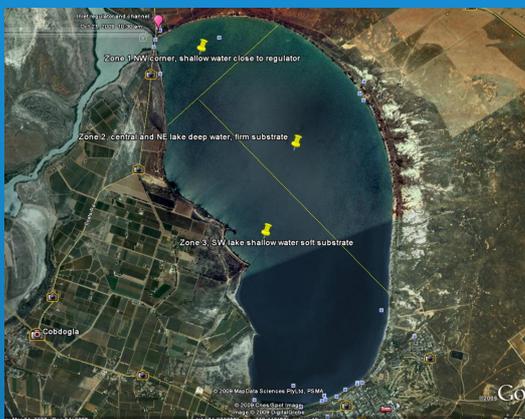
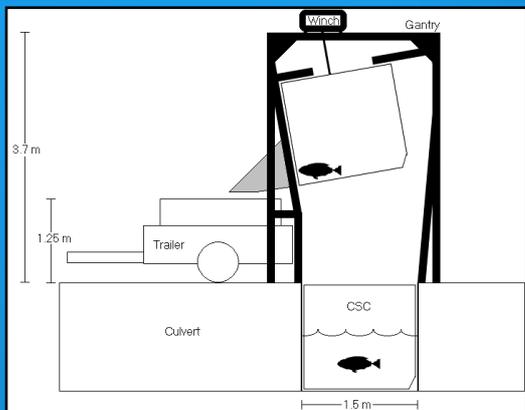


Design and installation of a novel wetland carp harvesting set-up at Lake Bonney, South Australia



Drs Leigh Thwaites & Ben Smith

**SARDI Publication No. F2010/000295-1
SARDI Research Report Series No. 469**

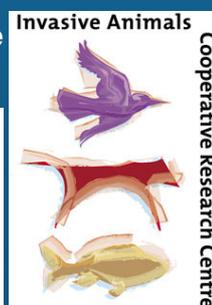
**SARDI Aquatic Sciences
PO Box 120 Henley Beach SA 5022**

October 2010

**A summary report for the South Australian Murray-Darling Basin Natural
Resources Management Board, Invasive Animals Cooperative Research Centre
and the Murray-Darling Basin Authority.**



**Government
of South Australia**



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EXECUTIVE SUMMARY

During the period from the 21st September 2009 to 18th January 2010, Lake Bonney received 26 GL of environmental water from the Murray River to maintain water conductivity <20,000 EC and to prevent likely large-scale kills of resident aquatic fauna (fish and turtles). The 20,000 EC upper-limit is the precautionary “threshold” adopted by the South Australian Murray-Darling Basin Natural Resource Management Board (SA MDB NRM Board) in order to stay within the laboratory derived upper salinity threshold of 23,000 EC for some species of native fish and turtles (Brad Hollis, SA NRM, pers. comm.). The water was delivered via a temporary flow control structure consisting of two box culverts constructed at the junction of Lake Bonney and Chamber’s Creek.

Prior monitoring of Lake Bonney suggested resident common carp (*Cyprinus carpio*, estimated abundance of between 50-100 tonne) would aggregate near the inflow point and attempt to leave the lake *en masse* during the filling event. Consequently, SARDI Aquatic Sciences was engaged to oversee the design, construction and installation of a prototype wetland carp separation cage (WCSC – including cage, gantry, hoist and mechanism to empty fish) within one of the culverts, to capture carp during the provision of the environmental water allocation.

Complementary fishing/tagging activities and monitoring in the lake proper and in the vicinity of the inflow point were also undertaken to evaluate:

- The population of carp and other key large-bodied native fish (>250 mm total length, TL, at maturity) in Lake Bonney including Murray cod (*Maccullochella peelii peelii*), golden perch (*Macquaria ambigua*), silver perch (*Bidyanus bidyanus*), freshwater catfish (*Tandanus tandanus*) and bony herring (*Nematalosa erebi*),
- The response of carp and native fish during the provision of water, and therefore the need to accommodate the passage of large-bodied native fishes during future water allocations, and
- The species diversity, abundance and size structures of captured fish (carp and large-bodied native fishes).

Design, installation and monitoring of a prototype Wetland Carp Separation Cage set-up

This report describes the work undertaken, the current status of the WCSC and considerations for future water allocations at Lake Bonney. The key outcomes are summarised below and a time-line summary of the monitoring and fishing activities undertaken is presented in Figures 1 & 2.

Design, construction, installation & monitoring of the wetland carp separation cage (WCSC)

- SARDI Aquatic Sciences' concept design for the WCSC was initially engineered by Parson's Brinkerhoff who were contracted on 20th June 2009 to produce engineering design drawings of the conceptual MKII WCSC, and to ensure that the design complied with all Australian design and OHS&W legislation. Parson's Brinkerhoff's engineering drawings did not meet SARDI's requirements and were incomplete at the conclusion of their contract term. The final product was re-engineered, fabricated and installed by Artec Engineering.
- SARDI Aquatic Sciences also designed associated infrastructure during the study - 'carp pivot screens' with 'carp deflector screens' (see below).
- The combined WCSC and carp pivot screens with carp deflector screens set-up will hereafter be referred to in this report as the 'set-up' or the 'wetland carp harvesting system- WCHS'.
- Work undertaken during September to December 2009 principally involved overcoming teething problems associated with taking concept designs to fruition. This included identifying and correcting design flaws and omissions in the initial engineering drawings as well as ensuring the final product complied with Australian OHS&W legislation. Securing the sites infrastructure against vandalism was also achieved during this period.
- The wetland carp harvesting system was therefore not able to be demonstrated during this study. However, standard operating procedures and a video guide for operating the wetland carp harvesting system have been finalised and the set-up is now ready for operation in 2010.

Lake Bonney fish assemblage & response to filling

- Scientific and commercial fishing activities within the lake and near the inflow point, combined with fish tagging, allowed estimation of the resident

population of several large-bodied fish species (native and alien) and their response to the inflow.

- The size of the resident adult carp population was estimated via a Petersen mark-recapture tagging experiment at $\approx 152,104$ kg (or $\approx 39,031$ individuals, given an average weight of 3.9 kg). A similarly large but unquantified biomass of bony herring was also detected. Otherwise, only three large catfish (>350 mm TL) and two golden perch (size unknown, commercial catch) were recorded, suggesting the lake's large-bodied native fish population is very low (with the exception of bony herring). This potentially reflects a prior fish kill in 2008, where Murray cod and golden perch were both recorded in the mortalities.
- Carp responded to the onset of flow by aggregating *en masse* around the inflow point within six hours. Carp spawning activity was observed within 24 hours. Carp continued to aggregate near the inflow point, where they attempted to exit the lake via the culverts (but their passage was blocked by carp screens) for two months until 20th November 2009.
- In contrast, relatively few large bony herring and no other large-bodied native fish were captured near the inflow point. However, thousands of juvenile bony herring were observed in January 2010, when carp were absent.
- Despite significant carp spawning activity observed around the inflow point during September to November 2009, fyke netting there in November and December 2009 and boat-electrofishing in January 2010 revealed few carp recruits (total $n = 119$, 22-68 mm TL).

Carp exclusion screens

Carp exclusion screens need to be used in conjunction with any WCSC to aggregate carp at the harvesting point, and to restrict carp movements when the WCSC is out of the water (for example, when it is being emptied). In this case, they were primarily required to prevent carp from escaping the lake.

- Two new carp screens considered for uses in low-velocity water were fabricated and trialled in the culverts (jail bars with 31 mm apertures between the bars and square grid-mesh with 44 x 44 mm internal dimensions). Despite mounting the screens at an angle of $\approx 39^\circ$ (oriented with the flow) with only 20 cm of screen protruding above the water, the screens (especially the

grid-mesh) would quickly foul with debris entrained in the high-velocity current flows ($\approx 1.9 \text{ m.s}^{-1}$). Fouling restricted flow delivery and probably the passage of small-bodied aquatic fauna, and increased the trapping of large-bodied aquatic fauna, including turtles.

