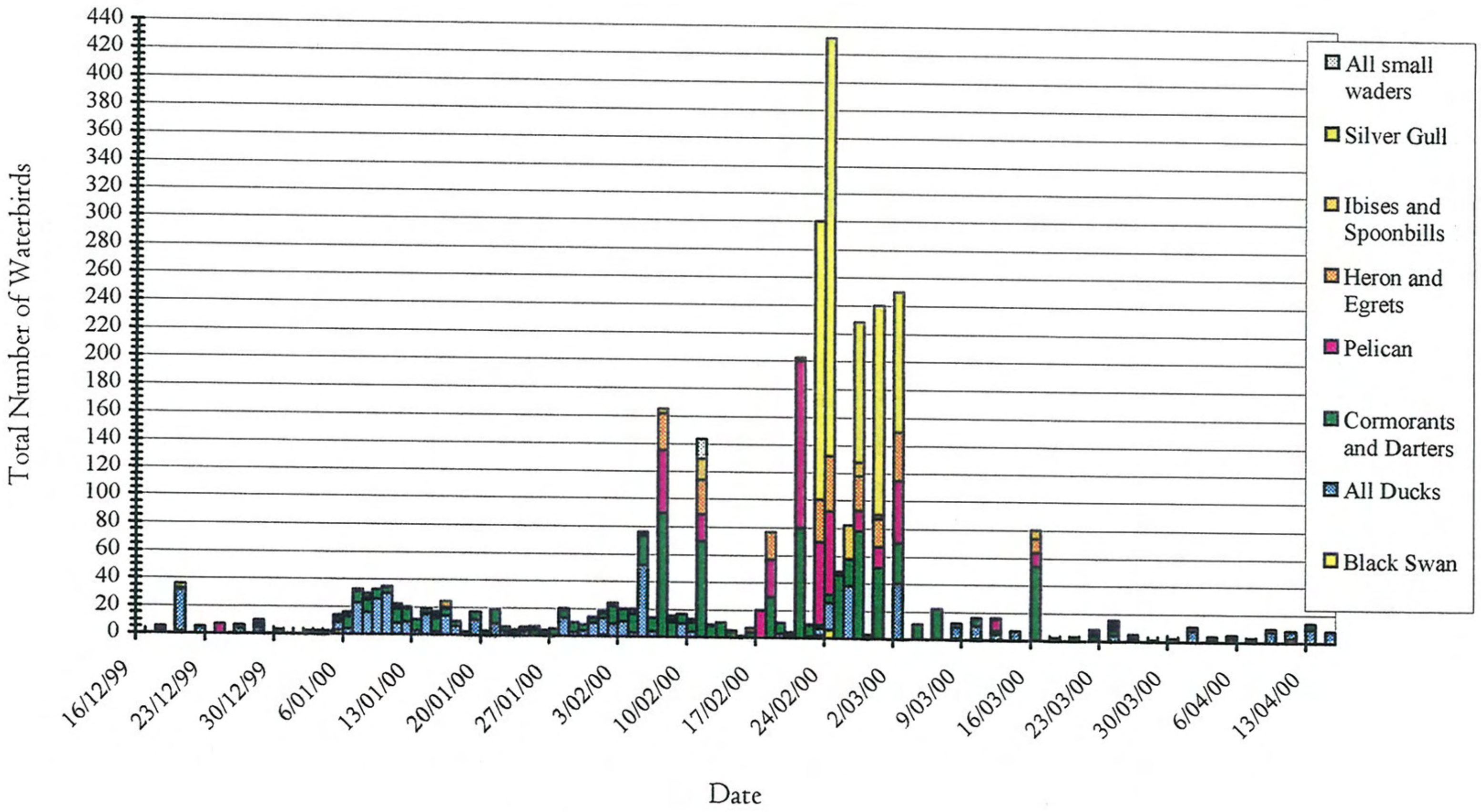


Figure 25. Waterbird abundance upstream of the Wonnerup floodgates.

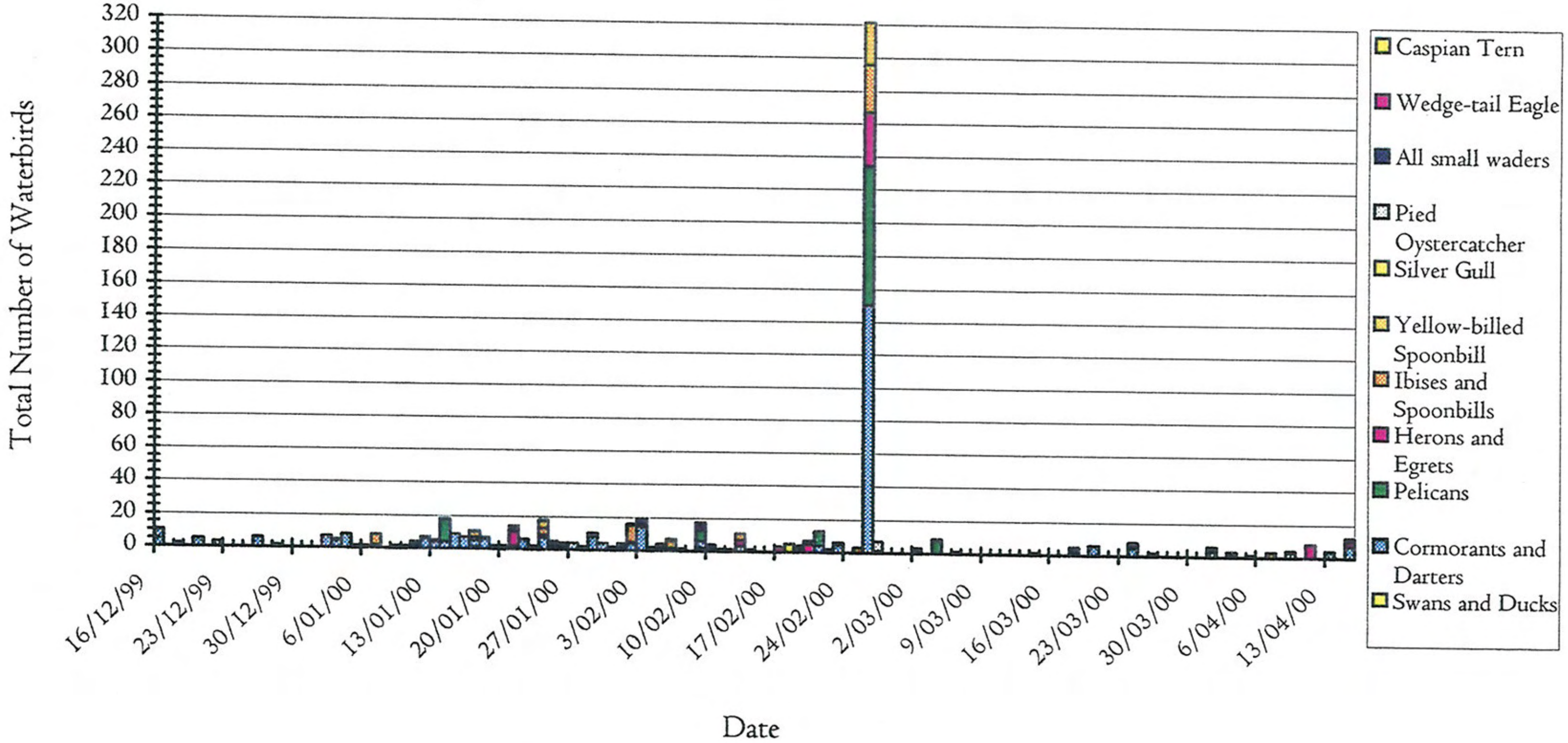


Figure 26. Waterbird abundance downstream of the Wonnerup floodgates.

APPENDIX 1: VASSE ESTUARY FISH KILL - February 15, 2000 – INCIDENT REPORT

Observations and actions taken

Afternoon Monday February 14, 2000:

- At 1615 hrs Jim Lane (CALM) saw hundreds of mullet milling against the floodgate stopboards on the upstream side of the structure. The tide was high and the fish were swimming in the strong inflow (leakage) of water. At 1630 hrs Jim telephoned Water Corporation Busselton and left a message on the answering machine requesting that the floodgates be opened the following morning to let fish out

Tuesday February 15, 2000:

Comments from Jim Black (An 85 year old fisherman who has fished at the floodgates every third morning for several decades, lives in Bunbury, Ph: 9721 7397):

- Arrived at 0530 and there were no fish schooling at the floodgates, and no visible fish or bird activity.
- About 0600, Jim Black saw the first fish splashing right at the floodgates.
- He noticed that there were hundreds of fish moving down towards the floodgates from further upstream with their noses above the water, slowly swimming at the surface. He commented that he immediately thought that it must be oxygen they were after, it was obvious from the way they were all trying to hold their heads above water, gasping at the surface.
- He thought that the activity had slowly become louder and more violent, with more and more fish splashing at the surface.
- Large numbers of fish started flapping and throwing themselves high out of the water right in front of the gates only just before I arrived (0625).

0625:

- I arrived at floodgates to find a mass of fish thrashing and flapping at the surface, with a flock of 15 to 20 silver gulls flying low, divebombing and pecking fish.
- Fish activity was greatest from the floodgates to about 50 m upstream.
- In this area, hundreds of mullet and black bream were flapping at the surface, most of them swimming on their sides or upside down, erratically thrashing, trying to push their heads above water or throw themselves above the water. Many would flap their body up and then slowly sink, upside down, for a couple of seconds, and then try again. Hundreds of fish were floating upside down, only flapping occasionally, and then slowly sinking. Between the thrashing fish, thousands more mullet were swimming slowly with their noses above the water, gasping at the surface, occasionally swirling rapidly under the surface, and jumping above the water. A few fish hit the floodgate stopboards as they tried to jump out of the water.
- Beyond 50 m, a sea of fish noses above the surface of the water (about 2cm sticking out – a little dark lump) could be seen. Dozens of mullet were regularly splashing at the surface and jumping out of the water between the sea of fish heads.
- There was a gentle leakage of seawater upstream, and it appeared as if it had just commenced flowing in, given the slow rate of flow, which rapidly increased.
- There was no wind, it was totally calm and the water surface was glassy.
- Less than 5% cloud cover – just very small patches of high cumulo-nimbus clouds. Trough line visible offshore.

0636:

- I telephoned Jim Lane's mobile and left a message advising that fish were dying and urgent action was needed.

0645:

- I measured the water levels with a tape measure next to the WRC gauge boards. Water levels (corrected to true AHD) were: upstream +0.02 m AHD; downstream +0.05 m AHD.
- I counted 12 dead fish right at floodgates, and many (several hundred) were floating upside down, some on the surface and some sinking, kicking only occasionally, not far from death.
- Activity at the floodgates, to 50 m upstream, was still intensifying, with more and more fish going belly-up and throwing themselves out of the water, slowly sinking, and then trying again.

- Thousands and thousands of fish noses were visible above the water surface to around 150 m upstream. The density of fish noses appeared to be at least 30 per square metre (to 150 m upstream).

0650:

- Inspected Wonnerup floodgates – there were no stressed fish, and mullet were very sporadically jumping actively at the floodgates and down the channel.

0705:

- Robyn Paice (WRC Bunbury) arrived at the Vasse Estuary floodgates and commenced taking photos of fish activity.

0710:

- I returned to the floodgates to find that the activity at the floodgates had quietened. Less fish were thrashing at the surface in front of the floodgates, and few were jumping above the surface.
- Thousands of fish could still be seen gasping at the surface, further upstream (from around 30 m to 150 m upstream).
- I counted 37 fish lying upside down on bottom (or slowly sinking) in a 20 m wide area (from floodgate to about 20 m upstream) on the south bank (near the gauge boards, where the water appeared clearest. Many of the fish were still occasionally finning and kicking their tails.
- The water was clear enough to see the bottom along the south bank (where the sandbar is), and also along the north bank.
- The wind slowly started to blow from the east (variable south east to north east at first), and gradually freshened (about 5 to 10 knots at this stage – slight ripples on surface of water).
- Despite the presence of people on the floodgates (Robyn, Jim Black and myself), approximately 40 silver gulls, 1 white-bellied sea-eagle and 1 caspian tern continued to dive bomb fish within 30 m of floodgate. Two great egrets were feeding on small fish in the shallows (50m up north bank).

0720:

- I estimated around 100 fish dead in the immediate vicinity of the floodgates (c. 30 m upstream).
- No fish jumped above surface, or thrashed at the surface since 0710.
- The number of fish gasping at surface, with their noses above water, gradually reduced, and the fish moved further upstream of the gates.
- Thousands of fish noses were still visible, mostly 50 m to 150 m upstream by this stage.

0800:

- One of the Vasse estuary floodgates was opened by John Moon and Clive Piggott of Water Corp Busselton. (Jim Lane had received my 0636 hrs phone message, phoned Graham Holtfreter (Water Corp) and requested urgent opening). Jim Lane arrived at floodgates at 0805 hrs.

0815:

- Wind had freshened to a moderate breeze (12 to 18 knots).
- Large numbers of fish fry (1 to 2 inches) and palaemonid shrimps were schooling at floodgates and exhibiting slow movement.
- Numbers of fish gasping at surface continually declined, and moved slightly further away from the gates, with the densest area about 100 m upstream.
- No fish were jumping out of the water since 0710.

0820 – 1030:

- Jim Lane waded to collect fish, shrimp, sediment and some water samples. Live shrimps could be picked fairly easily with tweezers.
- All dead fish were collected from an area 5 - 10 m wide, from the floodgate to 150 m upstream on the south bank.
- Robyn Paice collected a Fish Kill Kit from Geocatch's Busselton office.
- Robyn Paice and I commenced sampling with kit according to the provided protocol.
  - A representative sample of size and species killed were placed on ice – where possible, live but stressed fish were captured, however most were dead at time of sampling.

- A representative sample of the kill was dissected and formalin preserved.
- Sediment and water quality samples for determination of BOD, nutrients, organochlorines, sulphide and phytoplankton were taken.

- Charlie Broadbent (CALM; Chairman of Vasse Estuary Technical Working Group) reported many dead fish up to Ballarat Road (this had also been reported to Jim Lane by local resident Basil Hand at 0715 hrs).

0845:

- All severely stressed fish behaviour appeared to have ceased. No more fish were observed jumping or thrashing at the surface, and no fish were gasping at the surface.
- Immediately upstream of the floodgates, several fish were still finning very slowly below the surface (not far from death), however almost all visible adult mullet and bream were dead.
- Large numbers of small fish – 'pinheads' or 1 to 2 inch long fry – were swimming just below the surface at the floodgates, some swimming slowly or waywardly. Many were breaking the surface, leaping en masse in large, fast sprays across the surface, usually in response to gulls flying low over the water but also as if being chased underneath (but that was not confirmed). The sprays could be seen from 5 m to 150 m upstream.

0930 - 0945:

- Jim Lane (still wading at this stage) observed the first live adult mullet to recommence schooling 5 –25 m upstream of the floodgates. Schools of many hundreds of fish approached the incoming flow of seawater at the floodgates.

1040:

- Mullet were first observed to be migrating through the opened floodgate, slowly at first (100 a minute), then up to 200 a minute by 1050.
- Jim Lane and I took turns counting numbers of fish migrating through every few minutes to ascertain rate changes over the entire gate opening period. This allowed a fairly accurate estimate of numbers of fish that emigrated from the estuary.

1125:

- Large numbers of mullet (up to 340 per minute) were migrating through the gate.
- About 2% of the fish migrating through the gate were very large fish (<50cm long). No fish of this size class were observed in the kill at the floodgates (although 2 individuals were collected the following day).
- The water 0 – 20 cm behind the floodgates was thick with mullet, a seething mass of fish wriggling at the surface. The fish were so numerous you could dip a scoop net and bring up 10 mullet each scoop – most were Sea Mullet *Mugil cephalus*. Near the southern shore, the water was thick with mullet for at least 50 m upstream, many thousands of fish were present.

1300:

- Numbers of mullet emigrating steadily reduced to less than 100 per minute (mostly around 60 – 70 a minute), although the water immediately behind the floodgates was still thick with fish. Mullet could still be scooped up in numbers with a net dipped just behind the floodgates, to the side of the main inflow.
- It is possible that some of the smaller fish may have had difficulty escaping at this stage (most of the fish observed emigrating were larger at this stage), due to the high head of water in the inlet, which resulted in a very fast, gushing flow of water into the estuary.

1315:

- Numbers of fish escaping reduced to less than 20 per minute.

1340 – 1445:

- Jim Lane and I inspected Webster Road and Estuary View Drive and found no dead fish. Dead fish were observed at Ballarat Road only.

1600:

- Numbers of mullet emigrating through the floodgates were less than 15 per minute since 1500 hrs.
- As per the agreed schedule of operation for floodgate openings, the floodgates were closed after 8 hours open, despite the presence of many fish still schooling upsteam of the floodgates. When the upstream water level is

higher than -0.1 m AHD, the current floodgate operational guidelines allow for the floodgates to remain open for longer than 8 hours only if fish are still dying.

Wednesday February 16, 2000:

- I arrived at the Vasse estuary floodgates at 0530 hrs and found hundreds of dead fish (from yesterday morning) floating belly-up on the surface, for at least several hundred metres upstream.
- Jim Lane and I commenced the cleanup operation by 0630.
- Many gulls, terns, cormorants and whistling kites were feeding on the small fish early in the morning.
- By 1400 all the dead fish were removed. Most were disposed of at the Shire's offal pit, some were buried near the mouth of Wonnerup Inlet.
- While boating near the floodgates, we found that the reverse flap valve sill was 1 cm above the upstream water level. This could have prevented further fish releases, so later that day we lowered the frame by two stopboards (a total of about 30 cm) to facilitate future releases.
- During the cleanup, the only live fish observed were a small number of mullet sporadically surfacing near Ballarat Road. No live fish were observed closer to the floodgates.

Numbers of fish killed

- On February 15, about 60 Black Bream *Acanthopagrus butcheri*, 60 Yellow-Eye Mullet *Aldrichetta forsteri*, and 10 unidentified gobies were collected.
- On February 16, 306 Black Bream (mostly very small, with less than 150 mm lower jaw – fork length LJFL), 1037 Yellow-eye Mullet, 2 Sea Mullet and 1 unidentified juvenile fish (c. 100 mm) were collected between the floodgates and Ballarat Road.
- TOTAL: 1476 fish collected - in excess of 1500 fish were killed.
- It must be noted that the majority of mullet collected on the 16th were larger fish (>150 mm). It is likely that birds had consumed many of the smaller fish, which represented more than 50% of the mullet killed (based on the sub-sample collected the previous morning).

Numbers of fish released

- It is estimated that in excess of 35 000 mullet were released through the floodgates between 0800 and 1600 on February 15.