- Vandalism was also a problem. On at least one occasion, several jail bars were broken free and used to stab a stranded turtle.
- Given the above, SARDI Aquatic Sciences designed and tested new, stronger ‘carp pivot screens- CPS’ with ‘carp deflector screens- CDS’, and the SA MDB NRM Board erected new fencing to secure the site against vandalism. The carp pivot screens were of much stronger construction and were specifically designed for the high flow conditions. They comprise a ‘jail bar’ carp screen (10 mm bars with 31 mm apertures between the bars) held in position by a pivot frame which is hinged and bolted to the base of the culvert. The screen and pivot frame can be set at any angle ($0-90^\circ$) or be raised and locked in a vertical position (90°) where it can act as a traditional carp screen. The screen can also move vertically in the pivot frame to act as the gate for the WCSC or to be completely removed from the culvert for maintenance. The ‘carp deflector screen’ was mounted ≈ 15 cm above the water surface (above the top of the pivot screen), to prevent carp from jumping the pivot screen from the lake to the river while allowing entrained debris and fauna to pass over the top of the screen.
- Preliminary testing supports the use of the carp pivot screens with carp deflector screens. By setting the pivot screen on an angle of $\approx 33^\circ$ (orientation with the flow), with the top of the screen just above the water surface, fouling and flow constriction were significantly reduced. Most entrained fish and turtles were also able pass over the top of this screen design.

Future work and site requirements

The current carp harvesting system is ready for use in 2010. However, minor site adjustments are now needed to optimise the set-up for capturing carp and some further work is recommended. These are presented at the end of the document, although it is critical that a second v-notch rock weir is now constructed to reduce the head-difference between the river and lake water levels, and thereby reduce current

Design, installation and monitoring of a prototype Wetland Carp Separation Cage set-up

velocities and turbulence to enable carp access to the culverts and wetland carp harvesting set-up.

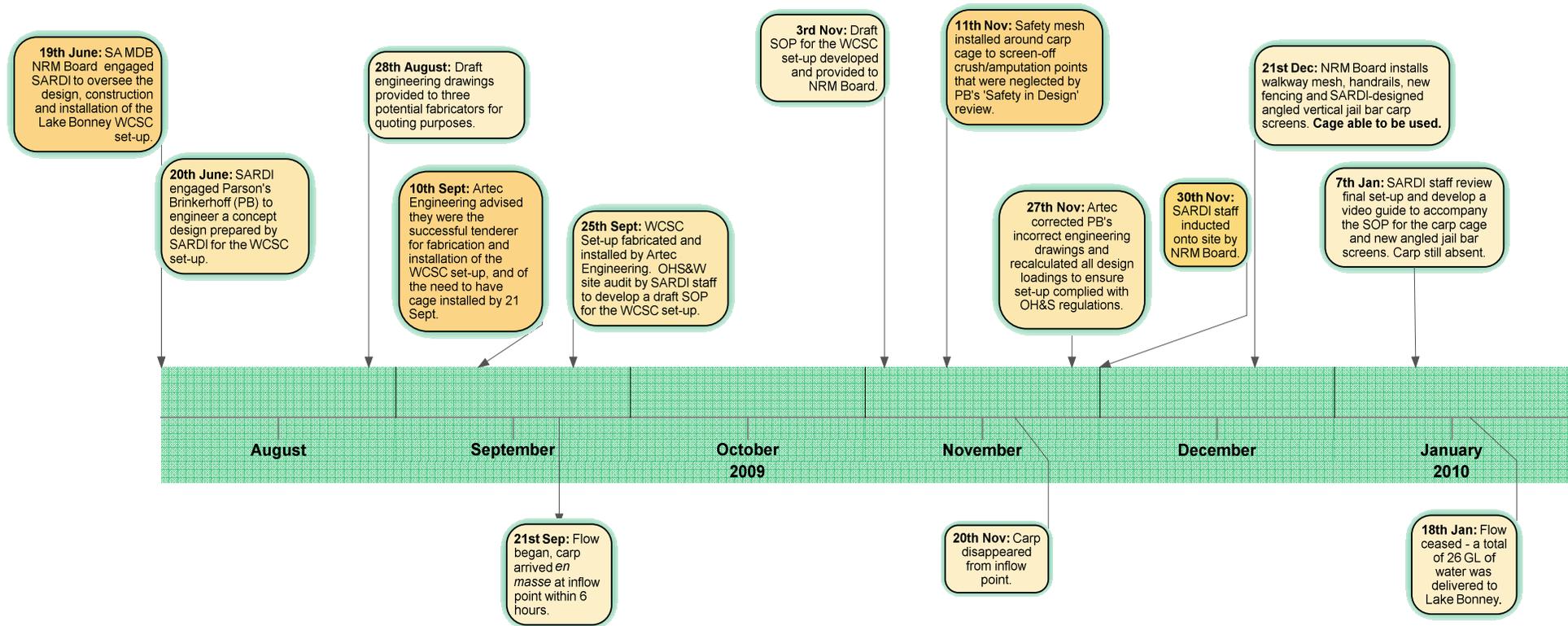


Figure 1. Overview of the wetland carp cage design, installation and management activities during June 2009 to January 2010.

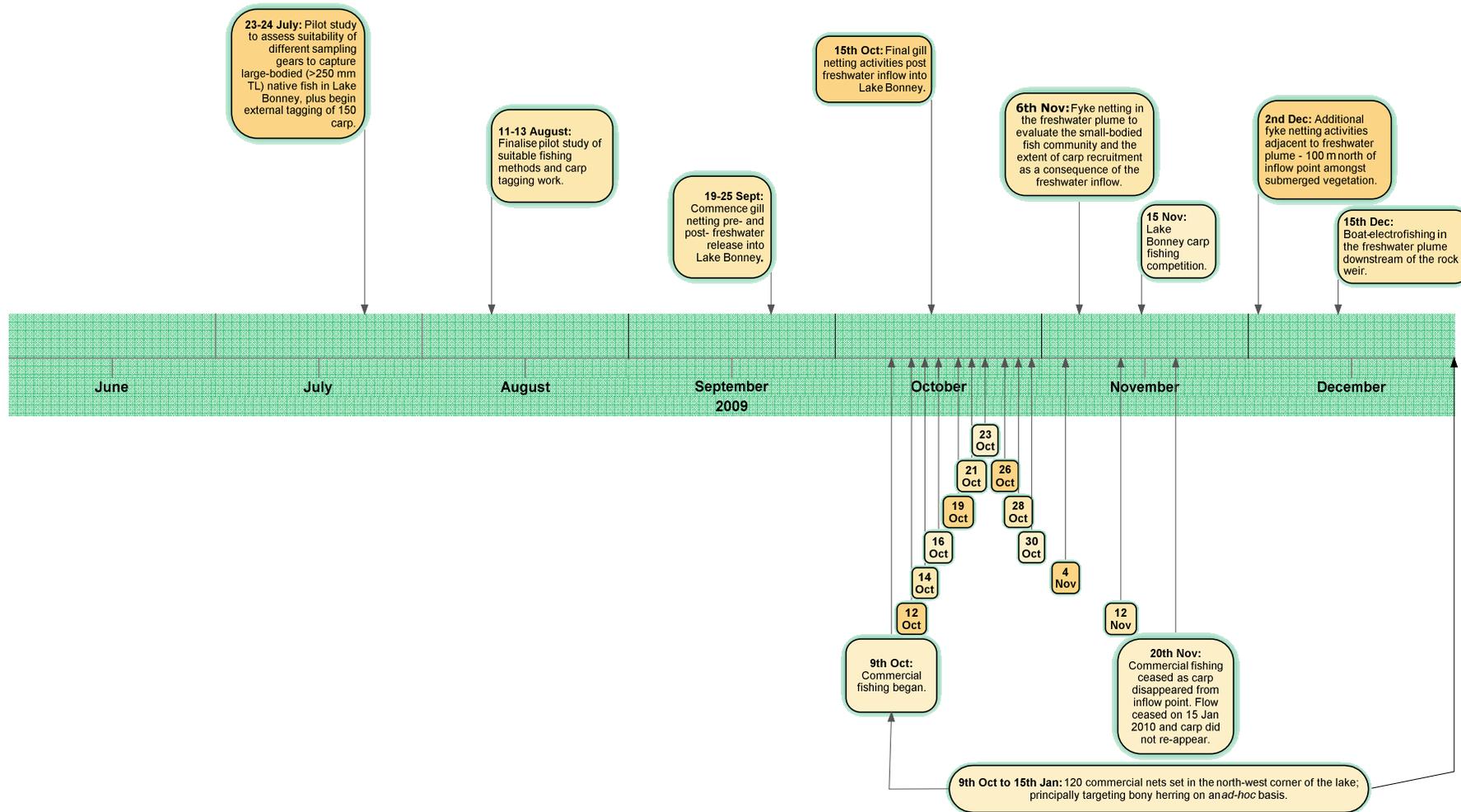


Figure 2. Overview of the fishing activities undertaken at Lake Bonney during July 2009 to January 2010.

BACKGROUND

Lake Bonney was disconnected from the main channel of the River Murray in mid-2007, via an earthen levee, to make water savings for critical human needs during ongoing drought conditions across the Murray-Darling Basin (Bond *et al.* 2008; Smith *et al.* 2009). Post disconnection, water levels in the lake reduced via evaporation and salinities gradually increased until the latter half of 2008 (when significant fish kills occurred). To reduce salinity levels, Lake Bonney received a partial refill allocation of 10 GL in November 2008.

The November 2008 filling event created an aggregation of carp at the inflow point. This aggregation formed quickly, persisted for the entire filling event and comprised large numbers of adult carp attempting to migrate from the Lake. Approximately 30 tonnes of aggregating carp were manually harvested by commercial fishers and a further five tonnes by the general public. The commercial harvest, however, was extremely labour intensive, and the harvest by the general public (including bows and arrows, pitchforks, spearguns etc) was unethical, unsafe and uncontrolled.

In 2009, the delivery of 26 GL of water to refill Lake Bonney was proposed. Initial plans suggested water delivery over a short period (about two months) during the cooler months (late winter). The intention was to minimise evaporative losses and maintain water conductivity <20,000 EC for as long as possible to prevent further kills of fish (especially of recreationally valuable species such as Murray cod and golden perch) and other fauna (e.g. turtles). The 20,000 EC upper-limit is the precautionary “threshold” as adopted by the NRM Board in order to stay within the laboratory derived salinity threshold of 23,000 EC for some species of native fish and turtles (Brad Hollis, SA MDB NRMB, pers. comm.)

A temporary flow control structure consisting of two box culverts was constructed at the junction of Lake Bonney and Chamber’s Creek (at Napper’s Bridge, on the Morgan Road) to deliver the water. Given that 35 tonnes of carp were removed during the 2008 filling event, the South Australian Murray-Darling Basin Natural Resources Management Board engaged SARDI Aquatic Sciences to oversee the design, construction and installation of a MKII prototype wetland carp separation cage

(WCSC, including the cage, gantry, hoist and mechanism to empty fish) within one of the culverts.

The MKII design aimed to eliminate manual handling requirements and OHS&W concerns identified during previous work with a MKI prototype WCSC design at Banrock Station, South Australia, where 8 tonnes of carp were captured in 4 months (SARDI Aquatic Sciences and The University of Adelaide; Unpub. Data). Essentially, the MKII WCSC was to be safe, effective, easy to operate and vandal-resistant (as far as possible).

In conjunction with overseeing the design, construction and installation of the cage, SARDI Aquatic Sciences sought co-investment from the Murray-Darling Basin Authority (MDBA) and the Invasive Animals Co-operative Research Centre (IA CRC) to evaluate the:

- Population extent of carp and other key large-bodied native fish (>250 mm total length, TL, at maturity) in Lake Bonney including Murray cod, golden perch, silver perch, freshwater catfish and bony herring.
- Movement patterns and the response of carp and native fish during the provision of water, and therefore the need to accommodate the passage of large-bodied native fishes during future water allocations.
- The species diversity, abundance and size structures of captured fish (carp and large-bodied native fishes), and the performance of the cage (proportion of the total carp population removed) and any design improvements.
- The percentage of the lakes resident carp population that could be harvested from the lake.

Finally, new 'carp pivot screens' with 'carp deflector screens' were designed, constructed and trialled. Carp exclusion screens (CES) are an integral component of a wetland carp harvesting system, and were necessary in this study to prevent the egress of carp from the lake when the cage was not in operation. However, vandalism and fouling of two CES designs developed for use in low-velocity water ($<0.4 \text{ m.s}^{-1}$, vertical jail bars with 31 mm apertures between the bars and square grid-mesh with internal dimensions of 44 x 44 mm; Hillyard *et al.* in press), required the design and construction of stronger, angled 'carp pivot screens' (e.g. mounted on an angle, rather

than vertically as is typical of CES in the Murray Darling Basin (MDB) (Hillyard *et al.* in press) with ‘carp deflector screens’ to prevent carp in the lake from jumping the screens. The carp pivot screens were subjected to pilot-level testing to evaluate:

- a) Their effect on flow velocity, and
- b) Whether the angled-mount and the high flow-velocities in the culverts ($\approx 1.87 \text{ m.s}^{-1}$) would combine to clear the screens by pushing debris towards the water’s surface (and potentially over the top of the screen).

This report describes the work undertaken, the current status of the wetland carp harvesting system, the large-bodied fishes of Lake Bonney and their response to the flow and filling event, and provides considerations for future water allocations to the Lake.

METHODS

Site description

Lake Bonney is adjacent to the Riverland township of Barmera, South Australia ($38^{\circ}12'56.80''\text{S}$; $140^{\circ}26'58.98''\text{E}$). The lake is ≈ 7 km long and 3.5 km wide with an average depth of $\approx 1\text{-}2$ m. The lake is ≈ 1577 ha at 7.83 AHD (minimum depth recorded on 22nd September 2009) and ≈ 1684 ha at 8.85 AHD (maximum depth recorded on 19th January 2010) (K. Marsland, SA MDB NRMB, pers. comm.). There is little riparian or submerged vegetation and the lake is exposed to strong wind and wave action.

Pre-disconnection in mid-2007, the mean lake salinity was $\approx 9,000$ EC (Brad Hollis, SA MDB NRMB, pers. comm.). Post-disconnection, salinity had increased (due to evapo-concentration) to $\approx 15,000\text{-}20,000$ EC (20,000 EC being the biological trigger point for environmental water allocations). Currently, the lake may receive water from the River Murray via two culverts (installed in September 2009) in Chamber’s Creek at its north-eastern inlet, and lesser inputs from town stormwater and catchment runoff (Figures 3 & 5).

Design, installation and monitoring of a prototype Wetland Carp Separation Cage set-up

Before the delivery of the environmental water allocation in 2009 there was a ≈ 1.7 m head differential between Chamber's Creek and Lake Bonney. Two box culverts, 1.5 m square with sluice gates at the upstream end (one undershot sluice gate on the northern culvert, and one 'combination' sluice gate in the southern culvert, where the WCSC was positioned), were constructed in the centre of the earthen bank to deliver the 26 GL of water. The base of the culvert was ≈ 1 m above the lake's water level. A rock weir was also constructed downstream of the culverts to maintain acceptable 'fish holding/harvesting' water levels (>70 cm) within the culvert, and a v-notch was later created within the rock-weir by SARDI Aquatic Sciences' staff, to facilitate the up-stream movement of carp toward the WCSC (Figure 3). Lake filling commenced on 21st September 2009, at a rate of ≈ 250 -300 ML d⁻¹ (combined flow from both culverts) and finished on the 11th January 2010.