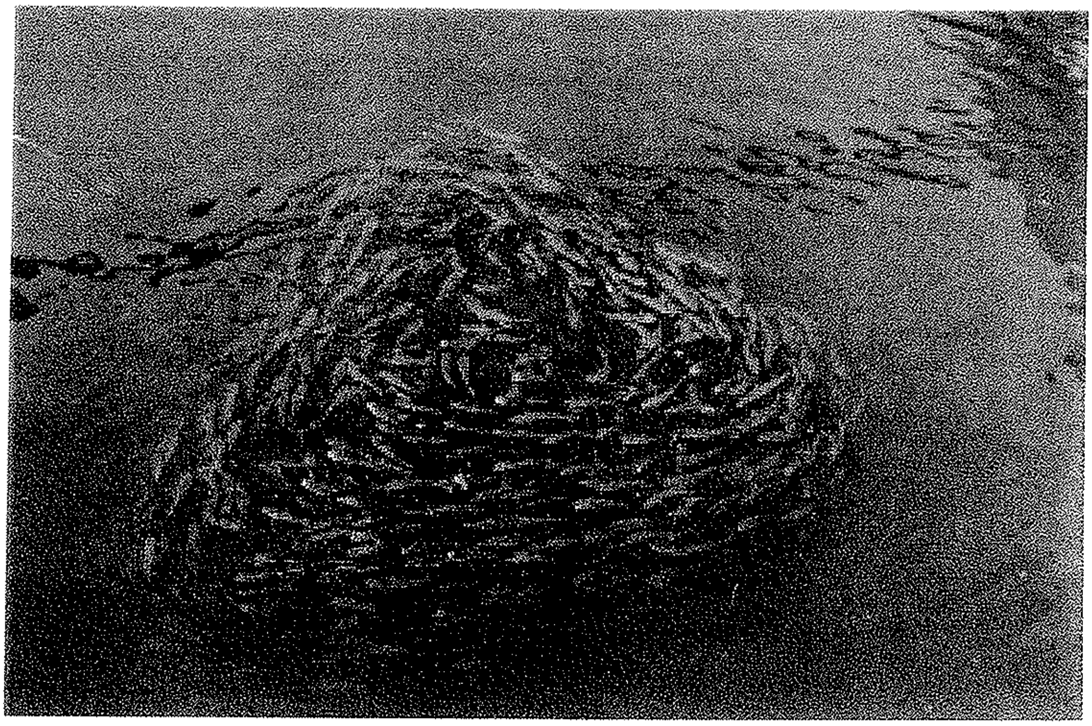
Important factors to consider

- Only Yellow-eye Mullet, Black Bream and small unidentified gobies were killed. Despite the presence of many thousands of Sea Mullet, only 2 individuals died (and these were very large specimens – both well in excess of 50cm).
- Not all year classes appeared to have been affected, and smaller fish made up the greatest proportions killed. Fish collected immediately following the kill on Tuesday morning (15 Feb) were sorted into obvious year classes and the following proportions were represented: Black Bream, 68% were 86 – 135 mm LJFL, 26% were 165 - 195 mm LJFL, and 6% were 265 – 295 mm LJFL; Yellow-eye Mullet, 62% were 95 – 145 mm LJFL, 22% were 220 – 260 mm LJFL, and 16% were 275 – 345 mm LJFL.
- Many of the fish appeared to have burst blood vessels along the side of the gill plate and around the viscera. All displayed very red gills.
- The inflow of Inlet water was steadily increasing all day (15 Feb), commencing at about 0630 - 0645, due to a high amplitude spring tide that was rising all day (peaking at about 0400 the following morning).
- Additionally, the bottom sill of the reverse flap valve, through which the fish were escaping, was about 2cm above the height of the estuary water when the floodgates were opened. It is fortunate that there was such a high incoming tide,
- A lower tide may have made it impossible to release fish, as they would not have been able to clear the sill of the reverse flap valve.
- It is likely that there was no leakage of seawater into the estuary for about 2 or 3 hours before the kill occurred.
- Conditions were calm when the kill occurred.

J. LANE

Monitoring of fish behaviour in the lower reaches of the Vasse – Wonnerup Wetland System during the summer of 1999/2000

Appendices 2 – 15: Monitoring Observations



Prepared for the Vasse Estuary Technical Working Group
Funded by the GeoCatch Network Centre

Prepared by
S.V. Elscot

~ July 2000 ~

≈ GREEN IGUANA ≈
Environmental and Heritage Research
45 Gibney Street
Dunsborough WA 6281
green_iguana@bigpond.com

CONTENTS

Appendix 2: Weather Conditions and Time of Inspections at the Vasse Floodgates

Vasse Floodgates DATE	Time	Wind Direction	Wind Strength	Cloud	Comments
16/12/99	1400	E	Fresh with strong gusts	Cloudy to the east	
18/12/99	1410	SW	Light to moderate	Cloudy to the east	
20/12/99	1350	SW	Light	Cloudy to the east, broad trough inland, very hot yesterday	
22/12/99	1420	SW	Moderate		
24/12/99	1400	E	Moderate		
26/12/99	1355	SW	Light to moderate		
28/12/99	1415	SW	Light		
30/12/99	1355	E	Moderate to fresh	100% cover	
2/01/00	1355	SE	Light - moderate		
3/01/00	1355	NE	Strong		
4/01/00	1330	NE	Light		
5/01/00	1400	SW	Light - moderate		
6/01/00	1400	NE	Calm - very light	Overcast	
7/01/00	625	E	Moderate		
8/01/00	615		Calm	Overcast	
9/01/00	625	E	Calm - light		
10/01/00	615	SE	Calm - light		
11/01/00	600	SW	Calm - light	Overcast	Fresh seabreeze yesterday
12/01/00	625	SW/SE	light - moderate gusts		
13/01/00	610	ENE	Moderate	Overcast	Cool wind - rain forecast
14/01/00	610	E	Fresh with strong gusts	Overcast	Light drizzle - cold wind – rained a little last night
15/01/00	615	ESE	Moderate	Very overcast	Cool wind - rained all night – drizzling this morning
16/01/00	630	SE	Light		Very heavy rain on Cape Naturaliste for hours - stopped raining as I came into Busselton, the roads are dry
17/01/00	610		Calm		
18/01/00	610	NE	Light		
19/01/00	610	SE	Light		
20/01/00	640	SE	Light		
21/01/00	610	SE	Moderater - Fresh	Very overcast	Cool – light rain
22/01/00	620	E/NE	Fresh with strong gusts	Very overcast	Cold – considerable rain this morning
23/01/00	610	NE	Fresh to strong	Cloudy to N and E again	Considerable rain yesterday
24/01/00	615		Calm		
25/01/00	615	SE	Light		
26/01/00	610	SE	Light to moderate		
27/01/00	630	NE	Fresh to strong		
28/01/00	615	NE	Moderate - fresh		
29/01/00	630	NE	Light		

Vasse Floodgates DATE	Time	Wind Direction	Wind Strength	Cloud	Comments
30/01/00	615	SE	Light to moderate		
31/01/00	610	SE	Light	Thin clouds	Rained considerably last night
1/02/00	630		Calm		
2/02/00	605		Calm	Cloudy to the north, east and south - ~ 25% cover	
3/02/00	620		Calm		
4/02/00	620	S	Light		Wind freshening
5/02/00	605		Calm		
6/02/00	610	NE	Light to moderate		
7/02/00	610	NE	Light to moderate	>95%	
8/02/00	610	SW/S	Fresh to strong gusts	>95%	Small amount of drizzle early this morning
9/02/00	615	SE	Light		
10/02/00	625	SE	Light		
11/02/00	615	S/SE	Light to moderate		
12/02/00	625	E/NE	Fresh		
13/02/00	610		Calm		
14/02/00	635	SE	Very light		
15/02/00	625		Calm		
16/02/00	535	ESE	Calm - very light		
17/02/00	615		Calm		
18/02/00	620	S	Light		Freshening quickly
19/02/00	630	SE	Light	~5%	Cloud on horizon to south and east – strong wind warning S/SE today
20/02/00	620	E	Calm - light		
21/02/00	700	NE	Calm - very light	~5%	
22/02/00	630		Calm	~5%	Cloud to the south - strong wind warning forecast – raining on Cape Naturaliste already
23/02/00	715	NE	Light	>90%	
24/02/00	630		Calm		
25/02/00	620	SE	Calm - light		
26/02/00	655	S/SE	Light		
27/02/00	630		Calm		
28/02/00	615		Calm	~20%	Cloud to NE
29/02/00	620		Calm	~30%	Cloud to NE
2/03/00	620	E	Calm - light	~50%	Cloud to the south - frontal
4/03/00	620	E	Light to moderate		
6/03/00	630	NE	Moderate		
8/03/00	655	E	Light		
10/03/00	645	SE	Strong	100%	Very grey, raining - under influence of tropical cyclone Steve
12/03/00	630	S/SE	Light-moderate	100%	Very grey and cool
14/03/00	640	E	Calm - very light		

Vasse Floodgates DATE	Time	Wind Direction	Wind Strength	Cloud	Comments
16/03/00	630		Calm		
18/03/00	645		Calm		
20/03/00	645	NE	Moderate	60%	Cloud to NE - influence of tropical cyclone Olga - no sun on water yet
22/03/00	635		Calm		
24/03/00	640		Calm		
26/03/00	640	S/SE	Light		
28/03/00	705		Calm		
30/03/00	655		Calm		
1/04/00	715		Calm		
3/04/00	730	E	Moderate to fresh		
5/04/00	715	E/NE	Fresh to strong		
7/04/00	720	NE	Calm - very light	80%	Looks like rain coming
9/04/00	730	NE	Calm- very light		Very high tide again -- floodgates are like a waterfall on upstream side
11/04/00	730	N/NW	Fresh to strong	70%	Rain coming
13/04/00	725	W	Calm to light	40%	Front approaching from south
15/04/00	715		Calm		

Appendix 3: Depth and Flow Measurements at the Vasse Floodgates

Vasse Floodgates DATE	Upstream Depth Observed	Downstream Depth Observed	Flow Direction Observed	Flow Rate Observed	Flow Rating
16/12/99	0.36	0.42	Upstream	Gentle leakage	1
18/12/99	0.38	0.39	Downstream	Gentle leakage	-1
20/12/99	0.36	0.39	Downstream	Gentle leakage	-1
22/12/99	0.34	0.38	Downstream	Gentle leakage	-1
24/12/99	0.39	0.34	Upstream	Very gentle leakage	0.5
26/12/99	0.31	0.28	Downstream	Moderate leakage	-2
28/12/99	0.3	0.36	Upstream	Moderate leakage	2
30/12/99	0.34	0.27	Upstream	Gentle leakage	1
2/01/00	0.27	0.41	Upstream	Moderate - fast leakage	2.5
3/01/00	0.25	0.35	Upstream	Fast leakage	3
4/01/00	0.22	0.37	Upstream	Fast leakage	3
5/01/00	0.25	0.34	Upstream	Very gentle leakage	0.5
6/01/00	M 1.825	M 1.560	Upstream	Gentle leakage – moderate in 2 bays	1
7/01/00	M 1.825	M 1.690	Downstream	Moderate leakage	-2
8/01/00	0.23	0.22	Downstream	Gentle leakage	-1
9/01/00	0.23	0.22	Downstream	Gentle leakage	-1
10/01/00	M 1.820	0.21	Downstream	Gentle leakage	-1
11/01/00	M 1.830	0.29	Downstream	Gentle leakage	-1
12/01/00	M 1.825	0.34	Upstream	Moderate leakage	2
13/01/00	M 1.835	0.28	Upstream	Gentle leakage	1
14/01/00	M 1.850	0.27	Upstream	Gentle leakage	1
15/01/00	M 1.820	0.27	Upstream	Very gentle leakage	0.5
16/01/00	M 1.825	0.26	Upstream	Very gentle leakage	0.5
17/01/00	M 1.830	0.19	Downstream	Gentle leakage	-1
18/01/00	M 1.830	M 1.755	Downstream	Gentle leakage	-1
19/01/00	M 1.835	0.15	Downstream	Moderate - fast leakage	-2.5
20/01/00	M 1.840	M 1.850	Downstream	Fast leakage	-3
21/01/00	M 1.860	M 1.875	Downstream	Moderate leakage	-2
22/01/00	M 1.870	M 1.810	Downstream	Fast leakage	-3
23/01/00	M 1.855	M 1.775	Downstream	Moderate - fast leakage	-2.5
24/01/00	M 1.855	0.19	Downstream	Gentle leakage	-1
25/01/00	M 1.870	M 1.745	Downstream	Moderate leakage	-2
26/01/00	M 1.875	M 1.720	Downstream	Very gentle leakage	-0.5
27/01/00	M 1.890	M 1.795	Downstream	Gentle leakage	-1
28/01/00	M 1.910	M 1.740	Downstream	Very gentle leakage	-0.5
29/01/00	M 1.895	M 1.575	Upstream	Moderate to fast	2.5
30/01/00	M 1.895	0.3	Upstream	Gentle leakage	1
31/01/00	M 1.900	M 1.620	Upstream	Gentle	1
1/02/00	M 1.895	M 1.680	Upstream	Very gentle leakage	0.5
2/02/00	M 1.900	M 1.740	None	Slack water	0
3/02/00	M 1.905	M 1.745	Downstream	Very gentle leakage	-0.5
4/02/00	M 1.905	M 1.760	Downstream	Gentle – moderate	-1.5
5/02/00	M 1.905	M 1.835	Downstream	Moderate	-2
6/02/00	M 1.940	M 1.805	Downstream	Gentle	-1
7/02/00	M 1.915	M 1.730	Downstream	Very gentle	-0.5

Vasse Floodgates DATE	Upstream Depth Observed	Downstream Depth Observed	Flow Direction Observed	Flow Rate Observed	Flow Rating
8/02/00	M 1.910	M 1.720	Downstream	Gentle	-1
9/02/00	M 1.925	M 1.770	None	No discernible flow	0
10/02/00	M 1.945	M 1.850	Downstream	Gentle	-1
11/02/00	M 1.950	M 1.870	Downstream	Gentle	-1
12/02/00	M 1.960	M 1.880	Downstream	Gentle	-1
13/02/00	M 1.985	M 1.810	None	No discernible flow	0
14/02/00	M 1.960	M 1.730	Upstream	Gentle	1
15/02/00	M 1.970	M 1.775	Upstream	Gentle	1
16/02/00	M 1.975	M 1.855	Downstream	Very Gentle	-0.5
17/02/00	M 1.980	M 1.840	Downstream	Gentle leakage	-1
18/02/00	M 1.970	M 1.825	Downstream	Moderate leakage	-2
19/02/00	M 1.980	M 1.890	Downstream	Moderate	-2
20/02/00	M 1.995	M 1.850	Downstream	Moderate leakage	-2
21/02/00	M 2.000	M 1.680	Upstream	Gentle	1
22/02/00	M 1.995	M 1.660	Upstream	Moderate leakage	2
23/02/00	M 2.010	M 1.635	Upstream	Moderate - fast leakage	2.5
24/02/00	M 2.010	M 1.720	Upstream	Moderate leakage	2
25/02/00	M 2.010	M 1.865	Downstream	Gentle leakage	-1
26/02/00	M 2.025	M 1.920	Downstream	Fast leakage	-3
27/02/00	M 2.030	M 1.880	Downstream	Moderate leakage	-2
28/02/00	M 2.040	M 1.810	None	No discernible flow	0
29/02/00	M 2.040	M 1.690	Upstream	Moderate to fast	2.5
2/03/00	M 2.030	M 1.860	None	No discernible flow	0
4/03/00	M 2.045	M 1.920	Downstream	Moderate	-2
6/03/00	M 2.070	M 1.610	Upstream	Moderate	2
8/03/00	M 2.075	M 1.510	Upstream	Fast leakage	3
10/03/00	M 2.030	M 1.700	Upstream	Gentle to moderate	1.5
12/03/00	M 2.040	M 1.650	Upstream	Moderate	2
14/03/00	M 2.050	M 1.860	None	No discernible flow	0
16/03/00	M 2.060	M 1.760	Upstream	Gentle	1
18/03/00	M 2.055	M 1.870	None	No discernible flow	0
20/03/00	M 2.075	M 1.615	Upstream	Fast leakage	3
22/03/00	M 2.055	M 1.600	Upstream	Fast leakage	3
24/03/00	M 2.060	M 1.550	Upstream	Fast leakage	3
26/03/00	M 2.050	M 1.550	Upstream	Fast leakage	3
28/03/00	M 2.065	M 1.710	Upstream	Moderate	2
30/03/00	M 2.055	M 1.710	Upstream	Moderate	2
1/04/00	M 2.060	M 1.595	Upstream	Moderate	2
3/04/00	M 2.055	M 1.620	Upstream	Moderate	2
5/04/00	M 2.055	M 1.600	Upstream	Moderate	2
7/04/00	M 2.070	0.6	Upstream	Very fast	3
9/04/00	M 2.070	0.5	Upstream	Very fast	3
11/04/00	M 2.080	0.55	Upstream	Very fast	3
13/04/00	M 2.055	0.47	Upstream	Moderate to fast	2.5
15/04/00	M 2.070	0.26	Upstream	Gentle to moderate	1.5

PLEASE NOTE: M refers to a depth measurement taken from a specific point to the water surface, these are not calibrated depths. All other readings are depths (m AHD) read from the installed gauge boards.