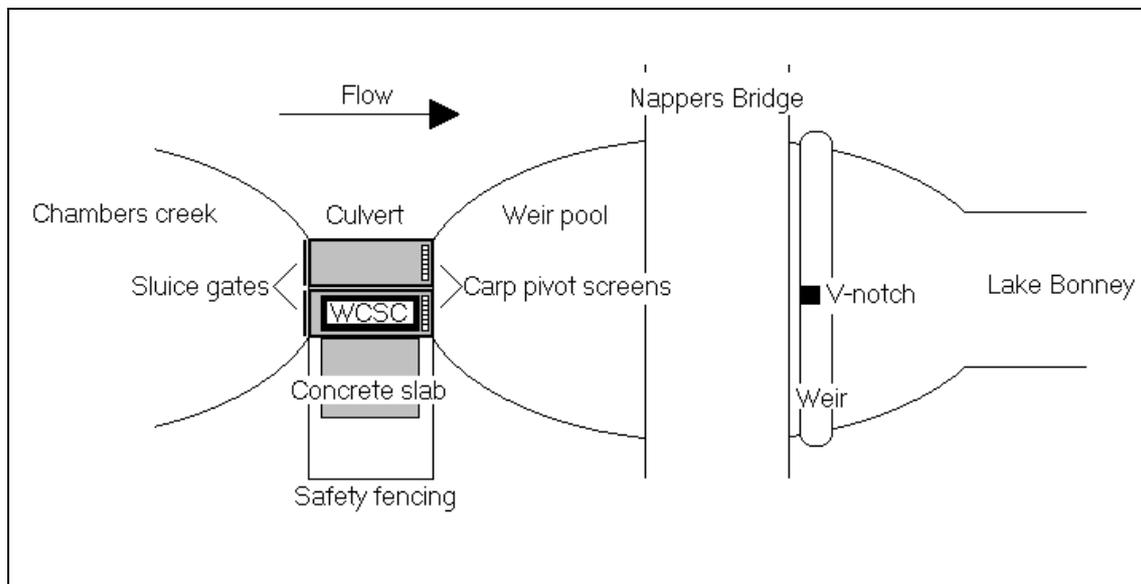


Figure 3. Schematic overview of the Lake Bonney Wetland Carp Harvesting System.

WCSC - Design, construction, installation & monitoring

The SA MDB NRM Board engaged SARDI Aquatic Sciences on 19th June 2009 to conceptually design, and to oversee the engineered design, construction and installation of a MKII prototype WCSC (including the cage, gantry, hoist and fish emptying mechanism) within the southern box culvert at Lake Bonney. The conceptual design for the MKII cage was to be designed such that it eliminated the manual handling requirements and OHS&W concerns identified during previous work with the MKI design at Banrock Station. The conceptual design was then to be

Design, installation and monitoring of a prototype Wetland Carp Separation Cage set-up

provided, along with key system requirements outlined in a project scope, to professional engineers for the development of a complete workshop design package to enable fabrication.

Lake Bonney fish assemblage & response to filling

Multiple sampling techniques (gill-netting, commercial harvesting, fyke-netting and boat-electrofishing) were utilised to:

- Assess the relative abundance and diversity of the lake's fish assemblage (native and invasive),
- Monitor their response to the filling event, and
- Tag fish for the Petersen population estimates (see below).

The WCSC was not able to be used, due to the lengthy commissioning process (see Results). Each method is described below and a timeline of fishing activities is presented in Figure 2.

Gill-netting

A pilot trial (23rd-24th July 2009) of methods to catch and tag large-bodied fish (seine-netting, baited set lines and multi-size gill-nets) for the Petersen population estimates, and to assess their relative abundance and diversity, indicated that gill-netting was the only viable method for Lake Bonney. The final mesh size used to capture carp, golden perch, silver perch and catfish, and to exclude bony herring (which were caught in extremely high numbers in smaller mesh sizes; SARDI Aquatic Sciences, Unpub. Data) was 180 mm (7", 50 m nets). To target larger Murray cod, a multi-panel gill-net comprising 250 mm (9.8", 25 m), 300 mm (11.8", 50 m) and 360 mm (14.2", 25 m) netting was used following consultation with local commercial fishers. A total of 10 sets of the 180 mm net and 9 sets of the multi-panel cod net were made between 23rd July and 15th October 2009 (including the additional netting detailed below; also see Figure 2).

To monitor the response of native and alien fishes to the filling event, the above gill-nets were set in pairs on two occasions; once before the onset of flow (19th-21st September 2009) and once afterwards (13th-15th October 2009, Figure 2).

Commercial fishing

Between the onset and cessation of flow into Lake Bonney (21st September 2009 to 18th January 2010), 13 separate commercial fishing operations occurred in the creek area downstream of the culverts, where carp aggregated *en masse* (see Figure 4). The commercial fishers were engaged to remove carp during the lengthy WCSC commissioning process. Commercial fishers reduced the water flow within the culverts and used 'stop nets' to contain the aggregated carp in the shallow creek section. Dip nets were then used to capture the fish before emptying them into an aluminium dinghy for subsequent transfer into holding containers for transport (see Figure 4). This operation generally took around 2 to 3 hours to complete.



Figure 4 a-f. Photographs of the commercial fishing operation at Lake Bonney.

Commercial fishers also undertook significant *ad-hoc* fishing in the north-western section of the lake (including, but not restricted to areas near the inflow point) using 120 mm (4.7") x 50 m nets (\approx 120 net sets). Whilst this fishing activity was to principally target bony herring for sale to local markets, the 120 mm gillnets used are known to adequately sample other large-bodied native fishes including golden perch, silver perch and freshwater catfish (Smith *et al.* 2007).

Boat-electrofishing

Due to the high salinity of the lake (15,000-20,000 EC), electrofishing in mid-December 2009 was restricted to the immediate vicinity of the inflow plume, where salinities were <2500 EC. Sampling was conducted with a boat-mounted 5 kW Smith-Root Model GPP electrofishing system (Smith-Root Inc. Vancouver WA, USA) at 320 and 500 Volts, 120 Hz and a duty cycle of 25%.

Fyke-netting

Opportunistically, two fyke-nets were set overnight in reeds (the only submerged vegetation in the north-western section of the lake) adjacent to the fresh water channel in November and December 2009 (see Figure 2), to assess possible carp recruitment that may have occurred as a result of the observed carp spawning near the inlet channel (Zone 1, Figure 5). The fyke-nets were made of 8 mm stretched mesh and had a single 6 m leader, 80 cm diameter entrance and a 6 m funnel with three chambers.

Environmental factors

Environmental factors including natural attractants (e.g. temperature and salinity gradients, current flow, food and 'earthy' odours, acoustic sounds) and chemical attractants (pheromones) are known to trigger innate behaviours in fish, especially those related to movements and migration for feeding and spawning (Sorensen & Stacey 2004). Thus, environmental data was collected to compare with fish movement patterns. Flow and salinity data (EC) were accessed from the SA MDB NRMB (unpublished), ambient air temperatures were collected from the Loxton Research Centre (averaged from max and min records), and water temperature was measured at hourly intervals with HOBOTM water temperature loggers (Onset, Cape Cod Massachusetts, USA) (see Figure 5).



Figure 5. Google earth image of Lake Bonney showing the position of four HOBOTM water temperature loggers and the three zones where carp were tagged and other fishing operations occurred.

Carp mark-recapture experiment

To evaluate the harvesting success of the WCHS versus commercial fishing, the resident carp population was estimated via a Petersen mark-recapture experiment according to Equation 1 from Robson and Regier (1964) (similar population estimates were planned for large-bodied native fishes, but insufficient numbers were captured):

$$\tilde{N} = MC/R \quad \text{(Equation 1)}$$

Where M is the number of fish marked and released, C is the number subsequently examined for marks, R is the number of marks found in the sample C, N is the total (and unknown) number in the population and, \tilde{N} is the Petersen estimate of N.

The following assumptions are implicit in studies of this kind:

- Both tagged and non-tagged fish suffer the same natural mortality rate,
- All fish have an equal opportunity for capture, and
- Fish will not lose their tags.

In this study, the assumptions were expected to hold as prior experience and knowledge of the lake suggested:

- Tagging will not significantly affect mortalities in carp,
- The vast majority of the lake's population of adult carp would attempt to migrate out of the lake during the filling process,
- Both tagged and non-tagged fish would mix between capture and recapture periods, and
- Loss of tagged and non-tagged carp (via fishing, natural mortality or emigration) would be minimal.

Further, to minimise error/bias:

- Carp were captured from all fishing Zones (Figure 5),
- All size classes of mature carp (>300 mm TL) were targeted with multiple capture techniques,
- All carp were double-tagged five weeks prior to the planned onset of recaptures to permit time for tagged fish to recover and mix with non-tagged fish. It was also hoped to minimise the time allowed for mortality and tag shedding,
- A different recapture method to the methods used during the tagging process (see above- response of fish to filling) was used,
- All tagged/non-tagged fish were enumerated during the recapture process, and sub-samples of the length and weight of captured fish were taken,
- Population estimates for each recapture event were calculated. This allowed an estimate of the variance, and
- Population estimates for grouped data at the completion of the experiment were calculated.

Carp tagging

To achieve a Petersen estimate of N that in 95% of trials would deviate no more than 25% from the true value of N, initial estimates of the lake's total carp population and the expected number of captured fish to be examined for tags was required to estimate the number of carp to initially tag (Figure 6; after Robson and Regier, 1964 and Ricker 1975).

From previous work by commercial fishers at Lake Bonney, it was estimated that the carp population within the lake was between 50-100 tonne (approx. 17,000-33,000 fish; assuming an average weight of 3 kg). It was expected that up to 80% of this population could be harvested during the 2-3 month lake filling event (approx. 13,000-26,000 carp). Thus, between 100 and 200 carp needed to be tagged (Figure 6). In total, 140 carp were captured, tagged and released.

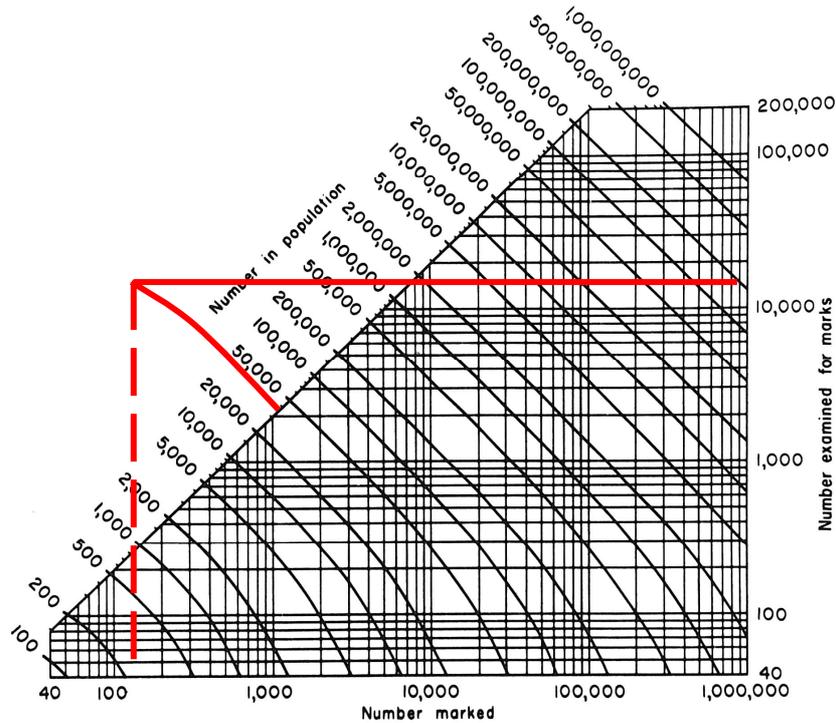


Figure 6. Combination of number of marks (M) and number subsequently examined for marks (C) for a series of population sizes (N- curved lines), which will provide Petersen estimates of N that in 95% of trials will deviate no more than 25% from the true value of N (from Robson and Regier, 1964 and Ricker 1975)

Carp were predominantly captured for tagging using the 180 mm gill-nets, although 5% were captured in shore-based seine hauls. Each carp was tagged with two external dart tags inserted between the dorsal pterygiophores (the internal extension of the dorsal fin ray structure) (Figure 7), before being released at the capture location.



Figure 7. Carp with two external dart tags, inserted between the dorsal pterygiophores.

Carp recapture and Peterson population estimates

To calculate Peterson population estimates, catch data from the 13 commercial fishing operations and from one lake fishing competition (15th November 2009) were used. Due to the large number of recaptures, each recapture event was recorded as total weight of carp removed (kg) and total number of tagged carp recaptured. The average weight of sub-sampled carp was then used to calculate the overall number of fish captured and the total number captured for each harvesting event. To gain an estimate of variance, population estimates were calculated (Equation 1) for each of 14 sampling events. For each calculation, the total number of tagged fish in the population was reduced by the number of tagged fish captured until that date. Finally, all recapture events and tag returns were pooled, and an overall population estimate was calculated.

Carp screens

Jail bar vs. grid mesh designs

Vertical ‘jail bar’ carp screens, with a 31 mm aperture between bars, have been recommended for application at wetland inlets in the Murray-Darling Basin that experience low-velocity flows ($<0.4 \text{ m.s}^{-1}$; Smith *et al.* in press). A square grid mesh design (with internal dimensions of 45 x 45 mm) has also been proposed (Hillyard *et al.* in press).

To qualitatively assess the utility of each screen design in the high velocity flows ($>1.5 \text{ m.s}^{-1}$) experienced in the culverts at Lake Bonney, we installed one screen type at the downstream end of each culvert. Screens were mounted in guide runners made of angle iron, which were bolted to the side of the culvert and fixed at an angle of $\approx 39^\circ$ (in an attempt to reduce fouling). Each screen was fabricated to fit the structural camber between the wall and the base of the culvert and protruded 20 cm above the water surface. The function of both screens (preventing the egress of carp from the lake) was then observed over the initial filling phase, and operational issues were documented.

Carp Pivot Screens & Carp Deflector Screens

Following problems with the above screens (see Results), the grid-mesh design was not investigated further, and a stronger ‘Carp Pivot Screen’ (CPS), based on the jail bar design, was specifically designed by SARDI Aquatic Sciences for application at Lake Bonney. The carp pivot screen (with 10 mm diameter bars spaced at 31 mm apart) is held in position by a ‘pivot frame’ which is fabricated from C-section. This frame is hinged and bolted to the base of the culvert (Figure 8). Using a braked-winch, the pivot frame holding the jail bar screen can be set at any angle ($0-90^\circ$) or can be raised and locked in a vertical position (90°), where it can act as a traditional carp screen. The jail-bar screen can also move vertically in the pivot frame to act as the gate for the WCSC or be completely removed from the culvert for maintenance (Figure 8). All components were hot-dip galvanised to avoid corrosion. It was anticipated that, if the carp pivot screen was lowered to an angle where the top of the screen was just above the water surface, then fouling would be minimised because entrained debris and fauna would be ‘washed’ over the top of the screen.

A ‘Carp Deflector Screen’ (CDS) was also designed for application at Lake Bonney, to prevent carp in the lake from jumping the carp pivot screens whilst they were in their operating position e.g. lowered to the water surface, yet allow entrained debris and fauna (i.e. carp, turtles, bony herring) to be washed over the top of the screen. The carp deflector screens were positioned out of the water, $\approx 15 \text{ cm}$ above the top of the pivot screen. This nominal distance is less than the mean depth ($>15 \text{ cm}$) of carp expected to jump vertically over the screens, and greater than the mean width ($\approx 9 \text{ cm}$) of large-bodied fauna expected to wash over the screens on their sides (Hillyard *et al.* in press) (Figure 8).

While it is not ideal to allow some carp into the lake, it was unavoidable due to the conflicting requirements of containing the existing population of carp, whilst dealing with other operational constraints such as:

- A desire to maintain near maximum flow volumes through both culverts, to deliver the 26 GL of water in the desired timeframe of three months.
- Resultant high-velocity flows ($\approx 1.87 \text{ m.s}^{-1}$) for >90% of the filling event.
- Fouling due to entrained debris and fauna.

As carp are positively rheotactic (Smith *et al.* 2005), it was anticipated that entrained carp that were washed over the screens, would subsequently orientate back into the flow and be vulnerable to capture in the WCSC.