Appendix 4: Water Quality Upstream of the Vasse Floodgates

Vasse Upstream DATE	Colour	Scum	Clarity	Clarity Rating	Comments
16/12/99	Pea-soup green		Poor	1	
18/12/99	Bright pea green		Poor	1	
20/12/99	Bright pea green	Golf ball size balls of spongy deep green and black scum at floodgate boards	Poor - very poor	0.5	
22/12/99	Khaki green		Poor	1	
24/12/99	Pea-soup green	1m x 1m patches of Ruppia matting with light brown spongy scum at FG and along banks	Very poor	0	
26/12/99	Olive green	Small amount of Ruppia matting with brown and green spongy scum and white froth on surface	Poor	1	
28/12/99	Light olive green		Poor	1	
30/12/99	Khaki brown		Poor	1	
2/01/00	Light olive (bright)	Small amount of olive coloured scum on surface at FG; in corner under tree, upstream, large patch of bright green very soupy scum	Poor	1	Bubbles rising at FG
3/01/00	Olive brown		Moderate	2	Appears to be clearing up; green bloom in corner no longer there
4/01/00	Olive brown		Poor	1	Few bubbles rising around pylons
5/01/00	Pea green	Khaki green scum on surface at FG boards	Very poor	0	Swirls of green phytoplankton visible on surface at FGs
6/01/00	Bright pea green	Small amount of brown filamentous scum with bubbles rising 10m upstream of FGs; blue-green coloured spongy scum on the surface at FGs	Very poor	0	Very thick and soupy looking; filamentous spirals of phytoplankton visible; area of filamentous, soupy bloom is confined from FG to 5m upstream and appears to have been blown against the FG boards – yesterday was the first real seabreeze in weeks
7/01/00	Dark green		Very poor	0	Very thick, stringy and soupy looking for 5m upstream of the FG
8/01/00	Bright green	Dark green spongy scum with bubbles on the surface to 15m upstream and across both banks	Very poor	0	Very visible swirls of dark green phytoplankton; this is the first day that the bloom has reduced the visibility to zero; water very thick and soupy for 15m upstream of the FG

Vasse Upstream DATE	Colour	Scum	Clarity	Clarity Rating	Comments
9/01/00	Bright green/dark green swirls	Spongy khaki scum with white froth all around edges	Very poor	0	Bubbles rising, bloom looks like light and dark green marbled paper, confined to 25m upstream
10/01/00	Bright green with dark green swirls	Large patches of khaki brown very bubbly/spongy scum on surface with white bubbles all around edges	Very poor	0	Bloom is noticeably extending up the channel
11/01/00	Bright green with dark green swirls		Very poor	0	Visible bloom confined to 30m upstream of FG only – looks very marbled and is criss-crossed by bird or fish tracks; surface scum has disappeared (fresh seabreeze yesterday); some white bubbles on surface
12/01/00	Bright green and darker green mottled	Small amount of spongy scum and a small amount of Ruppia at FG; few bubbles rising	Very poor	0	Very mottled looking
13/01/00	Bright green		Very poor	0	No surface scum - all homogenous
14/01/00	Bright green		Very poor	0	all homogenous in colour and texture; estuary smells on leeward shore
15/01/00	Bright green		Very poor	0	
16/01/00	Bright green with pale green surface film		Very poor	0	Bloom looks like an oily paint skin blown up against FG
17/01/00	Bright green	Small patches of spongy green scum surrounded by white foam bubbles at FG	Very poor	0	
18/01/00	Bright green	Dark khaki spongy mats (surrounded by bubbles) on surface to 30m upstream	Very poor	0	Nil visibility
19/01/00	Green	Large khaki/brown spongy sediment mats on the surface – thick from FG to 30m upstream	Very poor	0	Nil visibility; lots of bubbles on surface with scum mats
20/01/00	Bright green	Small amount of spongy green scum in corner of bay	Very poor	0	Mostly homogenous looking, although slight swirls of phytoplankton visible in the soup
21/01/00	Bright green		Very poor	0	all homogenous - no swirls or scum visible
22/01/00	Bright pea green		Very poor	0	
23/01/00	Olive green		Poor - very poor	0.5	Not quite as bright as it has been - all homogenous - can see about 2" into water instead of nil

Vasse Upstream DATE	Colour	Scum	Clarity	Clarity Rating	Comments
24/01/00	Bright green mottled with lighter green phytoplankton dots	Small patches (triangles) of spongy dark khaki scum at FG	Very poor	0	Most severe to 25m upstream and bay on north bank
25/01/00	Khaki green (very dark) mottled with lighter patches		Very poor	0	Looks like a thick colloid with phytoplankton flocculating together – thick and soupy - looks darker - not usual bright green
26/01/00	Dark khaki		Poor	1	Looks like it might be clearing - looks better today than in December
27/01/00	Khaki green		Poor	1	Colour is the same as the inlet - definitely appears to be improving
28/01/00	Dark khaki	Very small amount of Ruppia at FG	Poor	1	
29/01/00	Dark olive/brown	2 by 3m patch of dark brown crusty scum at FG - looks like sediment surface has risen	Poor	1	Some Ruppia scum also
30/01/00	Dark khaki with bright olive green swirls and patches at FG	Green and black spongy scum on surface for 4m upstream of FG	Very poor	0	Lots of bubbles on surface – looks like bloom beginning again – phytoplankton swirls visible in water column again
31/01/00	Bright and dark green	Thick and chunky spongy bright and dark green scum on surface to 70m upstream	Very poor	0	Nil visibility - thickest at FG to 10m upstream (looks like blocks of sponge) - bright green phytoplankton between darker spongy bits
1/02/00	Kaleidoscope of colours	Patches of khaki, teal green, bright green, olive green, brown, and pale brown spongy scum and thick mat on surface	Very poor	0	Lots of bubbles and froth on surface - worst it has looked all summer
2/02/00	Dark khaki with floccules of pale green phytoplankton	Kaleidoscope of olive, cyan, khaki, bright green, teal green	Very poor	0	Bloom confined to 10m upstream and along north bank for > 100m upstream; patches of scum up channel for 100m;
3/02/00	Very dark olive/khaki	Spongy olive brown/bright green and dark brown spongy scum, very thick at FG, along banks and in patches for 80m upstream	Very poor	0	
4/02/00	Very dark khaki	Cyan/bright teal green/brown scum and small fluffy clumps of green algae in the water column	Very poor	0	

Vasse Upstream DATE	Colour	Scum	Clarity	Clarity Rating	Comments
5/02/00	Dark khaki with small flecks of pale green clumps of phytoplankton (size of 10 cent piece)	Confined to small patch on SE end of FG	Poor	1	
6/02/00	Very dark khaki/brown	Only very small amounts of scum remain	Poor	1	
7/02/00	Very dark khaki/brown		Poor	1	No surface scum left
8/02/00	Dark khaki/brown		Poor	1	Hard to tell colour; overcast and little light
9/02/00	Dark khaki/brown		Poor	1	Residual bubbles/froth right at floodgates
10/02/00	Brown		Poor to very poor	0.5	Some residual bubbles and froth on surface
11/02/00	Pale brown		Poor	1	2ft wide line of froth on surface along north bank
12/02/00	Olive brown		Poor	1	Clarity improving on last 2 days; small amount of froth on north bank
13/02/00	Olive brown		Poor	1	
14/02/00	Olive brown		Poor to moderate	1.5	Bubbles on surface at FG, bank of North bay and to ~15m upstream
15/02/00	Olive brown		Moderate to good	2.5	Froth on surface; occasional bubbles rising; sulphur smell along North bank
16/02/00	Dark khaki - clear		Very good	4	Very clear - can see bottom on north bank – small bubbles on surface of water for at least 200m up the channel
17/02/00	Dark khaki		Moderate	2	Froth at FG
18/02/00	Dark khaki	Bright olive brown and pale cream frothy scum building up against FG boards, thick to the pylons; looks very marbled with many bubbles on the top	Poor	1	Scum looks similar to stuff floating at Estuary View Drive but slightly more green and frothy
19/02/00	Olive brown/khaki		Moderate to good	2.5	All the scum from yesterday has gone - small amount of bubbles on north bank; can see bottom along south bank
20/02/00			Moderate	2	Too dark to really see colour or clarity - bubbles on surface along N bank from FG to 120m upstream

Vasse Upstream DATE	Colour	Scum	Clarity	Clarity Rating	Comments
21/02/00	Dark khaki	Small amount of dark brown spongy scum (sediment surface?) floating at FG and along N bank (2 - 4m wide for about 120m upstream); small patches of bubbles rising around FG structures	Moderate	2	
22/02/00	Khaki brown	Large chunks of patchy coloured (pale to dark brown) shiny/spongy scum at FG – smaller patches to 20 m upstream; surface of water covered in bubbles - worst to 20 m upstream	Moderate	2	
23/02/00	Dark khaki	Large amounts of patchy coloured (pale-dark brown) lumpy/spongy scum at FG and more 200m+ upstream	Moderate	2	Bubbles rising at FG, bubbles on surface for 200m+ upstream
24/02/00	Dark khaki	Small chunks of spongy brown scum at FG and corner of bay only;	Moderate	2	Bubbles rising at FG – thick for about 10m upstream - thick also along N bank (1-2m wide) - small patches of bubbles on surface for 200m+ upstream
25/02/00	Pale milky green	Small amount of very dark brown spongy scum near some bays of FG	Moderate	2	Notable colour change at FG - bloom beginning again perhaps
26/02/00	Khaki green		Poor	1	Looks thicker than the last few days – sulphurous smell upstream on S bank
27/02/00	Bright olive green		Poor - very poor	0.5	Bloom visibly thickening in vicinity of FG - appears homogenous thick green with a slightly thicker band to ~5m upstream
28/02/00	Olive green	Very small patches of dark brown spongy scum on surface at FG	Poor	1	Sediments near S bank smell very sulphurous
29/02/00	Pea green (slightly cloudy)		Moderate	2	Bubbles on surface along N bank - appears to be clearer than yesterday – can see ~30-40cm into the water
2/03/00	Milky pale green		Moderate	2	Water column appears to be clearing slightly more – can see bottom for 4-5m wide strip along S bank
4/03/00	Dark khaki		Moderate	2	Not as bright as previous few days
6/03/00	Khaki		Moderate	2	Sediments along S bank very black; few bubbles rising at FG
8/03/00	Khaki green		Moderate	2	Appears a little clearer than 4 days ago

Vasse Upstream DATE	Colour	Scum	Clarity	Clarity Rating	Comments
10/03/00	Milky pea green		Moderate	2	
12/03/00	Milky pea green		Moderate to poor	1.5	Estuary really smells today
14/03/00	Milky green		Moderate	2	Sediments along both banks very black with pale green slime 'peeling off' in places; small patches of bubbles on surface along n bank for 100m+ upstream
16/03/00	Pale milky green		Poor	1	Bubbles on surface of water to 100m+ upstream
18/03/00	Milky green		Moderate	2	Bubbles on surface along N bank for 150m+ upstream
20/03/00	Milky green		Moderate	2	No bubbles on surface; sediments look very dark grey and black
22/03/00	Bright pea green		Moderate	2	Slightly milky still; bubbles on surface along N bank
24/03/00	Milky pea green	Very small amount of patchy and thin pale brown film on surface near N side of FG	Moderate	2	Bubbles on surface along N bank
26/03/00	Pea green		Moderate	2	No scum or bubbles
28/03/00	Bright green		Moderate	2	Bubbles along N bank
30/03/00	Milky pea green	Oily film with a small amount of pale brown and dark brown thin scum on surface - most in bay on N bank; some brown stringy scum around FG pylons as well	Moderate to poor	1.5	Bubbles along N bank – water quality notably deteriorated today
1/04/00	Khaki green		Poor	1	Small amount of bubbles along bank
3/04/00	Dark khaki		Moderate	2	No scum or bubbles
5/04/00	Khaki green		Moderate	2	
7/04/00	Looks very dark	Small amount of pale brown scum on bank margins - no scum on water surface	Moderate	2	May look dark because can see the bottom (black sediments) slightly today maybe
9/04/00	Khaki/olive green	Bubbles and pale brown stringy scum along N bank	Good	3	Water clearer upstream due to very strong leakage upstream for 3 days due to exceptionally high tides
11/04/00	Khaki		Good	3	Clearest it has been all summer - like when the fish died; no scum - can see things on the bottom in the channel as well as along the banks – sediments look dark
13/04/00	Green		Good	3	Clearest yet - no scum or bubbles - estuary very smelly today
15/04/00	Pale green	Very small amount of pale brown scum at FG with a few bubbles	Moderate	2	

Appendix 5: Water Quality Downstream of the Vasse Floodgates

Vasse Downstream DATE	Colour	Clarity	Clarity Rating	Comments
16/12/99	Light olive green	Poor	1	
18/12/99	Olive green	Poor	1	
20/12/99	Pea-soup green	Poor	1	
22/12/99	Olive green	Poor	1	
24/12/99	Coppery brown	Moderate	2	
26/12/99	Olive green	Moderate - poor	1.5	
28/12/99	Dark khaki green	Moderate - good	2.5	
30/12/99	Bright green	Moderate	2	
2/01/00	Khaki green	Good	3	
3/01/00	Light khaki green	Moderate - good	2.5	
4/01/00	Khaki green	Good	3	
5/01/00	Khaki green	Moderate - good	2.5	
6/01/00	Khaki green	Moderate - good	2.5	
7/01/00	Dark khaki green	Good	3	Clarity and colour appear very different in the early morning light
8/01/00	Dark khaki	Good	3	Water cloudy with phytoplankton cells visible in the immediate vicinity of FG due to leakage flow from upstream
9/01/00	Khaki green	Moderate	2	Very noticable plume of bright green phytoplankton leaking through FG is reducing clarity
10/01/00	Khaki green	Moderate	2	Visibility poor in immediate vicinity of floodgates due to leakage from upstream
11/01/00	Dark khaki green	Moderate	2	
12/01/00	Khaki green	Moderate	2	
13/01/00	Khaki green	Moderate - good	2.5	
14/01/00	Dark khaki	Moderate	2	Clouds and wind make it difficult to see water quality and fish
15/01/00	Khaki green	good - very good	3.5	
16/01/00	Khaki brown	Moderate	2	Very visible dots of green phytoplankton in the lee of FG
17/01/00	Khaki green/brown	Moderate - good	2.5	
18/01/00	Khaki	Good	3	
19/01/00	Khaki green	Good	3	
20/01/00	Khaki green	Good	3	Moderate in immediate vicinity of FG due to leakage from upstream
21/01/00	Khaki green	Moderate	2	Difficult to see because it is overcast
22/01/00	Khaki	Good	3	Moderate in immediate vicinity of FG due to leakage from upstream
23/01/00	Khaki green	Moderate	2	Overcast - makes it more difficult to see into water
24/01/00	Khaki	Moderate	2	
25/01/00	Khaki	Moderate - good	2.5	
26/01/00	Khaki	Moderate	2	
27/01/00	Khaki	Good	3	

Vasse Downstream DATE	Colour	Clarity	Clarity Rating	Comments
28/01/00	Khaki green	Good	3	
29/01/00	Khaki green	Good	3	
30/01/00	Dark khaki	Very good	4	
31/01/00	Khaki	Very good	4	
1/02/00	Khaki	Very good	4	
2/02/00	Clear	Very good	4	
3/02/00	muddy khaki	Good	3	Moderate in immediate vicinity of FG due to leakage from upstream
4/02/00	Dark khaki	Moderate	2	Some scum washing through reverse valve
5/02/00	Dark khaki	Moderate	2	
6/02/00	Dark khaki	Moderate	2	
7/02/00	Very dark khaki	Moderate to good	2.5	
8/02/00	Khaki green	Moderate	2	
9/02/00	murky khaki	Moderate	2	
10/02/00	Khaki green (tinge of brown)	Moderate to poor	1.5	
11/02/00	Khaki brown	Poor	1	Clarity poor in immediate vicinity of FG
12/02/00	Olive brown	Moderate	2	
13/02/00	Olive khaki	Moderate to good	2.5	
14/02/00	Khaki	Moderate	2	
15/02/00	Khaki green	Moderate	2	
16/02/00	Khaki	Moderate	2	
17/02/00	Olive brown	Moderate	2	
18/02/00		good - very good	3.5	
19/02/00	Khaki green	Moderate	2	
20/02/00		Good	3	
21/02/00	Olive green	Moderate	2	Brighter than upstream
22/02/00	Khaki green	Moderate - good	2.5	
23/02/00	Khaki green	Moderate	2	
24/02/00	Very clear	Very good	4	
25/02/00	Very clear	Very good	4	
26/02/00	Bright green	Poor	1	
27/02/00	Olive green	Poor	1	Visibility slightly better than upstream
28/02/00	Very clear	Very good	4	Must have flushed well with the tide since yesterday – dramatic improvement
29/02/00	Very clear	Very good	4	Bubbles on surface along N bank for >300m downstream – thick in the bay just downstream of the FG
2/03/00	Very clear	Very good	4	
4/03/00	Khaki	Good	3	Moderate at FG due to leakage from upstream
6/03/00	Khaki	Good	3	
8/03/00	Khaki green	Moderate - good	2.5	
10/03/00	Very clear	Very good	4	
12/03/00	milky pale green	Moderate to good	2.5	Clarity worst in immediate vicinity of FG due to leakage from upstream

Vasse Downstream DATE	Colour	Clarity	Clarity Rating	Comments
14/03/00	Clear	Very good	4	Patches of bubbles on surface in middle of channel and along N bank 200m downstream
16/03/00	Very clear	Very good	4	
18/03/00	Very clear	Very good	4	
20/03/00	Very clear	Very good	4	
22/03/00	Very clear	Very good	4	
24/03/00	Olive green	Very good	4	Bubbles along N bank
26/03/00	Very clear	Very good	4	
28/03/00	Very clear	Very good	4	
30/03/00	Very clear	Very good	4	
1/04/00	Khaki green	Moderate	2	Small amount of bubbles in patches to 200m downstream
3/04/00	Khaki	Good	3	
5/04/00	Khaki	Good	3	
7/04/00	Khaki	Very good	4	Small amount of stringy brown scum with white froth along shore of bay (windward shore)
9/04/00	Khaki	Good	3	Bubbles and pale brown stringy scum along N bank for 200m+ downstream
11/04/00	Khaki green	Moderate to good	2.5	Small dots of brown phytoplankton in water column - small amount of pale brown stringy scum blown down to FG by wind
13/04/00	Khaki	Good	3	Bubbles all along N bank
15/04/00	Khaki	Good	3	

Appendix 6: Fish Activity and Behaviour at the Vasse Floodgates

Vasse Floodgates DATE	Activity Rating Upstream	Upstream Behaviour Observed	Activity Rating Downstream	Downstream Behaviour Observed
16/12/99	1	Limited activity, few rises visible immediately upstream of floodgates	0	No visible activity
18/12/99	1	1 large fish swirl below surface, no other activity	1	Tens of thousands of inch long juvenile fish actively swimming in a dense school in leakage flow from upstream; few small active fish swirls below surface in bay on N side; 1 fish flash ~ 10cm fish
20/12/99	0	1 dead mullet on bank - partly decomposed; no visible fish activity	0	Tens of thousands of inch long juvenile fish in a dense packed school from FG boards to past old jetty; no visible larger fish activity
22/12/99	1	Few small swirls under surface	2	Small school of fish (<10) swimming below surface - ripples visible; school of fish swimming actively below surface in bay on N side; thousands of inch long juvenile fish darting around in leakage flow at FG boards
24/12/99	1	1 surface swirl	0	Hundreds of inch long juvenile fish darting around in all directions in shade of FG; no larger fish activity
26/12/99	0	Tens of inch long juvenile fish actively swimming alongside fringing vegetation 50m upstream; no larger fish activity	4	Hundreds of ~10cm long fish schooling in a tight vortex, swimming very fast at FG; school of tens of mullet - actively swirling below the surface and surfacing 10m upstream, some ~10-15cm long mullet jumping; school of tens of 10cm long fish swimming in tight circles; school of tens of mullet swimming in tight arcs
28/12/99	0	No visible activity	3	Tens of thousands of inch long juvenile fish in a dense packed school from FG boards to past old jetty, all slow moving facing south bank - no leakage out; few >40cm mullet swimming slowly around bay; 2 schools of tens of 15-35cm mullet surfacing, swirling under surface, and jumping around margins of bay; 4 herring in bay
30/12/99	2	Very large splashes; wakes of large fish darting around below surface; few small surface rings; school of tens of fish visible as ripples under surface; cormorant catching 4 - 5 cm long fish.	0	Hundreds of inch long juvenile fish at FG; no larger fish activity
2/01/00	0	No visible activity	3	School of hundreds of mullet jumping, splashing and swirling under surface; thousands of inch long fish swimming slowly behind FG and under old bridge