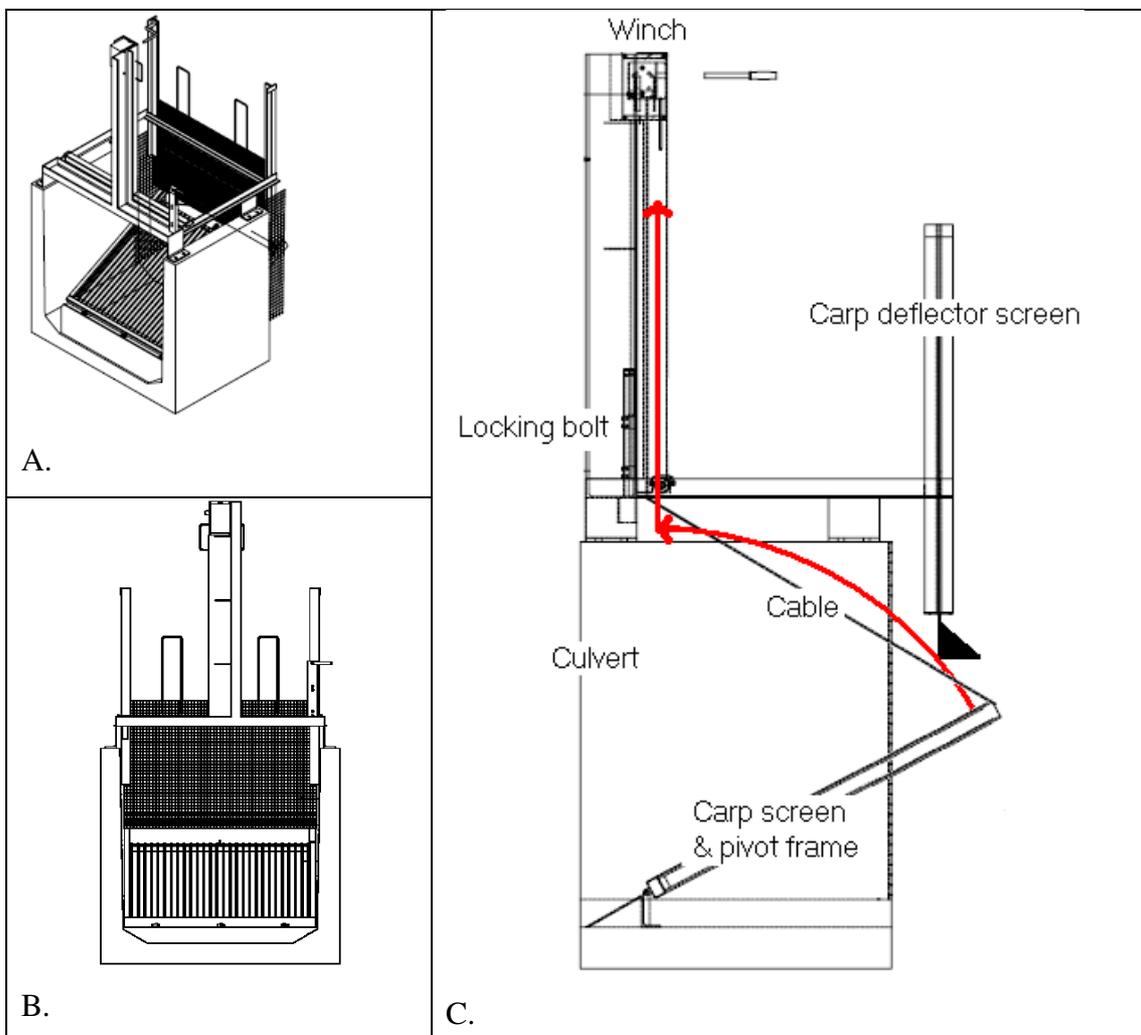


Figure 8. Workshop drawings of the carp pivot screen: A) Screen at 33°, B) screen in culvert fitted to the camber at the base of culvert C) showing the multi-function of the carp pivot screen—the red line indicates the direction of movement.

To assess the utility of the CPS in high-velocity flows, three pilot experiments were conducted:

- 1) *The effect of the CPS on flow velocity ($m.s^{-1}$):* For this study, the northern culvert's sluice gate was fully raised (maximum flow $\approx 1.87 m.s^{-1}$) and flow measurements were taken in the centre of the culvert, at $\approx 66\%$ of the water depth and $\approx 3 m$ downstream of the CPS using a Marsh-McBirney Flow Mate™ portable velocity meter (Marsh McBirney Frederick, Maryland, USA). Measurements were then recorded with the CPS set at 0° , 33° (screen at water surface) and 90° .
- 2) *The effect of fouling and screen angle on flow velocity:* For this study, two 20 L buckets of aquatic macrophytes (*Typha orientalis*, *Paspalum distichum*) and algae (*Nitella* sp.) were collected from Lake Bonney. While delivering maximum flow the CPS was set at 33° and one bucket of debris was slowly emptied into the culvert immediately downstream of the sluice gate, $\approx 3 m$ from the CPS. Subsequently, the flow velocity downstream of the CPS was measured. Retained debris was then removed and the procedure was repeated with the screen set at 90° . A decrease in flow velocity was considered to be indicative of fouling.
- 3) *The cleaning effect of lowering the CPS to 0° :* Two 20 L buckets of aquatic macrophytes and algae were collected (as above). At maximum flow, the CPS was set at 90° and one bucket of debris was rapidly added. The screen was then lowered to 15 cm below the water surface for ≈ 30 seconds until the debris was forced to the top of the screen and then raised. At this point, the second bucket of debris was added, and flow velocity measured. The screen was then lowered again to 0° and raised back to 33° before flow velocity was re-measured. Any change in flow velocity was considered to be indicative of fouling and/or cleaning potential.

RESULTS

WCSC - Design, construction, installation & monitoring

The conceptual MKII WCSC design developed by SARDI Aquatic Sciences incorporated the following key elements:

- Technology to separate carp >250 mm TL from native fish using jumping (Stuart *et al.* 2006) and pushing trap elements (Thwaites *et al.* 2010),
- Cage cladding (mesh; vertical jail bar design, with a 31 mm aperture between bars) designed to permit the unimpeded passage of small and medium sized native fish, while impeding the passage of carp ≥ 250 mm TL (Thwaites *et al.* 2010; Hillyard *et al.* in press),
- Infrastructure to mechanically lift and automatically funnel captured fish into trailer-mounted fish bins (Figure 9). When the jumping and pushing trap elements are in use, there are two cage sections (Holding Zone and Carp Cage, Figure 10) and these should be able to be emptied independently e.g. all fish in the Holding Zone (potentially including carp and native fish) would be emptied first, so that native fishes can be returned to the water,
- A modular WCSC design that permits straightforward management changes. For example, when fish aggregations comprised entirely of carp are present, the central baffle of the cage (comprising the jumping and pushing trap elements) can be removed, and the cage can be used as a large scoop, and
- Compliance with Australian design and OHS&W legislation.

A conceptual sketch of the MKII WCSC design is below (Figure 9 and 10).

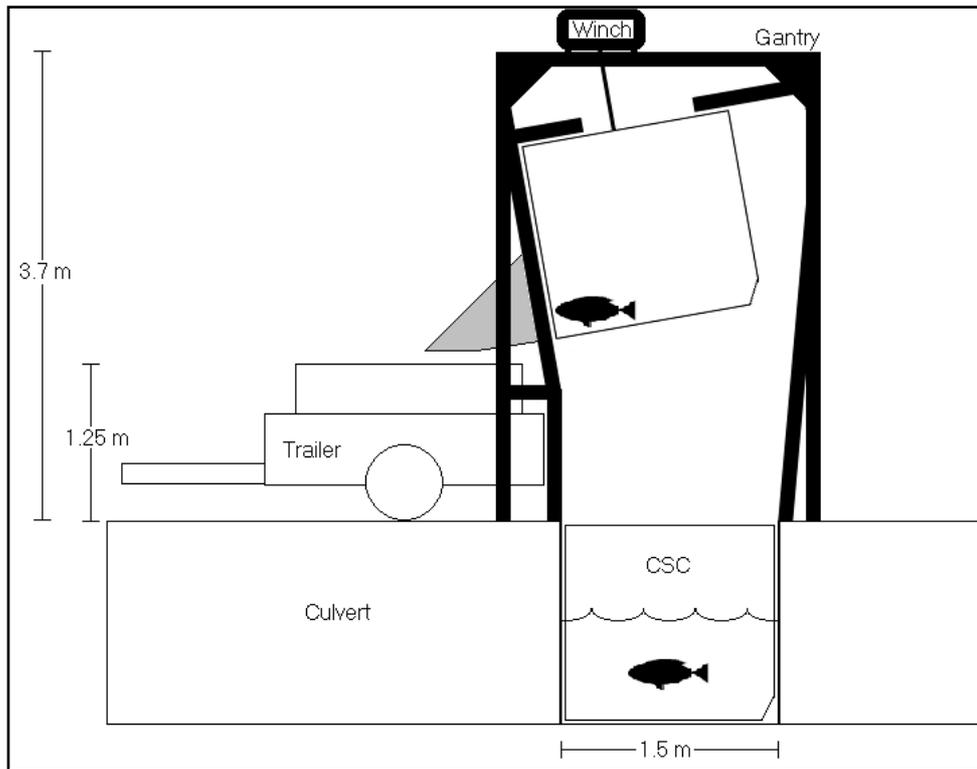


Figure 9. Schematic representation of the conceptual WCSC lifting infrastructure.