Vasse Floodgates DATE	Activity Rating Upstream	Upstream Behaviour Observed	Activity Rating Downstream	Downstream Behaviour Observed
3/01/00	1	Sporadic small swirls below surface; a few inch long fish around pylons and bank moving fast; 1 large fish swirl and splash; 1 large mullet >40cm swimming fast below surface	4	~60 mullet 15-25cm schooling slowly around behind FG boards; several schools of ~50-150 mullet 15-30cm long actively swimming; 1 larger fish predating the edge of a school (bream)
4/01/00	2	Several fast swirls below surface 10 – 50m upstream; several ripples below surface - fast moving fish 30m upstream; several schools of tens of mullet 15cm long, swimming very fast below surface 10 - 15m upstream;	4	Thousands of inch long juvenile fish swimming against FG and banks (for cover?); 4 schools of tens of mullet splashing, regularly surfacing and swimming fast below surface 10 - 50m upstream; small mullet jumping regularly everywhere from 10-200m+ upstream;
5/01/00	0	No visible activity	3	~40 mullet <10cm swimming in tight circles against each other at FGs; ~100 mullet schooling and surfacing at FGs; ~200-300 10cm long mullet schooling in the bay on the north bank
6/01/00	0	No visible activity	3	Fish jumping and splashing in bay; many surface rings in the channel to 300m upstream; ~30 mullet 15cm long jumping and splashing 10m upstream; hundreds of 6-10cm long fish in bay slowly schooling and surfacing; tens of thousands of inch long fish in bay
7/01/00	0	No visible activity	4	Several hundred mullet (15-25cm long) surfacing and splashing 10m downstream of the FG; tens of thousands of inch long fish swimming vigorously in the leakage flow from upstream; many fish jumping downstream as if being predated
8/01/00	0	No visible activity	4	Several schools of hundreds of mullet (>100 >20cm long) surfacing, splashing, and jumping 10-100m+ downstream; tens of thousands of inch long fish around FG and old bridge being heavily predated
9/01/00	0	1 dead mullet (~20cm long) floating 10 m upstream; no visible fish activity	4	Tens of thousands of inch long juvenile fish actively swimming in a dense school in leakage flow from upstream; hundreds of 15-20cm long mullet jumping, splashing and surfacing from 10-150m downstream - up to 20 surface rings visible at any time; more than 500 mullet (15-20cm) swimming with their heads just at the surface in a school ~ 30m downstream

Vasse Floodgates DATE	Activity Rating Upstream	Upstream Behaviour Observed	Activity Rating Downstream	Downstream Behaviour Observed
10/01/00	0	No visible activity	4	Hundreds of mullet (to 20cm) splashing and surfacing from 10-200m downstream; ~ 100 20cm long mullet jumping, splashing and surfacing en masse (looks like feeding) 10 m downstream of FG; tens of thousands of inch long juvenile fish swimming in leakage flow from upstream;
11/01/00	0	No visible activity	3	Many mullet > 20cm long jumping and splashing from FG to 100m downstream; several schools of tens of small mullet (<10cm long) swimimng under surface and jumping 10m downstream;
12/01/00	0	No visible activity	2	Tens of thousands of inch to two inch long juvenile fish being predated (jumping en masse) 10m downstream in shallows; flashes of several larger fish in Deadwater bay; mullet jumping very sporadically;
13/01/00	0	No visible activity	2	Mullet (~15cm long) jumping sporadically (one at a time) ~50m downstream; hundreds of inch long juvenile fish schooling behind FG
14/01/00	0	No visible activity	2	Occasional ~10-15cm mullet jumping 20-50m downstream (wind chop makes it difficult to see fish)
15/01/00	0	No visible activity	4	Mullet (10 - 20cm long) jumping and splashing everywhere from FG to 200m downstream; most activity downstream of old bridge; flashes of bream (~30cm long) around old bridge pylons
16/01/00	0	No visible activity	4	Mullet (10-20cm long) jumping everywhere from FG to 50m downstream (6 to 10 fish visible at any time); 3 very large mullet (>50cm long) swimming just below surface; flashes of bream on bottom at FG
17/01/00	0	No visible activity	4	Mullet (10-20cm long) jumping everywhere from FG to 200m downstream (6 to 10 fish visible at any time); tens of thousands of inch long juvenile fish in leakage flow form upstream; hundreds of mullet (>20cm long) surfacing near old bridge;
18/01/00	0	No visible activity	4	Mullet jumping everywhere from FG to 300m upstream; tens of thousands of inch long juvenile fish in leakage flow;
19/01/00	0	No visible activity	4	Mullet (<20 cm long) jumping everywhere from FG to 100m downstream (more than 15 visible at any time - surface rings everywhere); tens of thousands of inch long fish 'pinheads' in leakage flow;

Vasse Floodgates DATE	Activity Rating Upstream	Upstream Behaviour Observed	Activity Rating Downstream	Downstream Behaviour Observed
20/01/00	0	No visible activity	4	Mullet jumping from 20-200m downstream (~5 at one time); school of tens of 15cm long mullet schooling below surface downstream of old bridge;
21/01/00	0	No visible activity	2	Very few swirls below surface and mullet jumping
22/01/00	0	No visible activity	1	Few sporadic rises and swirls under surface
23/01/00	0	No visible activity	2	Thousands of pinheads in leakage flow; very sporadic surface swirls and surface rings
24/01/00	0	No visible activity	2	Sporadic surface rings down channel, from FG to 200m downstream; ripples of small fish schools below surface visible; thousands of pinheads jumping en masse in leakage flow;
25/01/00	0	No visible activity	2	Tens of thousands of juvenile fish < 2" long in leakage flow from upstream – dense for 10m; several large, sporadic fish swirls below surface and splashes, 30m downstream;
26/01/00	0	No visible activity	2	Tens of thousands of pinheads stirring up surface from FG to old bridge; sporadic surface swirls
27/01/00	2	Ripples of several fish schools; flashes of fish ~ 30cm at FG; couple of fish jumping	1	One mullet jumping at FG boards; thousands of pinheads in leakage flow – difficult to see activity because so choppy
28/01/00	2	Mullet sporadically jumping, splashing, swirling and swimming fast under surface from FG to 50m upstream	1	Couple of surface splashes
29/01/00	3	Mullet regularly jumping from 10 to 100m upstream - several jumps at once (20-30cm fish); school of tens of big mullet (>40cm long) darting around below surface around FG pylons;	0	Hundreds of pinheads at FG; no other activity
30/01/00	1	1 mullet jump, 1 splash	2	Flashes of large bream feeding on bridge pylons; infrequent mullet splashes 50-100m downstream; few small surfaces 10 m downstream
31/01/00	2	Ripples of small school of mullet, occasionally jumping and surfacing just upstream of the edge of the scum patch	2	Sporadic small surface rings in bay; several small bream feeding on each pylon
1/02/00	2	Sporadic mullet rises and jumps >50m upstream - on edge of algal scum	2	~ 20 black bream schooling right at gaps between FG bays; mullet sporadically rising from 20-200m+ upstream; pinheads behind FG;

Vasse Floodgates DATE	Activity Rating Upstream	Upstream Behaviour Observed	Activity Rating Downstream	Downstream Behaviour Observed
2/02/00	4	Fish surfacing everywhere; small mullet jumping regularly 20-200m + upstream; up to five surface rings visible at any time; large wake and ripples	2	> 40 large black bream around pylons of old bridge and behind FG; occasional surface splash 20-40m upstream
3/02/00	4	Thousands of fish present in channel - mullet jumping everywhere and many active fast swirls under surface, large schools of fish from 10-200m+ upstream – many around 15-20cm long	3	Thousands of pinheads and tens of black bream around pylons; ~ 100 15cm long mullet schooling and jumping 10 m downstream
4/02/00	4	Mullet jumping regularly 10-200m upstream, mostly 15-20cm long, at least 5 fish visible at any time	3	~ 30 black bream seething right behind reverse valve; schools of tens of small mullet (~10 cm long) near FG; occasional but regular mullet surfaces ~ 200m downstream
5/02/00	4	Mullet schooling, breaking surface and jumping regularly from 10-200m upstream - >6 rings visible at any one time	4	Mullet jumping everywhere 100-200m downstream; many splashes and surface rings visible; ripples of fast activity
6/02/00	4	Mullet jumping and splashing vigorously everywhere from 5-200m upstream; lots of activity 5-50m upstream; large ripples of big school 5m upstream	2	10s of bream in outflow with 100s of pinheads; occasional mullet splash
7/02/00	4	Mullet jumping regularly 10 - 150m upstream; mostly small fish (<15cm); small ripples; mostly individual fish seen, no large school movements	2	10s of black bream around pylons; no other fish
8/02/00	4	Mullet jumping and splashing everywhere from 5-100m upstream; large swirls; fast movements of many fish under surface; at least 3-4 surface rings and splashes visible at once	2	10s of black bream around pylons; no other fish
9/02/00	4	Occasional but regular splashes of mullet jumping and surfacing 10-50m upstream; large school of hundreds of mullet darting fast below surface	2	~10 30cm black bream swimming against gaps in FG and along pylons; very occasional mullet swirl
10/02/00	4	Mullet (mostly small <15cm) jumping everywhere from 10-300m upstream; regular splashes - at least 2 or 3 visible at any one time	3	Mullet jumping regularly 300m downstream; very sporadic swirls in bay
11/02/00	3	Sporadic mullet jumping and surfacing 10-50m downstream	3	Very occasional surface rings and sporadic mullet jumps 20-300m downstream
12/02/00	2	Ripples of small fish schools 80-100m upstream; egrets and cormorants catching small fish along banks 100m upstream; mullet jumping very occasionally 20-40m downstream	3	Regular mullet jumps 20-200m+ downstream; flashes of black bream right in leakage flow upstream

- The kill occurred 13 days after the floodgates were last opened to release fish, following a severe bloom of blue-green algae. Water quality appeared to visibly improve following the opening on February 3.
- In the week prior to the kill, water quality in the estuary appeared to have been the best it had been since early December. The water was becoming clearer, and appeared a coppery-brown to olive colour.
- Bubbles and residual froth on the water surface was observed in the immediate vicinity of the floodgates (to 30 m upstream and along banks) for several days before the kill.
- On the morning of the kill the water clarity was so good that the bottom was visible along the banks, the sediment appeared black, and a sulpherous smell was observed close to the north bank. Bubbles were rising at the floodgates.
- The water in the Inlet (i.e. downstream of the floodgates) appeared much greener, the clarity was moderate (less than 2 foot visibility), and phytoplankton cells were visible in the water column.

Likely cause of fish deaths

- Deoxygenation of the water appears to have been the cause of the fish deaths. As the water clarity had greatly improved since the fish release conducted on February 3, it is likely that deoxygenation was caused by algal bloom decay, in conjunction with night-time respiration of phytoplankton, (which had been steadily increasing in density at the floodgates due to the considerable tidal leakage of water from the inlet, which was visibly experiencing an algal bloom at the time). Respiration by the tens of thousands of fish present early on the Tuesday morning would also have contributed to the lowering of oxygen levels.
- Observations made the previous afternoon indicate that fish were already oxygen stressed during the afternoon. Leakage in of water from downstream was very rapid during the afternoon, due to the high head of water in the inlet. This would have oxygenated the water in the immediate vicinity of the floodgates. As DO levels are rarely observed to fall below 50% saturation during the day (due to phytoplankton photosynthesis – often causing supersaturation upstream of the floodgates), it is likely that the rate of benthic decay, and thus BOD, was extremely high the previous afternoon.
- The BOD alone may not have been sufficient to deoxygenate the water to critical levels, however, when combined with night-time respiration of the phytoplankton, appears to have lowered the DO to critical levels early on the morning of the 15th.
- When critical conditions were reached, the conditions were calm (no wind at all), and leakage into the estuary from upstream (which also oxygenates the water) had ceased several hours earlier.
- The fish deaths occurred in a very short space of time (all before the floodgates were opened), and those fish that had not already died appeared to rapidly recover as the sun rose (photosynthetic oxygenation of the water was occurring), and the breeze freshened (oxygenates the water). It appeared that critical levels of DO were overcome, and the fish were recovering, before the floodgates were opened. It is likely that the number of deaths on the Tuesday morning was not reduced by the opening of the floodgates at 0800 hrs. However the opening may have prevented the death of many more fish on subsequent mornings by allowing the escape of survivors.

Vasse Floodgates DATE	Activity Rating Upstream	Upstream Behaviour Observed	Activity Rating Downstream	Downstream Behaviour Observed
13/02/00	3	Mullet jumping regularly and swirling under surface 10-200m upstream; only 1 or 2 visible at a time; gaps of a couple of seconds in between; mostly small fish	3	Mullet regularly jumping and swirling under surface from FG to 200m + downstream; > 20 black bream swimming nose to the gap in FG where the reverse flap is open
14/02/00	4	Many schools of tiny fish (pinheads) breaking the surface and jumping en masse; looks like a fast spray of drops across the surface; at least 7 or 8 sprays at any time from FG to 250m+ upstream; appears like a very active feeding frenzy going on; regular mullet jumps from FG to 250m upstream	2	>50 black bream nose to the gap in the FG boards where leaking upstream; no other fish activity
15/02/00	-4	Thousands of fish schooling from FG to 200m+ upstream; flapping on surface, jumping upside down, floating then sinking belly up; flapping on surface sideways; trying to put head above water; very stressed; several dozen dead and many more dying; throwing themselves against FG	3	Mullet regularly jumping 300m+ downstream
16/02/00	2	Mullet jumping 100m downstream; cormorants catching small mullet 100m downstream		Not recorded
17/02/00	0	No visible activity	3	>50 black bream nose to the gap in the FG boards in leakage flow from upstream; small mullet jumping right behind FG boards occasionally; ~ 200 small mullet (~15cm long) schooling between bridge and FG
18/02/00	2	Very occasional mullet splashes 20 – 30 m upstream; 15 <2" long fish floating dead in corner near guage board	3	Tens of black bream together with ~ 300 mullet schooling behind FG where reverse flap is open, in the leakage flow from upstream, some mullet jumping right out of the water at the FG; no activity further up the channel
19/02/00	3	Occasional mullet jumping and surfacing 20-50 m upstream; fast splashes, one or two a minute then none for a couple of minutes	3	School of tens of fish swimming slowly below the surface at the FG; couple of splashes right at bay where leakage from upstream is; regular jumps and splashes 200m + downstream
20/02/00	0	No visible activity	4	Mullet jumping and rising to the surface very regularly from 30 to 250m + upstream; > 50 black bream in leakage flow; ~100 mullet (about 15cm long) schooling behind FG
21/02/00	3	Small mullet (~15cm long) jumping and splashing regularly from 100-300m upstream (a couple every minute)	4	Schools of tens of mullet jumping in small bay 20m downstream; large schools of mullet jumping and surfacing from 100-300m downstream (4 or 5 at any time)

Vasse Floodgates DATE	Activity Rating Upstream	Upstream Behaviour Observed	Activity Rating Downstream	Downstream Behaviour Observed
22/02/00	3	Mullet jumping and surfacing regularly 200m+ upstream - one or two visible every minute	4	Many mullet jumping and surfacing from 30-250m+ upstream - several visible at any moment; no activity near FGs
23/02/00	2	Very occasional mullet surface/splash 250m upstream – one every minute or so	3	Mullet jumping and surfacing regularly 100m+ downstream - several each minute; several schools of tens of small mullet rippling surface in bay
24/02/00	2	Mullet surfacing and jumping sporadically 250m upstream (one splach every couple of minutes); 1 mullet surface 20m upstream	3	~20-30 small mullet schooling at FG; mullet surfacing regularly 300m+ downstream; ~30 black bream at gaps between FG bays and around old bridge pylons
25/02/00	3	Wake of a large fish or fish school 20m upstream; very occasional mullet jump and splash 250m+ upstream (one or two every minute or two)	4	~100 mullet nosing hard up against FG at reverse flap valve, where leakage downstream is greatest - mostly nosing under surface - very occasionally surfacing; regular mullet jumps and surface splashes 200m+ downstream (several visible at any time)
26/02/00	4	Mullet sporadically jumping, splashing and surfacing at FG-30m upstream and also 200m upstream; many flashes of large school of big mullet (20-25cm long) darting fast below surface 5m upstream	4	>200 mullet (~20cm long) seething in a mass in the leakage flow from upstream – looks like they want to go upstream!!! Swimming fast - many flashes and splashes
27/02/00	2	Mullet irregularly surfacing and jumping 300m+ upstream (one or two every couple of minutes); 1 large, fast swirl under the surface 20m upstream; no other activity	4	~500-1000 juvenile black bream (<15cm long) swimming slowly in leakage flow and around bridge pylons; several schools of hundreds of mullet schooling in tight circles behind floodgates - shrimps jumping out of the water between the schools of fish; several thousand fish present in the channel from the FG to 300m+ downstream - very high activity - mullet surfacing, jumping and splashing very regularly - 2 or 3 visible at any time
28/02/00	4	Regular surface rises and small fish jumping from 20-200m+ upstream - at least 5 surface rings visible at any time - activity more frequent 100m+ upstream	4	Mullet jumping and surfacing regularly from FG to 200m upstream - at least five surface rings visible at any time; ~100 black bream (~15-20cm long) nosing in against gap in FG bays where reverse flap is
29/02/00	4	Small mullet gently surfacing and swirling under the surface from 20-300m+ upstream - few fish jumping or splashing; many fish present - at least five rings visible at once in each 100m of channel; occasional splash and jump – becoming more frequent	4	Mullet surfacing from 30-300m downstream; surface rings visible everywhere - more further downstream; occasional jump and splash; tens of black bream along FG and around pylons (mostly ~15cm long)