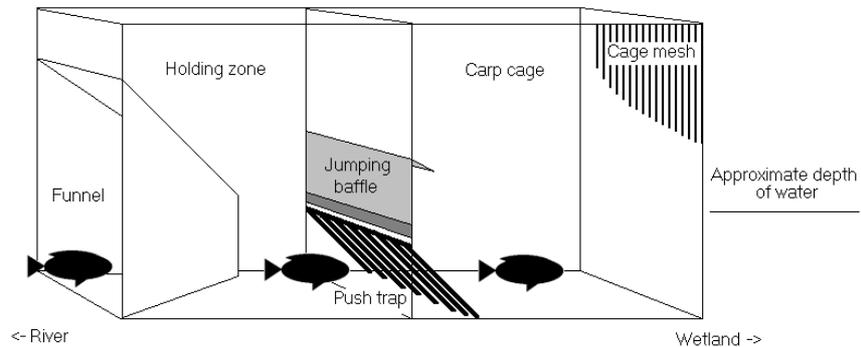


Figure 10. Schematic representation of the WCSC showing the entrance funnel, holding zone, jump/push trap element, carp cage and jail bar cladding with 31 mm aperture (cage mesh).

SARDI Aquatic Sciences originally contracted Parson's Brinkerhoff (PB) on 20th June 2009 to produce engineering design drawings of the conceptual MKII WCSC, and to ensure that the design complied with all Australian design and OHS&W legislation.

Cage manufacture from PB's drawings occurred during 10th-19th September 2009 by Artec Engineering and installation occurred during 23rd-25th September 2009. A SARDI OHS&W audit of the near-final WCSC set-up occurred on the final day of installation. Upon installation, it was clear the set-up was not functional and did not comply with Australian design or OHS&W legislation (in particular, section 3.2 Subdivision 1 [Duties of Designers] of the Occupational Health, Safety and Welfare Regulations, 1995). In regards to the latter, the initial design did not identify and provide controls (fine mesh screening) for the crush/amputation points that existed between the cage and the gantry during operation. Thus, SARDI Aquatic Sciences was required to immediately contract the on-site WCSC fabricator, Artec Engineering, to design, fabricate and install the mesh guarding for the crush/amputation points; calculate new design loadings based on the revised design, and, to ensure that the final design/structure complied with Australian OHS&W legislation (Figures 11, 12 & 13).

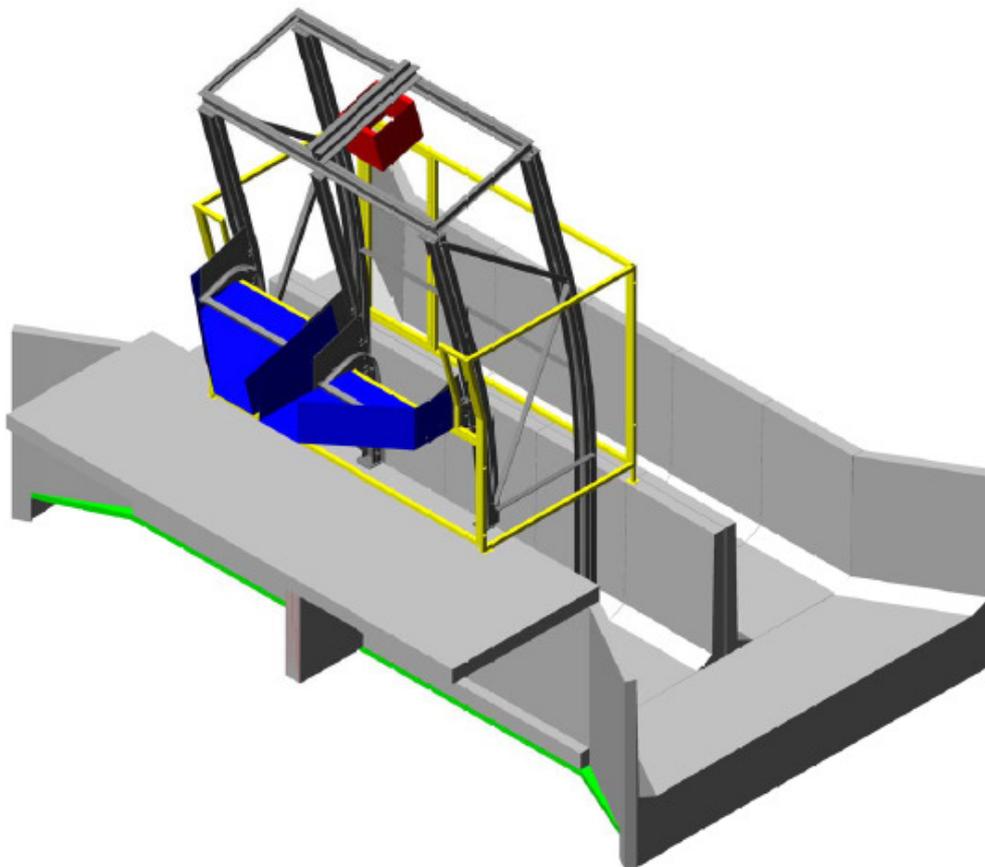


Figure 11. AutoCad drawing of the re-engineered MKII WCSC showing the position of the gantry within the culvert, the hoist (red), the fish funnel (blue) and the frame safety guarding (yellow). Note: the carp cage is not shown.

Draft Standard Operating Procedures (SOP) for the WCSC set-up were developed and provided to the SA MDB NRM Board on 3rd November 2009 (Appendix A). The mesh guarding of crush/amputation points was installed on 11th November 2009 (Figure 13).



Figure 12. Photographs of the WCSC set-up showing a) the two doors of the cage operating independently to allow each cage section to be emptied separately (with the holding cage door opening first), and b) both doors fully open when cage is fully lifted.

Cage testing was subsequently not permitted until the SA MDB NRM Board had installed appropriate fencing to secure the area, and walkway mesh and handrails had been fitted to both box culverts for OHS&W compliance, developed an overall site OHS&W audit and SOP and inducted SARDI staff back onto the worksite. This was completed on 21st December 2009. Subsequently, a video guide for the operation of the wetland carp harvesting system (WCSC and carp pivot/deflector screens) was developed by SARDI Aquatic Sciences on 7th January 2010, and flow ceased on 19th January 2010.

Although untested, the set-up is now fully commissioned, OHS&W compliant, vandal resistant, functions according to its intended design, and is ready for operation in 2010 (Figure 13).



Figure 13. Photograph showing the fully-commissioned MKII WCSC. Also shown is the perimeter fencing for the worksite, the walkway mesh, handrails and new angled ‘carp pivot screens’ (in the water) and ‘carp deflector screens’ (positioned above the water).

Lake Bonney fish assemblage & response to filling

Environmental factors

Water temperatures in Chamber’s Creek and Lake Bonney (surface and bottom) were correlated with ambient air temperature ($R^2 > 0.65$) (Figure 14). At the onset of filling (21st September 2009), lake water temperatures had already exceeded the known 16°C minimum required for carp spawning (Smith 2005). Water temperatures then decreased to $\approx 14^\circ\text{C}$ in late September 2009 before increasing to a maximum temp of $\approx 30^\circ\text{C}$ in mid-November 2009, after which time temperatures steadily declined to $\approx 20^\circ\text{C}$ in late-November 2009.