Vasse Floodgates DATE	Activity Rating Upstream	Upstream Behaviour Observed	Activity Rating Downstream	Downstream Behaviour Observed
2/03/00	0	Few small pinheads jumping individually 50-100m upstream; also small rises - only very small fish visible	3	~80 black bream (10-20cm long) swimming in gaps at FG; ~100 mullet chopping up surface along south bank 20m downstream; mullet occasionally surfacing and jumping 200m+ downstream
4/03/00	3	Occasional mullet surfacing and jumping from FG-200m+ upstream - one or two every couple of minutes	3	Seething mass of small mullet, ~500 (around 15cm long), at FG bay where leakage from upstream is greatest (reverse flap) - swimming hard up against boards into flow, with their heads at or above the surface (not gasping) - looks like they really want to go back upstream; occasional jump and splash around 20m downstream
6/03/00	2	Flashes of a school of ~40 mullet swimming fast below surface 5m upstream; no fish jumping further upstream; thousands of pinheads and palaemonid shrimps at FG	3	Mullet jumping regularly 200m+ downstream; no activity at FG; few small splashes 30m downstream; tens of black bream around FG and bridge pylons
8/03/00	4	Large numbers of mullet schooling upstream of FG; at least three schools of 500-1000 mullet (~15-30cm long) swimming fast below surface from 5-50m upstream – many fast flashes visible, many jumping and surfacing en masse; mullet jumping everywhere up the estuary channel, to 200m+ upstream (at least 5 visible at any time)	4	Mullet jumping very regularly 200m+ downstream - at least five visible at any time
10/03/00	3	Mullet jumping occasionally 250m+ upstream (a couple each minute); one very fast splash at surface near FG	4	Mullet regularly jumping 25-250m+ downstream (several visible at any time); large school of mullet swimming just below surface and surfacing 25m downstream
12/03/00	2	Very occasional surfaces 200m+ upstream - couple of fish jumping and then none for a couple of minutes	3	Regular mullet jumps and surfaces 200m+ downstream - 3 to 4 visible some minutes and then none at times
14/03/00	4	Mullet regularly jumping and splashing from FG to 200m+ upstream - mostly small fish; >10 fish visible at any time - very active	4	~150 black bream nosing hard up against gaps in FG bay where reverse flap is; mullet regularly jumping 100m+ downstream, mostly small fish - several visible at any time
16/03/00	4	Mullet swirling under surface, splashing and jumping from 5 to 200m+ upstream - at least 10 to 20 fish visible at any time; all mullet jumping are small <15cm long; very active	4	Many mullet jumping and surfacing 200m+ downstream (in front of Lockeville)

Vasse Floodgates DATE	Activity Rating Upstream	Upstream Behaviour Observed	Activity Rating Downstream	Downstream Behaviour Observed
18/03/00	4	~1000 big mullet (25cm+ long) milling slowly below surface around FG pylons; mullet jumping regularly 150m+ upstream - several visible at a time - mostly small fish; regular surface splashes (one to five a minute) 20-50m upstream;	4	Mullet regularly jumping, splashing and surfacing 200m+ downstream; ~100 bream at FG and around pylons
20/03/00	2	Very intermittent jumps and surface rises by mullet 70-200m upstream; long periods when nothing visible	2	Couple of small schools (40-60 fish) of 15cm long mullet, schooling below surface (not rising) around old bridge; very occasional splash 150m downstream
22/03/00	3	Regular rises and surfaces from 20-200m+ upstream - about one or two a minute; large school (200+) of large mullet schooling fast below surface at FG - many fast flashes visible	3	Regular surfaces and occasional mullet jumping from 20-200m downstream - 4 or 5 each minute;
24/03/00	4	Thousands of mullet (around 25cm long) schooling below surface behind FG pylons visible as fast flashes - moderate to fast movement but not surfacing or jumping; smaller mullet surfacing and jumping regularly from 20-150m upstream - 6 to 10 fish visible at any time	3	Mullet regularly jumping 100m+ downstream - 6 to 8 per minute
26/03/00	2	Very occasional surface rings visible 20-100m upstream; no other fish activity, no fish jumping at all	3	School of ~200 mullet swimming just below surface, little black dots of noses just breaking surface, not gasping or stressed - appear to be feeding - darting around and wriggling fast 20m upstream; no other activity
28/03/00	3	Large school of mullet (about 25cm long) swimming back and forth across channel parallel to FG, 10-20m upstream - visible by flashes, fast moving, not surfacing or jumping; occasional fish surfacing and jumping 150m+ upstream - 2 or 3 each minute	3	~300 small mullet swimming with just the tip of their noses above the water (not stressed or gasping); occasional mullet jumping 150m+ upstream
30/03/00	3	School of hundreds of mullet (20-25cm long) darting around below surface under mat of algal scum at FG - swimming very fast, surfacing and jumping; mullet surfacing, rising and jumping regularly in channel from FG to 200m upstream - >12 each minute	4	Mullet regularly jumping and surfacing 150m+ downstream; school of about 250 mullet swimming in a tight pack with just their nose tips (maybe some fin tips) above the surface of the water, occasional small splashes, 20m downstream
1/04/00	2	Irregular surfaces and fast swirls below surface from 40-200m upstream - no fish jumping; ripples of fish moving fast below surface 50m upstream	3	Mullet jumping regularly 100m+ downstream; ~200 mullet (15cm long) swimming with the tips of their noses at surface, occasionally jumping; black bream around old bridge pylons

Vasse Floodgates DATE	Activity Rating Upstream	Upstream Behaviour Observed	Activity Rating Downstream	Downstream Behaviour Observed
3/04/00	3	Irregular mullet surfaces, jumps and splashes from 25-250m upstream – two or three visible each minute	3	School of ~50 2" long juvenile fish at FG; regular surfaces and splashes 100m downstream - up to 8 or 9 a minute
5/04/00	3	Irregular mullet jumps 150m+ upstream - several fish jumping then none for a minute or two; sporadic surface splashes 50-100m upstream; water surface very choppy, makes it difficult to see fish	4	Mullet jumping regularly 150m+ downstream - >5 each minute
7/04/00	4	Regular surfaces and jumps by mullet from 10-250m+ upstream – several every minute; surface ripples of several fish schools darting around very fast 10-15m upstream – where leakage of seawater is like a waterfall	4	Thousands of mullet 25cm+ long, schooling downstream from FG to at least 30m downstream - all swimming slowly below surface, turning on their side (flashing), and circling in dense schools - obviously want to go upstream with the very high tide; occasional mullet jumps and splashes 100m+ downstream as well
9/04/00	3	Occasional mullet surfacing and jumping from FG to 200m+ upstream - around 5 a minute visible	4	School of about 1000 mullet swimming with the tips of their noses above water, 20m downstream; mullet regularly jumping down channel
11/04/00	1	Couple of surface swirls 25m upstream; no other activity - water surface very choppy due to strong wind	2	Very sporadic splash at surface 100m+ downstream; no more than 2 a minute
13/04/00	4	Schools of hundreds of mullet (many >40cm, most > 20cm long) swimming fast below surface from FG to 50m+ upstream - many flashes visible but no surface activity; many small mullet regularly jumping and splashing 150m upstream	4	Several schools of hundreds of mullet swimming with the tips of their noses at the surface (not gasping) in dense schools in the bay on N bank; mullet regularly surfacing and jumping 20-250m+ downstream
15/04/00	3	Large schools of mullet swimming fast under surface - large ripples, occasional surfaces, splashes and fish jumping from 10-250m+ upstream	4	School of thousands of small mullet (<10cm long) swimming in a dens school with just their noses on the surface, occasionally rising and splashing; thousands of mullet in the channel - regularly rising, splashing and jumping from 20-250m+ downstream; hundreds of pinheads schooling on surface near bridge

Appendix 7: Waterbird Abundance Upstream of the Vasse Floodgates

Vasse Floodgates Upstream / DATE	Black Swan	Pacific Black Duck	Musk Duck	Hardhead ducks	All Ducks	Darter	Little Pied Cormorant	Little Black Cormorant	All Cormorants	Pelican	Nankeen Night Heron	White-faced Heron	Great Egret	Australian White Ibis	Yellow-billed Spoonbill	Silver Gull	Purple Swamphen	Dusky Moorhen	Caspian Tern	Common Tern	White-bellied Sea Eagle	TOTAL
16/12/99						1	1	1														3
18/12/99						1																1
20/12/99								1														1
22/12/99								1														1
24/12/99					10			3														13
26/12/99								1				1										2
28/12/99						1							1									2
30/12/99	7				7	1	1	1														17
2/01/00						1		2				1										4
3/01/00						1	1	1					1									4
4/01/00							1	1			1		1									4
5/01/00							1	1			1											3
6/01/00		3				1		2					1									7
7/01/00	3				1					6			1	1								12
8/01/00		4						1														5
9/01/00					4			1														5
10/01/00		2																				2
11/01/00																						0
12/01/00													1	1								2
13/01/00							1					1		3								5
14/01/00		4	3			1	9							1								18
15/01/00							3	2														5
16/01/00						1	4					1	2		1							9
17/01/00					9		2															11
18/01/00																						0
19/01/00					2		1								1							4
20/01/00										1												1
21/01/00			2				3	2						2								9
22/01/00			3			2	2			1			1									9
23/01/00			8				8	1				1		2	4							24
24/01/00			2			1	12							2	3							20
25/01/00			4				4	1						1								10
26/01/00						1	6	1				1		1								10
27/01/00		4					7	4				1	1	1	1							19
28/01/00							8							2								10
29/01/00					6		6					1		2								15
30/01/00		5	2							1		1										9
31/01/00		6	1				1															8
1/02/00							2										2					4
2/02/00		2					3															5

Vasse Floodgates Upstream DATE	Black Swan	Pacific Black Duck	Musk Duck	Hardhead ducks	All Ducks	Darter	Little Pied Cormorant	Little Black Cormorant	All Cormorants	Pelican	Nankeen Night Heron	White-faced Heron	Great Egret	Australian White Ibis	Yellow-billed Spoonbill	Silver Gull	Purple Swamphen	Dusky Moorhen	Caspian Tern	Common Tern	White-bellied Sea Eagle	TOTAL
3/02/00		6					6			1												13
4/02/00							5															5
5/02/00		1					1			1		1	1									5
6/02/00		5					2										1					8
7/02/00							3	6		3		2					1					15
8/02/00							4					1										5
9/02/00							1			30												31
10/02/00							3	2														5
11/02/00		2				1	4			15			4									26
12/02/00		1				2		8		1		1	2						1			16
13/02/00			1						34													35
14/02/00							5					1					1					7
15/02/00					8											40			1		1	50
16/02/00			8					40	8	40			20			150			2	10		278
17/02/00							4	2		30		1		4								41
18/02/00		6					12			11												29
19/02/00	17		3	2													2					24
20/02/00	12						8			7							3					30
21/02/00	2	5					7	1		1		2					3					21
22/02/00	2		1						3			3										9
23/02/00	6																					6
24/02/00		3	2																			5
25/02/00		2					2	1					1									6
26/02/00							1															1
27/02/00		4		2			1	1				2			2		2					14
28/02/00		1					8					1		3	2							15
29/02/00							3			1		2					1					7
2/03/00		4	1				1				1				2							9
4/03/00		4					2					1			1							8
6/03/00		7					2	100		100	1	1	2					1				214
8/03/00		8					3			2	2	1	1	1								18
10/03/00			1				3					1	1			1						7
12/03/00	1	2	1				2			14	1											21
14/03/00	1	3	2				4			1	1	1	1			1		2				17
16/03/00							2				2	1	1				2					8
18/03/00		2	3				2			1	3	1				2						14
20/03/00	1		3				2			1		1				4						12
22/03/00	1		3				3			1	2					2						12
24/03/00	1		2				3			2		1				4	1					14
26/03/00						1	1			1		1				2						6
28/03/00			2				1					1										4
30/03/00	1		1				1										1					4

Vasse Floodgates Upstream DATE	Black Swan	Pacific Black Duck	Musk Duck	Hardhead ducks	All Ducks	Darter	Little Pied Cormorant	Little Black Cormorant	All Cormorants	Pelican	Nankeen Night Heron	White-faced Heron	Great Egret	Australian White Ibis	Yellow-billed Spoonbill	Silver Gull	Purple Swamphen	Dusky Moorhen	Caspian Tern	Common Tern	White-bellied Sea Eagle	TOTAL
1/04/00			2				4			1		1										8
3/04/00		3										1					2					6
5/04/00		5					3															8
7/04/00		7					2					1										10
9/04/00												1	1									2
11/04/00		2	2				5					1	1									11
13/04/00							1															1
15/04/00			1				1					1										3

Appendix 8: Waterbird Abundance Downstream of the Vasse Floodgates

Vasse Floodgates Downstream DATE	Pacific Black Duck	Musk Duck	All Ducks	Darter	Little Pied Cormorant	Little Black Cormorant	All Cormorants	Pelican	Nankeen Night Heron	White-faced Heron	Great Egret	Australian White Ibis	Silver Gull	Purple Swamphen	TOTAL
16/12/99				1											1
18/12/99						7		3							10
20/12/99	8	1													9
22/12/99						1									1
24/12/99						1									1
26/12/99						3					1				4
28/12/99						1									1
30/12/99															0
2/01/00															0
3/01/00															0
4/01/00															0
5/01/00															0
6/01/00					1	1									2
7/01/00															0
8/01/00					1					1	1				3
9/01/00															0
10/01/00								2			1				3
11/01/00		1													1
12/01/00															0
13/01/00					1										1
14/01/00										1	1				2
15/01/00										1					1
16/01/00															0
17/01/00				1											1
18/01/00												1			1
19/01/00															0
20/01/00											1	2			3
21/01/00	3			1				2							6
22/01/00					1						1	1			3
23/01/00				1							1				2
24/01/00					1					1	1				3
25/01/00					1			1		1	1				4
26/01/00	4				2	1		1							8
27/01/00								1			1				2
28/01/00					1						1				2
29/01/00															0
30/01/00															0
31/01/00								1							1
1/02/00															0
2/02/00															0

Vasse Floodgates Downstream DATE	Pacific Black Duck	Musk Duck	All Ducks	Darter	Little Pied Cormorant	Little Black Cormorant	All Cormorants	Pelican	Nankeen Night Heron	White-faced Heron	Great Egret	Australian White Ibis	Silver Gull	Purple Swamphen	TOTAL
3/02/00					1										1
4/02/00	1														1
5/02/00															0
6/02/00															0
7/02/00					1										1
8/02/00	2														2
9/02/00															0
10/02/00	2							2							4
11/02/00															0
12/02/00					1										1
13/02/00	1														1
14/02/00															0
15/02/00															0
16/02/00															0
17/02/00															0
18/02/00															0
19/02/00															0
20/02/00					1							2			3
21/02/00															0
22/02/00															0
23/02/00															0
24/02/00										1					1
25/02/00										1		2		2	5
26/02/00															0
27/02/00					1										1
28/02/00															0
29/02/00															0
2/03/00															0
4/03/00	2								1						3
6/03/00		1													1
8/03/00													3		3
10/03/00															0
12/03/00				1						1					2
14/03/00					1								1	1	3
16/03/00															0
18/03/00					1					1					2
20/03/00													1		1
22/03/00				1						1					2
24/03/00															0
26/03/00				1						1					2
28/03/00															0
30/03/00				1	1					1					3

Vasse Floodgates Downstream DATE	Pacific Black Duck	Musk Duck	All Ducks	Darter	Little Pied Cormorant	Little Black Cormorant	All Cormorants	Pelican	Nankeen Night Heron	White-faced Heron	Great Egret	Australian White Ibis	Silver Gull	Purple Swamphen	TOTAL
1/04/00				1											1
3/04/00			3	1											4
5/04/00				1											1
7/04/00				1											1
9/04/00				1											1
11/04/00				1											1
13/04/00															0
15/04/00															0

Appendix 9: Weather Conditions and Time of Inspections at the Wonnerup Floodgates

Wonnerup Floodgates DATE	Time	Wind Direction	Wind Strength	Cloud	Comments
16/12/99	1430	SE	Fresh		
18/12/99	1410	SW	Moderate		
20/12/99	1440	SW	Moderate		
22/12/99	1450	SW	Moderate		
24/12/99	1430	E	Moderate - Fresh		
26/12/99	1425	SW	Moderate		
28/12/99	1440	SW	Moderate		
30/12/99	1515	E	Fresh	100%	
2/01/00	1425	SE	Moderate - Fresh		
3/01/00	1425	NE	Fresh - Strong		
4/01/00	1400	NE	Light - Moderate		
5/01/00	1430	SW	Moderate - Fresh		
6/01/00	1430	NE	Light - Moderate		
7/01/00	645	E	Light - Moderate		
8/01/00	645		Calm		
9/01/00	655	E	Light		
10/01/00	645	SE	Light	Overcast	
11/01/00	630	SW	Calm - Very Light	Overcast	
12/01/00	650	SE	Moderate	Overcast	Cool wind
13/01/00	640	ENE	Moderate		
14/01/00	635	E	Strong		Unseasonal cold, windy and rainy day
15/01/00	640	SE	Moderate - Fresh	Overcast	Cold and rainy - wind to freshen
16/01/00	655	SE	Light		Heavy rain on the cape this morning - thousands of swallows flying around
17/01/00	640		Calm		
18/01/00	640	NE	Light		
19/01/00	635	SE	Light		
20/01/00	705	SE	Moderate		Wind freshening quickly
21/01/00	650	SE	Moderate - Fresh		
22/01/00	645	E/NE	Strong	Very overcast	Rainy
23/01/00	630	NE	Strong	Very overcast	Rain considerably yesterday
24/01/00	640	SE	Light		
25/01/00	640	SE	Light		
26/01/00	635	SE	Moderate		
27/01/00	655	E/NE	Fresh-Strong Gusts		Very choppy
28/01/00	640	NE	Fresh With Strong Gusts		
29/01/00	655	NE	Light - Moderate		Wind freshening
30/01/00	635	SE	Light - Moderate		
31/01/00	635	SE	Light		
1/02/00	715		Calm	Cloud cover rapidly increasing from the south	

Wonnerup Floodgates DATE	Time	Wind Direction	Wind Strength	Cloud	Comments
2/02/00	635	E	Calm - Very Light	Cloud on horizon - all directions	
3/02/00	645	E	Very Light		
4/02/00	655	S	Very Light		
5/02/00	635	SE	Light		
6/02/00	635	NE	Moderate		
7/02/00	634	NE	Light To Moderate	>95%	
8/02/00	645	S/SW	Strong	>90%	Some drizzle early this morning
9/02/00	645	SE	Moderate To Fresh	<5% cloud to south	Wind quickly freshening
10/02/00	705	E/SE	Light		
11/02/00	655	S/SE	Moderate		
12/02/00	655	E/NE	Fresh With Strong Gusts		
13/02/00	640	NE	Light		
14/02/00	700	SE	Light		
15/02/00	700	E	Light		
16/02/00	630		Calm		
17/02/00	650	SE	Light		
18/02/00	645	S/SE	Moderate - Fresh		
19/02/00	655	SE/S	Moderate		Icy cold wind - freshening
20/02/00	645	E	Moderate - Fresh Gusts		Choppy on upstream side
21/02/00	735	NE	Calm - Very Light		
22/02/00	655		Calm	~10%	Cloud cover increasing - already windy and raining in Dunsborough
23/02/00	740	NE	Light	>90%	
24/02/00	700		Calm		
25/02/00	700	SE	Calm - Light		
26/02/00	710		Calm		
27/02/00	710	NE	Light - Moderate		Wind quickly freshening
28/02/00	640		Calm	~20%	Cloud to the NE
29/02/00	650		Calm	70%	
2/03/00	645	E	Calm - Light	~40%	Cloud to the south
4/03/00	645	E	Moderate To Fresh		Freshening quickly - water surface very choppy
6/03/00	705	NE	Moderate		
8/03/00	730	E	Light To Moderate		
10/03/00	715	SE	Strong To Gale	100%	Raining - under influence of TC Steve
12/03/00	655	S/SE	Light To Moderate	100%	
14/03/00	710	E	Light		Wind freshening
16/03/00	700		Calm		
18/03/00	720	NE	Light To Moderate		
20/03/00	715	NE	Light To Moderate	20%	
22/03/00	655	E/SE	Calm - Very Light		
24/03/00	710	ENE	Light		

Wonnerup Floodgates DATE	Time	Wind Direction	Wind Strength	Cloud	Comments
26/03/00	710	S/SE	Light		
28/03/00	725	E	Calm - Very Light		
30/03/00	730	E	Very Light		
1/04/00	745	SE	Light - Moderate		
3/04/00	800	E	Fresh To Strong		Wind freshened fast
5/04/00	745	E/NE	Strong To Gale		Water surface very choppy
7/04/00	755	NE	Light	90%	Such a high tide that water is overtopping all stopboards - like a waterfall at each bay - storm surge?
9/04/00	755	E	Moderate		Very fast torrent of water leaking in again
11/04/00	755	N/NW	Fresh To Strong	70%	Raining
13/04/00	755	Variable	Calm - Light	70%	Front approaching from SW
15/04/00	740		Calm		

Appendix 10: Depth and Flow Measurements at the Wonnerup Floodgates

Wonnerup Floodgates DATE	Upstream Depth Observed	Downstream Depth Observed	Flow Direction Observed	Flow Rate Observed	Flow Rating
16/12/99	0.38	0.37	Downstream	Gentle leakage	-1
18/12/99	0.36	0.36	Upstream	Very gentle leakage	0.5
20/12/99	0.35	0.35	Upstream	Gentle to moderate (where stop boards missing)	1.5
22/12/99	0.35	0.35	Upstream	Very gentle leakage - may be wind driven	0.5
24/12/99	0.35	0.35	Upstream	Very gentle leakage	0.5
26/12/99	0.3	0.24	Downstream	Moderate leakage	-2
28/12/99	0.3	0.31	Downstream	Moderate leakage	-2
30/12/99	0.3	0.34	Upstream	Moderate leakage	2
2/01/00	0.36	0.4	Upstream	Fast leakage	3
3/01/00	0.26	0.3	Upstream	Moderate leakage	2
4/01/00	0.25	0.35	Upstream	Fast leakage	3
5/01/00	0.24	0.32	Upstream	Moderate leakage	2
6/01/00	0.23	0.3	Upstream	Gentle leakage	1
7/01/00	0.23	0.13	Downstream	Moderate leakage	-2
8/01/00	0.22	0.17	Downstream	Gentle leakage	-1
9/01/00	0.22	0.16	Downstream	Gentle leakage	-1
10/01/00	0.22	0.14	Downstream	Gentle leakage	-1
11/01/00	0.21	0.24	Upstream	Gentle leakage	1
12/01/00	0.19	0.28	Upstream	Gentle leakage	1
13/01/00	0.2	0.22	Upstream	Gentle leakage	1
14/01/00	0.19	0.22	Upstream	Gentle to moderate leakage	1.5
15/01/00	0.22	0.2	Downstream	Very gentle leakage	-0.5
16/01/00	0.21	0.22	Upstream	Gentle leakage	1
17/01/00	0.21	0.14	Downstream	Gentle leakage	-1
18/01/00	0.2	0.13	Downstream	Moderate leakage	-2
19/01/00	0.2	0.15	Downstream	Moderate leakage	-2
20/01/00	0.19	M 0.05	Downstream	Fast leakage	-3
21/01/00	0.18	M 1.310	Downstream	Moderate leakage	-2
22/01/00	0.2	M 1.265	Downstream	Moderate - fast	-2.5
23/01/00	0.21	M 1.190	Downstream	Moderate leakage	-2
24/01/00	0.17	M 1.150	Downstream	Gentle leakage	-1
25/01/00	0.16	M 1.170	Downstream	Gentle leakage	-1
26/01/00	0.15	M 1.120	Downstream	Very gentle leakage	-0.5
27/01/00	0.18	M 1.220	Downstream	Moderate	-2
28/01/00	0.16	M 1.170	Downstream	Moderate	-2
29/01/00	0.15	0.27	Upstream	Moderate leakage	2
30/01/00	0.13	0.25	Upstream	Gentle	1
31/01/00	0.15	0.28	Upstream	Moderate	2
1/02/00	0.14	M 1.070	Upstream	Gentle leakage	1
2/02/00	0.13	M 1.130	None	Slack water	0
3/02/00	0.13	M 1.155	Upstream	Very gentle	0.5
4/02/00	0.11	0.11	Downstream	Very gentle	-0.5
5/02/00	0.1	0.01	Downstream	Fast leakage	-3
6/02/00	0.1	0.06	Downstream	Moderate	-2

Wonnerup Floodgates DATE	Upstream Depth Observed	Downstream Depth Observed	Flow Direction Observed	Flow Rate Observed	Flow Rating
7/02/00	0.1	0.1	Upstream	Moderate	2
8/02/00	0.08	0.13	Upstream	Moderate	2
9/02/00	0.08	0.1	Upstream	Very gentle	0.5
10/02/00	0.07	0.03	Downstream	Gentle to moderate	-1.5
11/02/00	0.06	0	Downstream	Moderate	-2
12/02/00	0.07	M 1.310	Downstream	Fast leakage	-3
13/02/00	0.05	0.08	Upstream	Gentle	1
14/02/00	0.04	0.14	Upstream	Fast leakage	3
15/02/00	0.03	0.1	Upstream	Gentle leakage	1
16/02/00	0.03	M 1.250	Upstream	Very Gentle	0.5
17/02/00	0.02	0.04	Upstream	Very Gentle	0.5
18/02/00	0.02	M 1.250	Upstream	Gentle leakage	1
19/02/00	0.01	M 1.330	Downstream	Moderate - fast	-2.5
20/02/00	0.01	0	None	Not discernible	0
21/02/00	0	0.18	Upstream	Moderate leakage	2
22/02/00	0	0.1	Upstream	Moderate leakage	2
23/02/00	0	0.22	Upstream	Moderate - fast	2.5
24/02/00	0	0.1	Upstream	Moderate leakage	2
25/02/00	-0.02	0	None	not discernible	0
26/02/00	-0.02	-0.05	Downstream	Very gentle	-0.5
27/02/00	-0.02	0.02	Upstream	Very gentle leakage	0.5
28/02/00	-0.02	0.07	Upstream	Fast leakage	3
29/02/00	-0.03	0.2	Upstream	Fast leakage	3
2/03/00	-0.04	0.01	Upstream	Gentle - moderate leakage	1.5
4/03/00	-0.04	-0.07	Upstream	Gentle leakage	1
6/03/00	-0.03	0.25	Upstream	Moderate to fast	2.5
8/03/00	-0.04	0.38	Upstream	Fast leakage	3
10/03/00	-0.02	0.17	Upstream	Moderate to fast	2.5
12/03/00	-0.03	0.2	Upstream	Moderate to fast	2.5
14/03/00	-0.03	0.05	Upstream	Moderate leakage	2
16/03/00	-0.03	0.1	Upstream	Moderate	2
18/03/00	-0.04	0	Upstream	Gentle leakage	1
20/03/00	-0.04	0.26	Upstream	Fast leakage	3
22/03/00	-0.04	0.26	Upstream	Fast leakage	3
24/03/00	-0.04	0.35	Upstream	Fast leakage	3
26/03/00	-0.05	0.34	Upstream	Fast leakage	3
28/03/00	-0.04	0.17	Upstream	Fast leakage	3
30/03/00	-0.04	0.11	Upstream	Fast leakage	3
1/04/00	-0.04	0.3	Upstream	Very fast	3
3/04/00	-0.04	0.26	Upstream	Moderate	2
5/04/00	-0.02	0.24	Upstream	Fast leakage	3
7/04/00	-0.03	0.57	Upstream	Very Fast	3
9/04/00	-0.04	0.49	Upstream	Very fast	3
11/04/00	-0.04	0.53	Upstream	Very fast	3
13/04/00	-0.04	0.32	Upstream	Moderate	2
15/04/00	-0.03	0.24	Upstream	Gentle to moderate	1.5

PLEASE NOTE: M refers to a depth measurement taken from a specific point to the water surface, these are not calibrated depths. All other readings are depths (m AHD) read from the installed gauge boards.

Appendix 11: Water Quality Upstream of the Wonnerup Floodgates

Wonnerup Upstream Date	Colour	Scum	Clarity	Clarity Rating	Comments
16/12/99	Brown	Small amount of Ruppia matting at FG	Moderate to poor	1.5	
18/12/99	Brown - green		Poor	1	
20/12/99	Brown		Poor	1	
22/12/99	Brown - green		Moderate to poor	1.5	
24/12/99	Olive brown	Blue-green coloured spongy algal scum floating in water column alongside bank	Poor – very poor	0.5	
26/12/99	Olive brown	Some blue-green coloured spongy scum along banks – not on surface - floating mid-water	Poor	1	
28/12/99	Brown - green	Yellowy-green coloured filamentous growth on pylons, spongy green algal growth on banks	Poor	1	
30/12/99	Brown		Poor – very poor	0.5	
2/01/00	Brown - olive		Poor	1	
3/01/00	Light olive brown		Poor – very poor	0.5	
4/01/00	Brown		Poor	1	
5/01/00	Brown	Spongy scum below surface along both banks	Poor	1	
6/01/00	Brown	Spongy scum along banks	Poor	1	
7/01/00	Coppery brown	Some Ruppia scum at FG	Very poor	0	
8/01/00	Brown	Swirls of light brown and green scum on surface to 20m upstream - looks like marbled paint	Very poor	0	
9/01/00	Olive brown	Light green surface film – looks like green oil paint marbled over brown water	Very poor	0	Surface bloom confined to 10 m upstream of FG
10/01/00	Olive brown	Light green surface film – looks like green oil paint marbled over brown water; some Ruppia scum at FG	Very poor	0	Marbled bloom on surface to about 20 m upstream
11/01/00	Brown	Pale green surface film – looks marbled	Very poor	0	
12/01/00	Olive brown	Small amount of pale green surface film along east bank and corner of FG only	Very poor	0	
13/01/00	Olive brown		Very poor	0	No scum or phytoplankton swirls visible - all homogenous today
14/01/00	Olive brown		Very poor	0	

Wonnerup Upstream Date	Colour	Scum	Clarity	Clarity Rating	Comments
15/01/00	Olive brown		Poor - very poor	0.5	
16/01/00	Olive brown	Olive brown oily looking scum appearing on surface at FG and on leeward bank	Very poor	0	Nil visibility - water is mottled with dots of phytoplankton appearing
17/01/00	Khaki brown	Swirls of pale green/brown phytoplankton skin on surface - marbled and mottled looking	Very poor	0	Nil visibility - bloom thick for at least 50 m upstream – water starting to smell
18/01/00	Surface covered by shiny pale olive green oily surface film with small dark khaki patches		Zero visibility	0	Bloom confined to 10 m upstream of FG
19/01/00	Olive green/brown	Bright green surface film – looks like a paint skin	Very poor	0	Water looks more brown up channel and green at FG
20/01/00	Olive brown	Small amount of pale green/brown film on surface	Very poor	0	Nil visibility – phytoplankton swirls becoming visible
21/01/00	Brown		Very poor	0	Filamentous cladophora or chaetomorpha sp. on banks (ID: Dr. Anne Brearley UWA)
22/01/00	Khaki - brown		Very poor	0	Hard to see because its grey and overcast, very choppy
23/01/00	Olive brown		Poor - very poor	0.5	All homogenous after wind
24/01/00	Bright green	Phytoplankton flocculating together (wind is pushing up against FG) to form a surface film	Very poor	0	Nil visibility - bloom thickest for 10 m upstream
25/01/00	Dark khaki with large patches of pale green phytoplankton bloom	Pale green shiny film – looks like paint skin – where bloom has been blown up against FG	Very poor	0	Bloom most severe from FG to 15 m upstream – surface film confined to first 3 m only;
26/01/00	Olive green/brown		Poor	I	Clarity has improved - can see filamentous chlorophyte growth on pylons
27/01/00	Olive green		Poor - very poor	0.5	Can see about 10 cm into water - heavy algal growth on pylons and banks
28/01/00	Olive green	Dark green/black scum forming at FG and along banks	Poor	I	Considerable filamentous algal growth on pylons and along banks
29/01/00	Olive green	Bright green and olive spongy scum at FG and along banks	Poor	I	Small amount of Ruppia scum; huge amount of filamentous algal growth on submerged structures; water is clearing a little, although lots of phytoplankton cells still visible in water

Wonnerup Upstream Date	Colour	Scum	Clarity	Clarity Rating	Comments
30/01/00	Mostly olive green	Several types of scum visible: one produces olive green long strings (>30cm long and 2mm wide) against FG boards; another produces bright green paint-skin like film on surface; another produces bright green spongy scum along banks for > 25m and at FG;	Poor	1	Scum confined to 4 m upstream of FG; sediment surface appears to have also risen in small patches
31/01/00	Khaki	Bright green "paint skin" bloom forming against FG – small amount of dark khaki spongy scum around FG and along bank	Very poor	0	Bloom confined to 20 m upstream although skin on surface for only 3 m upstream
1/02/00	Olive green with bright green phytoplankton swirls		Poor - very poor	0.5	Thick for 20 m upstream
2/02/00	Dark khaki green	Bright green paint-like scum (some stringy) at FG;	Poor	1	Can see about 10 cm into water - spongy and filamentous algal growth on pylons and banks
3/02/00	Dark olive brown with pale green phytoplankton visible	Pale green strings or lines visible - perpendicular to wind as cells aggregate together	Poor	1	
4/02/00	Pale milky green		Moderate to good	2.5	Water much clearer on upstream side, clearest day this summer
5/02/00	Brown		Moderate	2	
6/02/00	Brown		Moderate	2	
7/02/00	Khaki		Moderate to good	2.5	
8/02/00	Olive brown		Moderate	2	
9/02/00	Olive brown		Moderate to poor	1.5	
10/02/00	Olive brown		Poor	1	Considerable filamentous green algal growth on pylons and banks; residual bubbles and froth on surface at FG; water quality rapidly deteriorating
11/02/00	Dark brown	Small amount of very stringy brown scum with froth on windward shore	Poor	1	
12/02/00	Olive brown		Moderate	2	Clarity improving slightly
13/02/00	Coppery brown		Moderate	2	
14/02/00	Olive green	Small amount of very stringy pale brown scum at FG only (looks like long spaghetti)	Moderate to good	2.5	Lots of bright green cyan filamentous algae growth on pylons (~20cm thick)

Wonnerup Upstream Date	Colour	Scum	Clarity	Clarity Rating	Comments
15/02/00	Olive brown		Moderate	2	
16/02/00	Khaki	Small amount of stringy brown scum	Good	3	Bubbles on surface for 40 m upstream; water slightly more cloudy on windward (NW) shore
17/02/00	Khaki green		Moderate	2	Froth collecting on surface in windward corner
18/02/00	Khaki green		Good	3	
19/02/00	Light khaki	Small amount of bubbles and long stringy brown scum in N corner	Good	3	
20/02/00	Milky khaki		Good	3	Small amount of bubbles on surface from FG to 5m upstream
21/02/00	Pale milky green		Very good	4	
22/02/00	Pale milky green		Very good	4	Can see bottom for a long way upstream - bubbles rising all along shores - fish oil all over surface at FG
23/02/00	Very clear		Very good	4	Bubbles on surface along banks (1-3 foot wide) for 200m upstream, and around FG and pylons
24/02/00	Pale khaki - very clear		Very good	4	Bubbles and beige/brown froth on water surface around FG - also all along banks
25/02/00	Pale milky green	Small amount of pale brown stringy scum at FG	Good	3	Bubbles on surface - thick at FG in gauge board corner
26/02/00	Milky khaki green		Good-very good	3.5	Small amount of froth in gauge board corner – greener than in previous days; Chris Webb (WRC Bunbury) and Jim Lane oxygen profile the channel today
27/02/00	Olive green		Moderate to good	2.5	Cloudy but can see shapes on bottom
28/02/00	Light olive green		Good	3	no bloom developing like at Vasse - can see fish and the bottom
29/02/00	Light olive		Good	3	Water surface looks very oily - smells fishy
2/03/00	Dark khaki		Moderate to good	2.5	Can only just see bottom today; bubbles on surface in gauge board corner
4/03/00	Dark khaki		Moderate	2	
6/03/00	Mostly clear but olive green tinge in places	Some Ruppia scum at FG	Good	3	Very clear where salt water leaking in
8/03/00	Light khaki	Some Ruppia scum at FG	Good to very good	3.5	Bright yellow-green filamentous algae growing attached along both banks

Wonnerup Upstream Date	Colour	Scum	Clarity	Clarity Rating	Comments
10/03/00	Olive green		Moderate	2	
12/03/00	Clear		Very good	4	Very clear because of a few days of fast leakage into the estuary?
14/03/00	Green		Good	3	Bubbles on surface in a dense band along FG for 3m upstream
16/03/00	Milky green		Good	3	Dense bubbles on surface from FG to 15m upstream
18/03/00	Pale milky khaki	Very small amount of shiny pale brown long stringy scum on surface at FG	Very good	4	Bubbles on surface at FG
20/03/00	Very clear (pale green tinge)		Very good	4	
22/03/00	Very clear		Very good	4	
24/03/00	Very clear	Spongy chlorophyte scum along banks	Very good	4	Residual froth and bubbles building up on surface at FG
26/03/00	Very clear (khaki tinge)		Very good	4	
28/03/00	Very clear	Small amount of brown stringy scum at FG	Very good	4	Small amount of bubbles at FG
30/03/00	Olive green	Small amount of brown stringy scum at FG - packs together to form an oily film - covered in bubbles	Very good	4	
1/04/00	Khaki	Film of brown stringy scum at FG	Moderate to good	2.5	Bubbles at FG
3/04/00	Khaki green		Good	3	No scum or bubbles
5/04/00	Light khaki tinge		Good	3	
7/04/00	Clear	Some small patches of light brown scum at FG	Very good	4	
9/04/00	Khaki	Thin surface film of pale brown stringy scum at FG	Good	3	Some Ruppia and spongy green algae scum along banks
11/04/00	Exceptionally clear		Very good	4	No scum at floodgates; spongy green chlorophyte for 1-2 foot along both banks
13/04/00	Light khaki		Very good	4	
15/04/00	Clear		Very good	4	

Appendix 12: Water Quality Downstream of the Wonnerup Floodgates

Wonnerup Downstream DATE	Colour	Scum	Clarity	Clarity Rating	Comments
16/12/99	Green - brown	Small amount of Ruppia matting at FG	Moderate	2	
18/12/99	Olive green		Moderate	2	
20/12/99	Green - brown		Moderate	2	
22/12/99	Brown - green		Moderate – poor	1.5	
24/12/99	Brown		Moderate	2	
26/12/99	Olive brown	Light chocolate brown scum on surface at FG	Moderate	2	
28/12/99	Khaki green	White and brown scum on surface	Good	3	
30/12/99	Khaki green		Moderate – good	2.5	
2/01/00	Khaki green		Good	3	
3/01/00	Light khaki green		Good	3	
4/01/00	Pale khaki		Good	3	
5/01/00	Pale milky green		Moderate	2	
6/01/00	Pale milky green		Moderate	2	
7/01/00	Cloudy khaki green		Moderate	2	
8/01/00	Dark khaki		Good	3	
9/01/00	Khaki green		Moderate	2	Visibility reduced by leakage of water from upstream
10/01/00	Khaki green		Poor – moderate	1.5	
11/01/00	N/a		N/a		
12/01/00	Khaki green		Good	3	
13/01/00	Khaki green		Good - very good	3.5	
14/01/00	Khaki brown		Good	3	
15/01/00	Clear		Very good	4	Can see details on bottom – even in shade
16/01/00	Khaki		Very good	4	
17/01/00			Good	3	Difficult to see colour
18/01/00	Khaki		Good	3	
19/01/00	Clear		Very good	4	
20/01/00	Dark khaki		Good	3	
21/01/00	Khaki		Good	3	moderate in immediate vicinity of FG due to leakage from upstream
22/01/00	Khaki		Good	3	moderate in immediate vicinity of FG due to leakage from upstream
23/01/00	Khaki brown		Moderate to good	2.5	
24/01/00	N/a		N/a		
25/01/00	Khaki		Good	3	
26/01/00	Khaki		Very good	4	

Wonnerup Downstream DATE	Colour	Scum	Clarity	Clarity Rating	Comments
27/01/00	Khaki green		Good	3	
28/01/00	Khaki green		Very good	4	
29/01/00	Clear		Very good	4	
30/01/00	Clear		Very good	4	
31/01/00	Khaki in shade		Very good	4	
1/02/00	Khaki		Very good	4	
2/02/00	Khaki		Very good	4	
3/02/00	Khaki		Very good	4	
4/02/00	Cloudy khaki green	Very small amount of shiny yellow-green coloured scum on surface at FG boards	Good	3	
5/02/00	Khaki		Moderate to good	2.5	
6/02/00	Dark khaki		Moderate to good	2.5	
7/02/00	Paler khaki		Very good	4	
8/02/00	Khaki green		Very good	4	
9/02/00	Milky khaki green (quite clear)		Very good	4	
10/02/00	Clear		Very good	4	
11/02/00	Murky khaki		Moderate	2	
12/02/00	Olive brown		Good	3	
13/02/00	Clear		Very good	4	
14/02/00	Clear		Very good	4	
15/02/00	Clear		Very good	4	
16/02/00	Very clear		Very good	4	
17/02/00	Very clear		Very good	4	
18/02/00	Very clear		Very good	4	
19/02/00	Very clear		Very good	4	
20/02/00	Very clear		Very good	4	
21/02/00	Milky green		Good	3	
22/02/00	Very clear		Very good	4	
23/02/00	Very clear		Very good	4	
24/02/00	Very clear		Very good	4	
25/02/00	Very clear		Very good	4	
26/02/00	Slightly cloudy green		Very good	4	
27/02/00	Very clear		Very good	4	
28/02/00	Olive green		Good	3	
29/02/00	Very clear		Very good	4	
2/03/00	Very clear		Very good	4	
4/03/00	Very clear		Very good	4	
6/03/00	Dark khaki		Good - very good	3.5	
8/03/00	Pale milky khaki		Good - very good	3.5	
10/03/00	Very clear		Very good	4	
12/03/00	Very clear		Very good	4	

Wonnerup Downstream DATE	Colour	Scum	Clarity	Clarity Rating	Comments
14/03/00	Green (tinge)		Very good	4	
16/03/00	Very clear		Very good	4	
18/03/00	Very clear		Very good	4	
20/03/00	Very clear		Very good	4	
22/03/00	Very clear		Very good	4	
24/03/00	Very clear		Very good	4	
26/03/00	Very clear		Very good	4	
28/03/00	Very clear		Very good	4	
30/03/00	Khaki green		Very good	4	
1/04/00	Milky green		Good	3	
3/04/00	Khaki		Very good	4	
5/04/00	Khaki		Very good	4	
7/04/00	Very clear		Very good	4	
9/04/00	Khaki	Very thin film of mottled pale brown scum at FG and under bridge	Very good	4	
11/04/00	Clear (khaki tinge)		Very good	4	
13/04/00	Clear		Very good	4	
15/04/00	Clear		Very good	4	

Appendix 13: Fish Activity and Behaviour at the Wonnerup Floodgates

Wonnerup Floodgates DATE	Activity Rating Upstream	Upstream Fish Behaviour	Activity Rating Downstream	Downstream Fish Behaviour
16/12/99	0	No visible activity	0	No visible activity
18/12/99	2	More than ten >40cm mullet, actively swimming, swirling under surface, from FG to 15m upstream, some have several scales missing; more than 50 ~10cm juvenile sea mullet actively feeding on visible schools of palaemonid shrimps at FG boards.	0	No visible activity
20/12/99	1	2 small swirls below surface at FG; 1 small swirl 15m upstream; hundreds of inch long juvenile fish schooling immediately behind FG boards; hundreds of palaemonid shrimp visible at FG boards also; 1 larger fish swirl	0	Hundreds of inch long juvenile fish schooling tightly in shade of bridge; no larger fish activity
22/12/99	2	School of tens of mullet <15cm, sporadically swirling fast under surface; Water Corp technicians working on FG may have scared the fish away.	2	Few larger fish swirls under surface downstream of bridge
24/12/99	0	2 juvenile fish swimming around pylons; no larger fish activity	3	Hundreds of inch long juvenile fish swimming slowly in shade of bridge; school hundreds of mullet feeding on bottom at bridge; 1 mullet jumping in Deadwater Bay
26/12/99	1	1 ~15cm mullet swirling below surface; 1 ~10cm mullet jumping; 1 swirl below surface; few inch long fry in shade of gates	2	Tens of thousands of inch long fry darting around in all directions from FG to 10m downstream of bridge; school of tens of 20cm long mullet actively swimming
28/12/99	1	Large fish swirl below surface at FG; surface splash at FG; 1 large mullet swimming fast below surface; many inch long juvenile fry at FG boards	3	School of hundreds of 15-20cm long fish downstream of bridge
30/12/99	0	No visible activity	3	Tens of inch long juvenile fish slowly schooling behind FG (swimming parallel to boards, very slow); 2 x schools of hundreds of mullet 10 – 15cm long lying still ~1 foot below surface (off bridge); occasional flash visible
2/01/00	1	School of tens of 15cm long mullet darting under surface 10m upstream.	3	Tens of thousands of inch long juvenile fish from FG back to past the bridge swimming slowly around; tens of bream lolling around bridge pylons; school of tens of mullet surfacing and splashing 15m downstream

Wonnerup Floodgates DATE	Activity Rating Upstream	Upstream Fish Behaviour	Activity Rating Downstream	Downstream Fish Behaviour
3/01/00	0	No visible activity	4	Tens of thousands of inch long juvenile schooling very slowly at FG and in shade of bridge; tens of bream feeding (probably on palaemonid shrimps) around pylons of bridge; several schools tens to hundreds of mullet in deadwater bay and shallows upstream of bridge; school of ~20 10cm long fish with black tail tips - look like herring
4/01/00	2	Sporadic surfaces 10 - 20m upstream; several fish moving fast below surface - visible as ripples;~15 10-15cm mullet darting back and forth below surface 20m upstream;	4	School (around 100) of juvenile tailor chasing mullet and smaller fish in shallows 20m downstream; mullet jumping everywhere; hundreds of 15cm long mullet swimming under bridge; tens of thousands of inch long juvenile fish swimming against FG; thousands of 8-10cm long mullet schooling, jumping and splashing in shallows 20m downstream;
5/01/00	0	No visible activity	3	1 30cm bream flash at FGs; tens of thousands of inch long fish at FG boards and under bridge; ~100 6-10cm mullet swimming parallel to FGs; several mullet jumping; ~20 10-15cm long tailor darting up from bottom near bridge; ~20cm long mullet surfacing near banks 30m downstream.
6/01/00	0	No visible activity	0	Tens of thousands of inch long fish from FG to the other side of the bridge; no adult fish activity although choppy water surface makes it difficult to see
7/01/00	0	No visible activity	4	Thousands of inch long fish swimming actively in leakage flow; hundreds of small mullet (10-15cm long) jumping and splashing (several at a time) everywhere in shallows downstream
8/01/00	1	Few sporadic swirls below surface, one at a time	4	Thousands of inch long fish in leakage flow; more than 100 large mullet (>20cm) swimming slowly under surface 10m downstream; several schools of hundreds of small mullet (<10cm) surfacing and splashing in shallows downstream of bridge; many small mullet jumping in Deadwater bay
9/01/00	0	No visible activity	4	Tens of thousands of inch long juvenile fish in leakage flow from upstream; several schools of less than 100 mullet in each, different size classes in different schools (schools of ~6cm, 15cm and 25 cm long fish), surfacing sporadically and swimming fast below the surface; smaller mullet splashing and surfacing in shallows;

Wonnerup Floodgates DATE	Activity Rating Upstream	Upstream Fish Behaviour	Activity Rating Downstream	Downstream Fish Behaviour
10/01/00	0	No visible activity	3	Sporadic mullet surfaces and splashes in Deadwater bay and for 50m upstream; more than 100 15cm long mullet surfacing 20m downstream; small fish (<10cm) jumping en masse;
11/01/00	0	No visible activity	3	Several schools of tens of small mullet (<10cm long) swimming fast below surface and sporadically surfacing and splashing form 10-100m downstream;
12/01/00	2	Sporadic swirls under surface and ripples of small fish school along SW bank	2	Flashes of small bream around bridge pylons; one mullet jumping at FG boards (trying to go upstream?); ripples of school of tens of small mullet 15m downstream; several small fish jumping around 60m downstream;
13/01/00	0	No visible activity	2	Hundreds of inch long juvenile fish behind FG - jumping en masse (being predated); 5 unidentified silver fish ~ 20cm long darting around below surface;
14/01/00	0	No visible activity	1	Large bream around bridge pylons; tens of thousands of inch long fish between FG and bridge
15/01/00	0	No visible activity	1	Tens of thousands of inch long fish swimming slowly between FG and bridge pylons; 1 larger fish (~ 40 cm – not mullet) darting across bottom
16/01/00	0	No visible activity	3	Tens of thousands of inch long fish behind FG; 6 large bream (20-30cm) around bridge pylons; ripples of fish school visible 50m downstream; very occasional fish swirl and jump 150m downstream
17/01/00	0	No visible activity	3	Sporadic small mullet jumping in Deadwater bay and 100m downstream; large school of 2 inch long fish jumping 50m downstream;
18/01/00	0	No visible activity	3	Schools of tens of small mullet (~10cm long) surfacing in shallows downstream of bridge; ripples of one fish school visible
19/01/00	0	No visible activity	4	Hundreds of mullet (15-20cm long) schooling on bottom, surfacing, and splashing in shallows 20-25m downstream; many small fish jumping in Deadwater bay; large wake/ripples of big fish school below surface
20/01/00	0	No visible activity	3	Small mullet (10-15cm long) jumping in Deadwater bay and in shallows to 150m downstream; ripples of several fish schools visible
21/01/00	0	No visible activity	2	Sporadic surface swirls only

Wonnerup Floodgates DATE	Activity Rating Upstream	Upstream Fish Behaviour	Activity Rating Downstream	Downstream Fish Behaviour
22/01/00	0	No visible activity	2	Tens of thousands of pinheads in leakage flow; sporadic ripples on surface of larger fish schools
23/01/00	0	No visible activity	2	Ripples of several fish schools visible – difficult to distinguish due to wind chop
24/01/00	0	No visible activity	3	Tens of thousands of pinheads in leakage flow; occasional surface rings and ripples of larger fish school visible; small mullet (<10cm) jumping 50m downstream
25/01/00	1	4 surface rings in 15 minutes	2	Ripples of school of mullet, occasionally jumping (small fish <10cm) and splashing 100m downstream;
26/01/00	0	No visible activity	2	Tens of thousands of pinheads behind FG and under bridge; ripples of several small fish schools 50-150m downstream; sporadic surface rings
27/01/00	0	No visible activity	2	School of tens of mullet jumping; sporadic surface rings and splashes around 50m downstream
28/01/00	0	No visible activity	3	Mullet jumping regularly 100m downstream - chop making it difficult to see fish
29/01/00	0	No visible activity	3	Splashes and fish jumping sporadically in Deadwater channel; small mullet very occasionally jumping 10 and 100m downstream; ripples of small school of fish visible 20m downstream; ~ 30 small tailor (juvenile - 15cm long) jumping away from predator en masse – 20m downstream;
30/01/00	2	Mullet surfacing and swirling under surface, 50m upstream; mullet jumping 10m upstream	3	Schools of tens of small mullet (~10cm long) surfacing in shallows downstream of bridge; regular rises 50-100m downstream
31/01/00	3	Mullet regularly jumping, surfacing and splashing from 20 to 50m upstream; school of tens of mullet breaking the surface en masse 10m upstream;	3	Large school of mullet regularly splashing and surfacing 20m downstream; school of hundreds of 10cm long mullet splashing and surfacing near bridge
1/02/00	3	Very large fish swirls below surface at FG; ~50 20-25 cm long mullet schooling fast through phytoplankton at FG; many very active swirls and ripples visible; mullet jumping occasionally up to 200m upstream	2	Mullet jumping sporadically from 50-200m+ downstream; several schools visible as surface ripples

Wonnerup Floodgates DATE	Activity Rating Upstream	Upstream Fish Behaviour	Activity Rating Downstream	Downstream Fish Behaviour
2/02/00	0	No visible activity	3	Several splashes and surfaces in Deadwater Bay; mullet jumping sporadically >100m downstream; schools of tens of small mullet jumping and swirling around under surface 30m downstream;
3/02/00	3	Mullet jumping sporadically 10-100m upstream, more frequently around 200m upstream	3	Mullet jumping and surfacing sporadically in Deadwater and along banks mostly; tens of small mullet actively swimming under surface
4/02/00	4	Greater than 300 20-50cm long mullet schooling very slowly along bottom - not surfacing; mullet jumping and surfacing regularly from floodgate to 300m upstream	4	100s of small tailor (to 15cm) schooling from bridge downstream; mullet jumping and surfacing regularly; 10s of black bream and sea trumpeter around pylons under bridge
5/02/00	2	Sporadic fish splashes; ripples of small schools	4	Mullet jumping, splashing, swirling fast under surface; several schools visible at once; fish being chased and chopping up surface in large schools
6/02/00	2	Occasional mullet splash 20-50m upstream	4	Swirls and surface ripples of several large schools of small mullet (<15cm long) mostly 20-50m downstream; several fast splashes or runs as if being chased
7/02/00	3	Mullet jumping sporadically; one school of ~10 >40cm mullet schooling at FG	3	Mullet jumping; school of ~20 small mullet jumping en masse; regular ripples and sprays as fish predated
8/02/00	2	~20 >40cm long mullet schooling around FG; particularly bay where stopboards are missing; no other fish activity	2	Ripples of large fish school visible in lee of wind
9/02/00	3	Sporadic mullet jumps and splashes 10-50m upstream; ~20 very large (30-40cm+) mullet schooling at FG bay with boards missing	2	Occasional mullet jumping and swirling fast under surface in Deadwater bay
10/02/00	4	Regular mullet jumps from FG to 250m+ upstream; one every five seconds or so; flashes of large school of mullet (~100) schooling below surface at FG	3	Mullet jumping regularly in Deadwater bay and from 20-150m + downstream; occasional whole school rippling up surface with fast movements 20-40m downstream in shallows
11/02/00	0	No visible activity	3	Small mullet schools rippling surface 100-150m downstream; occasional surface ring and splash and very small mullet jumping in shallows 30m downstream and in Deadwater bay
12/02/00	0	No visible activity	0	no visible activity
13/02/00	2	Flashes of ~20 mullet (25cm long) swimming fast under surface 3m upstream; very occasional mullet jump	2	Occasional mullet swirls and jumps in Deadwater bay; mostly small fish

Wonnerup Floodgates DATE	Activity Rating Upstream	Upstream Fish Behaviour	Activity Rating Downstream	Downstream Fish Behaviour
14/02/00	3	Occasional mullet splash, jump and swirl under surface from 30-80m upstream; ~100 mullet (~15cm long) schooling slowly at FG in saline in flow; ripples of mullet schools 200m upstream	3	~100 mullet (15-20cm long) jumping and swirling under surface in shallows and Deadwater bay; regular activity 30-100m downstream
15/02/00	2	Occasional mullet flash at FG in bay where boards missing; sporadic splash and jumps from FG-100m upstream	3	Regular mullet jumps in Deadwater bay and in shallows 50m downstream
16/02/00	3	~200 fish schooling in front of bay where boards missing - range in size from 15-40cm+; mullet occasionally breaking surface and jumping from 40-200m upstream	4	Mullet jumping underneath bridge regularly; tens of small mullet and yellow-tail perch schooling behind FG; many mullet regularly breaking surface and less frequently jumping in Deadwater Bay and 100m downstream
17/02/00	4	6-700 large mullet (~25cm long) schooling on bottom right at FG in bay where boards missing - not jumping - not breaking the surface; further along FG another 500 mullet (~15cm long) displaying same behaviour	4	Large schools of mullet rippling surface in deadwater bay and shallows just downstream of bridge; occasional jumps and splashes; wake of very large fish at bridge
18/02/00	3	~100 mullet (15-20cm long) schooling 10m upstream; very occasional mullet jumping and surfacing 100-200m upstream	3	~100 mullet schooling and splashing in shallows 30m downstream; schools of tens of small mullet swimming just under surface 10m downstream
19/02/00	3	Regular mullet jumping and splashing from 10-100m upstream mostly along SW bank - a couple jumping each minute	4	Mullet jumping under bridge; mullet splashes and surface rings in Deadwater bay and shallows on SW side 20-50m downstream
20/02/00	4	~1000 mullet >25cm long schooling along all bays of the FG, not jumping and not surfacing, swimming slowly; regular jumps and splashes from 10-200m upstream (several each minute)	3	Regular small mullet surfaces and jumps in Deadwater bay and shallows along both banks to 100m+ downstream
21/02/00	-3	>1000 large mullet (30cm + long) schooling in a seething mass at FG where boards missing and seawater leaking in; probably another 1000 milling around FG, none surfacing or splashing; very occasional splash (<1 every 3 or 4 minutes)	3	Schools of tens of mullet in shallows 30m downstream and in Deadwater bay

Wonnerup Floodgates DATE	Activity Rating Upstream	Upstream Fish Behaviour	Activity Rating Downstream	Downstream Fish Behaviour
22/02/00	-3	~800-1000 large mullet (>25cm – many 35cm+ long) milling around behind the FGs, occasionally breaking the surface with tails or fins; fish surfacing and jumping regularly (several visible at a time) from 10-250m+ upstream; by 7.15am mullet are seething in a mass nose to the FG boards (they definitely look like they want to go out) in one bay - thick enough to scoop up many with a scoop net; most activity seen here to date - thousands of large fish in the channel today, many hundreds of small fish as well	4	Several large schools of small mullet rippling surface and jumping in Deadwater bay and in shallows 20-150m upstream; tens of black bream around pylons and bridge structure
23/02/00	-3	Around 1000 mullet 20-30cm+ milling around FG and pylons, regularly splashing and surfacing, swimming vigorously from the FG to 200m+ upstream; ~100 large mullet nosing hard up against bay where stopboards are loose (the release bay) in a seething mass; Jim Black (local fisherman) caught 3 small bream from between the seething mass of mullet (who wouldn't take a bait) - all had very red gills	3	Ripples of several fish schools in shallows and in Deadwater bay; occasional mullet jumping
24/02/00	-3	>2000 mullet schooling at FG from (10-40cm+), surfacing and splashing regularly (several every minute); seething mass of the largest mullet (all 30cm+) at FG where seawater leaking upstream; large number of pinheads above FG also	4	Ripples of 6 large schools of fish below surface in shallows 60m+ downstream and in Deadwater bay; mullet regularly jumping and surfacing - many patches of fish visible at any time
25/02/00	-3	~200 large mullet (30cm+ long) milling slowly along the bottom between the pylons - not surfacing, not hard up against FG boards though either; ~200 small mullet (10-15cm long) swimming with their heads above the surface 4m upstream; tens of thousands of pinheads slowly milling on surface - occasional 'sprays' across surface becoming more regular; >5000 ~15cm long mullet milling slowly below the surface; many very small mullet heads on the surface to 100m upstream, no mullet jumping or surfacing at all; as wind freshens and surface of water becomes more rippled, number of heads above surface reduced and then stopped	4	Very small mullet regularly surfacing in Deadwater bay and in shallows for 200m upstream - most just surfacing only (not jumping or splashing) - more than 5 surface rings visible at any instant

Wonnerup Floodgates DATE	Activity Rating Upstream	Upstream Fish Behaviour	Activity Rating Downstream	Downstream Fish Behaviour
26/02/00	4	Behaviour much more active than the last few days - thousands of pinheads swimming slowly on surface at FG (short darts across surface); mullet regularly jumping from FG to 100m+ upstream (>12 per minute) - mostly very small fish (~15cm long) - very active looking; ~500-1000 mullet (~25cm long) schooling at FG pylons and swimming fast below the surface – many flashes;	2	Ripples of small mullet school in Deadwater entrance channel; no fish jumping or surfacing
27/02/00	4	~1000 mullet (around 15cm long) in two schools at FG and around pylons, occasionally breaking surface and splashing, swimming fast; pinheads swimming in short fast darts at FG	4	Mullet surfacing at FG; several small yellowtail perch near guage board; large school of mullet (thousands) rippling surface, rising, and splashing in shallows 50m downstream; regular rises (surfaces) in Deadwater bay (several each minute)
28/02/00	4	>2000 small mullet (~15cm long) and >200 small black bream swimming fast under surface - very actively - at FG and around pylons; many small mullet jumping and surfacing down the channel from the FG - 200m+ upstream - at least five surface rings visible at any time; no fish swimming right in fast leakage flow - much more active than last week	4	Mullet surfacing and jumping everywhere from FG to 200m+ downstream - greatest activity in shallows 100m downstream and in Deadwater bay - at least 5 surface rings visible at any time
29/02/00	4	>3000 very small mullet (10-15cm long) actively swimming in fast leakage flow from FG to 20m upstream (though not swimming hard up against FG boards) - very active – splashing, surfacing and jumping; occasional splash further upstream	4	~800 mullet (around 20cm long) schooling along FG - fast swimming (flashes visible), splashes and jumps; ripples of mullet schools in shallows to 50m upstream and in Deadwater bay; occasional fish jumping
2/03/00	4	Massive bird feeding frenzy; several thousand mullet, mostly around 15cm long, schooling very actively from FG to 100m upstream - swimming very fast, many flashes; regular surface rises, splashes and jumps - >10 surface rings visible each minute;	2	Very occasional surface ring in Deadwater bay (one or two a minute); ripples and surface rings of very small fish in shallows of Deadwater bay; no fish jumping
4/03/00	2	Very occasional mullet jumping 30-40m upstream	2	Very occasional mullet jumping and surfacing in Deadwater bay - one or two every five minutes

Wonnerup Floodgates DATE	Activity Rating Upstream	Upstream Fish Behaviour	Activity Rating Downstream	Downstream Fish Behaviour
6/03/00	4	~50 uniform size small black bream (~15cm long) schooling at FG; school of hundreds of mullet breaking surface en masse 20m upstream; school of hundreds of large mullet (>30cm long) swimming fast around FG pylons but not surfacing; small mullet jumping sporadically to 50m upstream	3	Occasional mullet jumping in Deadwater bay and in shallows 30m upstream (one every minute or so)
8/03/00	3	~200 large mullet (30cm+ long) schooling hard up against FG boards where inflow greatest; schools of around a hundred mullet (either 15cm or 30cm long - all in schools of same size fish) swimming fast below surface 10m upstream, only very occasional surfaces;	2	Occasional mullet splashing and jumping in Deadwater bay - one every few minutes; ~50 small mullet swimming below surface in shallows 20m downstream
10/03/00	2	Sporadic mullet jumps 200m upstream (a couple and then none for a few minutes); no fish at FG at all	3	Two schools of ~300 mullet each – occasionally surfacing and jumping 50-70m downstream
12/03/00	4	Mullet jumping everywhere from 10-200m+ upstream - many fish visible above water at any moment; ~50 very large mullet (>40cm long) swimming very fast around FG pylons - very active	0	No visible activity
14/03/00	4	~1000 large mullet (30cm+ long) schooling around FG, swimming fast under surface, occasionally jumping but not surfacing; many smaller fish regularly jumping and splashing from 30-100m upstream	2	Mullet occasionally swirling under surface and surfacing in Deadwater bay and in shallows along SE bank
16/03/00	4	Small mullet regularly rising and jumping 100m+ upstream - at least 3 or 4 visible at any time	2	Mullet sporadically surfacing in Deadwater bay and in shallows to 100m downstream
18/03/00	4	Mullet regularly jumping everywhere from 10-200m+ upstream - up to 10 visible at a time - dozens each minute; several small schools (50-100 fish) of mullet milling fast around FG pylons	3	Mullet surfacing regularly in Deadwater bay - 2 or 3 at a time; few ripples in shallows 100m downstream
20/03/00	3	Occasional run of small mullet jumping and splashing 50-100m upstream - 3 or 4 splashes then none for a couple of minutes; ~100 black bream schooling slowly, almost stationary, around FG pylons	2	Very occasional surface ring visible, otherwise no visible activity
22/03/00	4	Regular small surface rises 40-100m upstream - approximately five visible at any time; school of around 40 large mullet swimming very fast below surface at FG; ~100 small black bream around FG pylons	0	No visible activity

Wonnerup Floodgates DATE	Activity Rating Upstream	Upstream Fish Behaviour	Activity Rating Downstream	Downstream Fish Behaviour
24/03/00	2	School of about 50 large mullet (30cm+ long) darting around fast behind FG; approximately 50 small black bream around FGg pylons	1	Very sporadic surface rings visible in Deadwater bay
26/03/00	4	Mullet regularly surfacing and occasionally jumping (small ones) 150-200m upstream; ~50-100 smal black bream around pylons	1	Very occasional fish jump and splash in entrance to Deadwater; no other activity
28/03/00	4	~50 very large mullet (>40cm long) darting around very fast below surface at FG; ~500 small black bream darting around FG very fast; small mullet surfacing and jumping (>12 per minute)	2	Very occasional surface ring visible 100m+ downstream and in mouth of Deadwater
30/03/00	4	~500 large mullet (>30cm long) schooling around in leakage flow 2-10m upstream (not hard up against FG boards though) - swimming fast and darting around - few surfacing or jumping; many small mullet jumping and splashing regularly in channel from 5-150m upstream - at least 3 visible at any time	2	Occasional surfaces in channel and shallows 40-100m downstream
1/04/00	4	Mullet regularly jumping from 50-200m upstream - 3 at a time; activity rapidly increased as wind freshened to 10 mullet visible jumping at any time	4	~50 small mullet jumping in shallows; mullet jumping regularly in Deadwater bay and most area of shallows - 4 or 5 visible a minute
3/04/00	4	Thousands of pinheads at FG; hundred small black bream (about 10cm long) darting around pylons; mullet jumping regularly from 40-200m upstream - >10 visible each minute	3	Mullet jumping regularly 150m downstream - 6 or 7 visible each minute
5/04/00	4	Thousands of pinheads at FG; hundreds of small black bream (about 10cm long) darting around pylons; mullet jumping regularly 30m+ upstream	3	Mullet jumping, surfacing and splashing irregularly in Deadwater bay and shallows 50m downstream - 0-10 fish visible each minute
7/04/00	4	Several thousand mullet 25cm+ long schooling around, rolling on their sides as they swim, surfacing occasionally - swimming in torrential leakage flow from downstream, 10-40m upstream (not coming right up to FG boards; smaller mullet regularly jumping up the channel to 200m+ upstream of the FG; hundreds of small black bream darting around on the bottom at FG	2	2 large black bream, 1 blue manna crab, 1 large fish (maybe mulloway) and 3 herring seen from bridge; no other fish activity visible

Wonnerup Floodgates DATE	Activity Rating Upstream	Upstream Fish Behaviour	Activity Rating Downstream	Downstream Fish Behaviour
9/04/00	3	<100 mullet (20cm+ long) darting around fast on bottom, 10m upstream; occasional surface splash 150m+ upstream - a couple every minute	2	Sporadic surfaces and mullet jumping in shallows 50m downstream
11/04/00	4	Thousands of mullet (most >20cm long) surfacing and jumping regularly all the way up the channel - up to 20 visible at a time; many very large mullet (>30cm long) darting around on the bottom in schools of about 50 fish	2	Few bream around bridge pylons; no mullet activity on the surface
13/04/00	4	Hundreds of small bream darting around FG pylons; mullet jumping regularly up the channel 20-200m+ upstream - up to 10 visible at a time	3	Mullet regularly jumping in shallows – several at a time and then none for a few minutes
15/04/00	4	Thousands of mullet in estuary channel, surfacing and jumping regularly - more than 20 surface rings and five whole fish visible at any time; most activity >50m upstream; hundreds of small black bream darting around FG pylons on bottom; 1 blue manna crab and 2 large unidentified fish spooked near FG	3	Few bream around bridge pylons; mullet rising occasionally in shallows 100m downstream

Appendix 14: Waterbird Abundance Upstream of the Wonnerup Floodgates

Wonnerup Floodgates Upstream DATE	Black Swan	Pacific Black Duck	Musk Duck	All Ducks	Darter	Little Pied Cormorant	Little Black Cormorant	Pied Cormorant	All Cormorants	Pelican	Nankeen Night Heron	White-faced Heron	Great Egret	Australian White Ibis	Yellow-billed Spoonbill	Silver Gull	All small waders	TOTAL
16/12/99																		0
18/12/99			1							3			1					5
20/12/99	1			30						1			1	3				36
22/12/99				5														5
24/12/99										7								7
26/12/99				4	1								1					6
28/12/99	1	3				2	1			2			1					10
30/12/99						1	2											3
2/01/00										1		1						2
3/01/00					1	1												2
4/01/00					1					1								2
5/01/00	3	5				3				1				2				14
6/01/00		4			1	3	5			2				1				16
7/01/00		23				1	7			1						1		33
8/01/00				16	1	5	3			1			1	3				30
9/01/00				26	1				6									33
10/01/00				30					4				1					35
11/01/00		4	4		1	6	4			2			1					22
12/01/00				9		8	2			1								20
13/01/00			3						8									11
14/01/00				15		3				1								19
15/01/00				2		5	5			2			1	2				17
16/01/00		12	2		1	2	2						1	4				24
17/01/00				6					4									10
18/01/00									1				1					2
19/01/00				11	1				5									17
20/01/00						3												3
21/01/00		7	1		2	9												19
22/01/00		2	1		1				2									6
23/01/00					1				1				1	1				4
24/01/00			3		2									1				6
25/01/00						4				1				2				7
26/01/00					2	1							1					4
27/01/00					1				4									5
28/01/00				13					6								1	20
29/01/00				3					7									10
30/01/00			4		1	3												8
31/01/00				10	1	2								1				14
1/02/00	1			12	1	3											1	18
2/02/00				9	1	12				1				1				24

Wonnerup Floodgates Upstream DATE	Black Swan	Pacific Black Duck	Musk Duck	All Ducks	Darter	Little Pied Cormorant	Little Black Cormorant	Pied Cormorant	All Cormorants	Pelican	Nankeen Night Heron	White-faced Heron	Great Egret	Australian White Ibis	Yellow-billed Spoonbill	Silver Gull	All small waders	TOTAL
3/02/00		11			2				7									20
4/02/00				3	1				13	1		1		1				20
5/02/00				52					22	2								76
6/02/00				4		10												14
7/02/00									90	45		2	25	3				165
8/02/00						11				2				1	1			15
9/02/00		10				7												17
10/02/00				4					7					2				13
11/02/00							70			19			25	5	10		15	144
12/02/00									8								1	9
13/02/00						10		1										11
14/02/00						4									1			5
15/02/00									1									1
16/02/00									4					2	1			7
17/02/00										20								20
18/02/00							30			27			20					77
19/02/00		3				6	2											11
20/02/00		2										2						4
21/02/00							80			120		1	1					202
22/02/00			1						8				1					10
23/02/00	2	5							3	60			30			200		300
24/02/00	6			20					6	60			40			300		432
25/02/00						6	40						3					49
26/02/00				38					20						24			82
27/02/00						3	75			15		5	20	5	5	100		228
28/02/00						3												3
29/02/00						2	50			15		5	15	3		150		240
2/03/00				40					30	45		10	25			100		250
4/03/00							11											11
6/03/00							22											22
8/03/00	1	9												2				12
10/03/00	1	9				5								1				16
12/03/00		4				3				8				1				16
14/03/00				7														7
16/03/00									54	10			10	1	5			80
18/03/00						2												2
20/03/00						1	1			1								3
22/03/00									4	2							2	8
24/03/00			4						4	3		2			2			15
26/03/00				1		2				1			1					5
28/03/00						1												1
30/03/00						2												2

Wonnerup Floodgates Upstream DATE	Black Swan	Pacific Black Duck	Musk Duck	All Ducks	Darter	Little Pied Cormorant	Little Black Cormorant	Pied Cormorant	All Cormorants	Pelican	Nankeen Night Heron	White-faced Heron	Great Egret	Australian White Ibis	Yellow-billed Spoonbill	Silver Gull	All small waders	TOTAL
1/04/00		5	3			2				1								11
3/04/00			2			2												4
5/04/00			3			2												5
7/04/00						3												3
9/04/00		6	2			2												10
11/04/00	3			5														8
13/04/00		10				4												14
15/04/00			8															8

Appendix 15: Waterbird Abundance Downstream of the Wonnerup Floodgates

Wonnerup Floodgates Downstream DATE	Black Swan	Pacific Black Duck	Darter	Little Pied Cormorant	Little Black Cormorant	Pied Cormorant	All Cormorants	Pelican	White-faced Heron	Great Egret	Little Egret	Eastern Reef Egret	Australian White Ibis	Yellow-billed Spoonbill	Silver Gull	Pied Oystercatcher	All small waders	Wedge-tail Eagle	Caspian Tern	Total
16/12/99							10													10
18/12/99								1		1										2
20/12/99							5													5
22/12/99			1				2													3
24/12/99																				0
26/12/99							6													6
28/12/99										1										1
30/12/99																				0
2/01/00							7													7
3/01/00							4			1										5
4/01/00			1	2	5															8
5/01/00										1										1
6/01/00										1										1
7/01/00				2									6							8
8/01/00																				0
9/01/00										1										1
10/01/00									1											1
11/01/00					2				1								1			4
12/01/00							6											1		7
13/01/00				2	2												1			5
14/01/00				4				14												18
15/01/00							9													9
16/01/00							7													7
17/01/00	1		1				3		1	1			3				1			11
18/01/00							6		1											7
19/01/00									1	1										2
20/01/00									1								1			2
21/01/00								2	8	1				1			1			13
22/01/00						6														6
23/01/00				1				1												2
24/01/00			2				5	1	1					4			1			14
25/01/00							2	2	1											5
26/01/00							2		1								1			4
27/01/00							4													4
28/01/00									1	1										2
29/01/00				8									2							10
30/01/00			1				3													4
31/01/00			2																	2
1/02/00						1			1	1							1			4

Wonnerup Floodgates Downstream DATE	Black Swan	Pacific Black Duck	Darter	Little Pied Cormorant	Little Black Cormorant	Pied Cormorant	All Cormorants	Pelican	White-faced Heron	Great Egret	Little Egret	Eastern Reef Egret	Australian White Ibis	Yellow-billed Spoonbill	Silver Gull	Pied Oystercatcher	All small waders	Wedge-tail Eagle	Caspian Tern	Total
2/02/00				3		1			1				10				1			16
3/02/00				13		1								1			3			18
4/02/00				2																2
5/02/00		1							1				2							4
6/02/00									1	1			3	1						6
7/02/00				1																1
8/02/00																				0
9/02/00	2			4				7	1	1				1						16
10/02/00					2				1								1			4
11/02/00																	1			1
12/02/00								1												1
13/02/00							3		4				4							11
14/02/00				1																1
15/02/00																				0
16/02/00																				0
17/02/00									3											3
18/02/00	5																			5
19/02/00	2				1														1	4
20/02/00									1	4			2							7
21/02/00				1	3			9												13
22/02/00					2															2
23/02/00							5		1											6
24/02/00																				0
25/02/00													3							3
26/02/00					150			84	10	23			4	25						296
27/02/00	1															6				7
28/02/00																				0
29/02/00																				0
2/03/00														1			1			2
4/03/00								8					1							9
6/03/00									1											1
8/03/00																				0
10/03/00																				0
12/03/00																				0
14/03/00									1											1
16/03/00																				0
18/03/00											2		2		1					5
20/03/00							6													6
22/03/00																				0
24/03/00							5			1			2							8
26/03/00				2																2

Wonnerup Floodgates Downstream DATE	Black Swan	Pacific Black Duck	Darter	Little Pied Cormorant	Little Black Cormorant	Pied Cormorant	All Cormorants	Pelican	White-faced Heron	Great Egret	Little Egret	Eastern Reef Egret	Australian White Ibis	Yellow-billed Spoonbill	Silver Gull	Pied Oystercatcher	All small waders	Wedge-tail Eagle	Caspian Tern	Total
28/03/00																				0
30/03/00																				0
1/04/00				2	1				1	1			1							6
3/04/00				1					1	1										3
5/04/00									1											1
7/04/00													3							3
9/04/00				2	1				1											4
11/04/00										8										8
13/04/00							4													4
15/04/00				3		4			1			2	2							12