Carp

Carp responded to the onset of flow by aggregating *en masse* around the inflow point within six hours. The aggregation was dense within a ≈ 400 m long x ≈ 100 m wide area of the shallow (<0.5 m) shoreline around the inflow point, and was estimated to contain >90% of the population. Carp persisted to aggregate near the inflow point, where they attempted to exit the lake via the culverts, for two months until 20th November 2009.

The observed re-distribution of carp towards the inflow area with the onset of flow was reflected in changes in the gill-net catches across Zones 1-2 (using a standard CPUE of one 50 m gill net with 7" mesh set for 24 hours per zone per period). That is, with the onset of flow, catch rates declined dramatically in Zone 2 (away from the inflow point; from 20-1) and increased in Zone 1 (near the inflow point; from 10-16).

Carp spawning activity was observed within 24 hours after the onset of filling. It was most pronounced then, but was also observed intermittently until carp disappeared on 20th November 2009. However, no young carp were captured in the fyke nets in November 2009, and only 119 were detected in December 2009 (size range, 22-68 mm TL; estimated age range, 44 days [spawned early-November 2009] to 136 days [spawned pre-flow] - using estimated growth rate per day of 0.5 mm in South Australia; B. Smith, Unpub. Data).

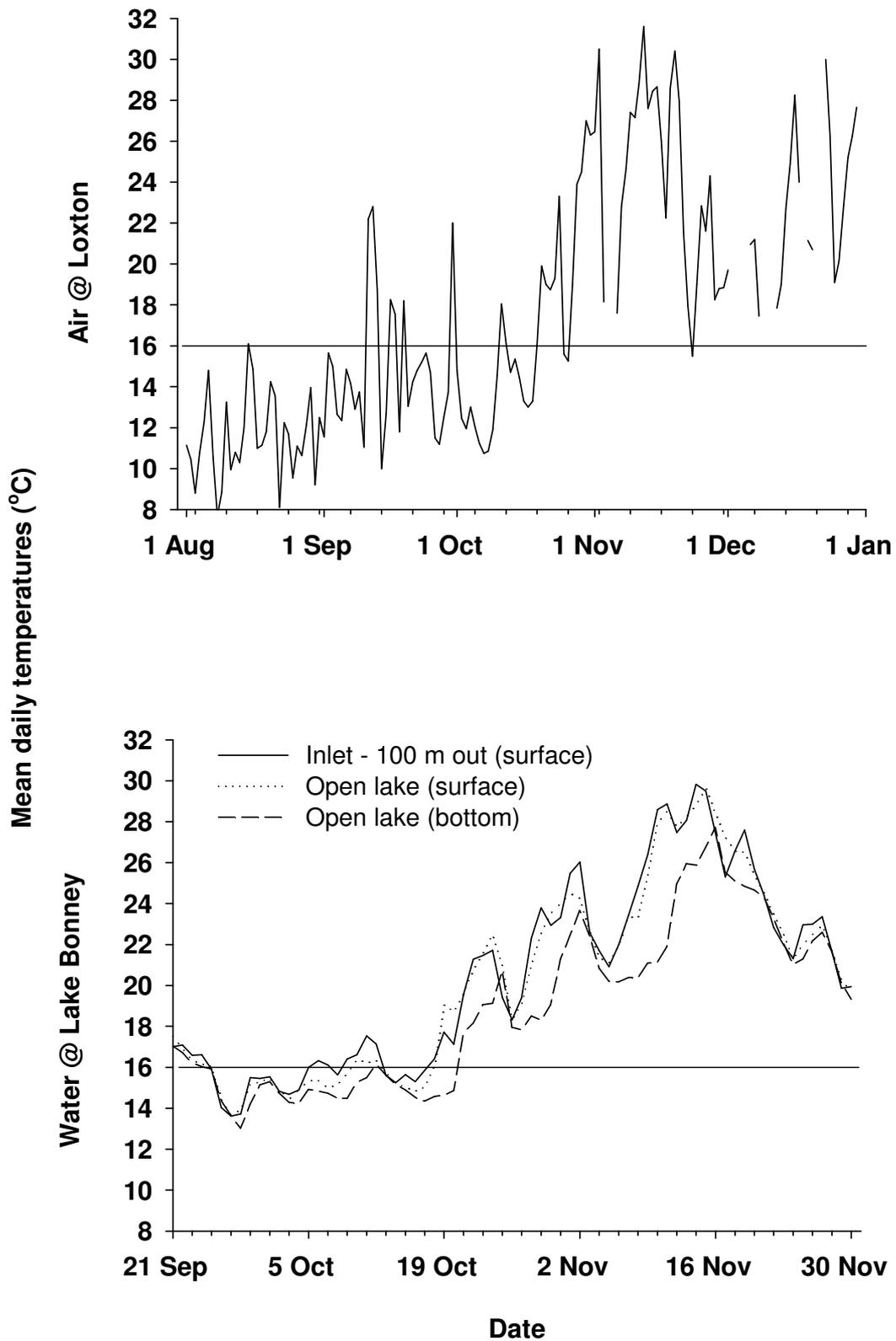


Figure 14. Average daily a) air temperatures at Loxton (averaged from max and min records) and b) water temperature at three locations in Lake Bonney (averaged from hourly records) during August to December 2009. Solid horizontal line indicates the minimum spawning temperature for carp (16°C). Note varying x-axis scales.

Native fish

Bony herring were the only large-bodied native species captured or observed in high abundance. Large bodied bony herring were principally captured in the 140 mm gill-nets during the pilot trials of fishing methods ($n = 552$, >220 mm TL; note that the use of these nets was discontinued after the pilot trials to avoid capture of this abundant species) and the 120 mm commercial nets targeting bony herring (G. Warwick, Commercial fisher; Unpub. Data). Juvenile bony herring were observed aggregating in their thousands downstream of the rock weir in January 2010. Otherwise, a total of two freshwater catfish were captured in Zone 2 (570 & 560 mm TL) from a total of 16 net sets (6 x 50 m x 140 mm mesh and 10 x 50 m x 180 mm mesh research nets), and one freshwater catfish (size unknown- commercial catch) and two golden perch (size unknown- commercial catch) were captured from 120 individual sets (50 m x 120 mm mesh commercial nets). No Murray cod were captured in any of the nine multi-panel large-mesh nets (100 m x 250-260 mm mesh).

Petersen mark-recapture experiment

In total, 52,150 kg of carp were recaptured over 14 harvesting events (13 commercial operations and one fishing competition*, Table 1). This equates to an estimated 13,382 individuals, given an average weight of sub-sampled carp of 3.9 kg ($n = 147$). Re-captures of tagged carp and therefore population estimates per fishing event were highly variable (recaptures, 1-12; population estimates 3,000-100,000 fish), with a total of 48 re-captures recorded overall (Figure 15 and Table 1). The Peterson population estimate from pooled data was $\approx 39,039$ carp at the time of sampling. Subtracting the commercial harvest from this estimate suggested a population of $\approx 25,649$ carp (99,954 kg; Table 2). Thus, at the lake's minimum depth of 7.83 m AHD (recorded 22nd September 2009) and surface area of 1577 ha, the estimated carp density was 63.4 kg ha^{-1} . At the lake's maximum depth of 8.85 m AHD (recorded 19th January 2010) it was 59.4 kg ha^{-1} .

Table 1. Summary of commercial fishing activities which occurred at Lake Bonney between the 09/10/2009 and 20/11/2009 and catch results from Lake Bonney fishing competition (15/11/2009). Refer to figure 3 for location of weir pool

Date	Weir pool included	Weight of carp removed (kg)	Total tags retrieved
9 October	n	4225	6
12 October	n	5050	4
14 October	y	2875	1
16 October	n	4425	2
19 October	n	3025	1
21 October	n	4800	2
23 October	n	5000	7
26 October	n	3625	3
28 October	n	4000	3
30 October	n	1975	1
4 November	y	2400	2
12 November	y	10000	12
*15 November	n	500	2
20 November	y	250	2

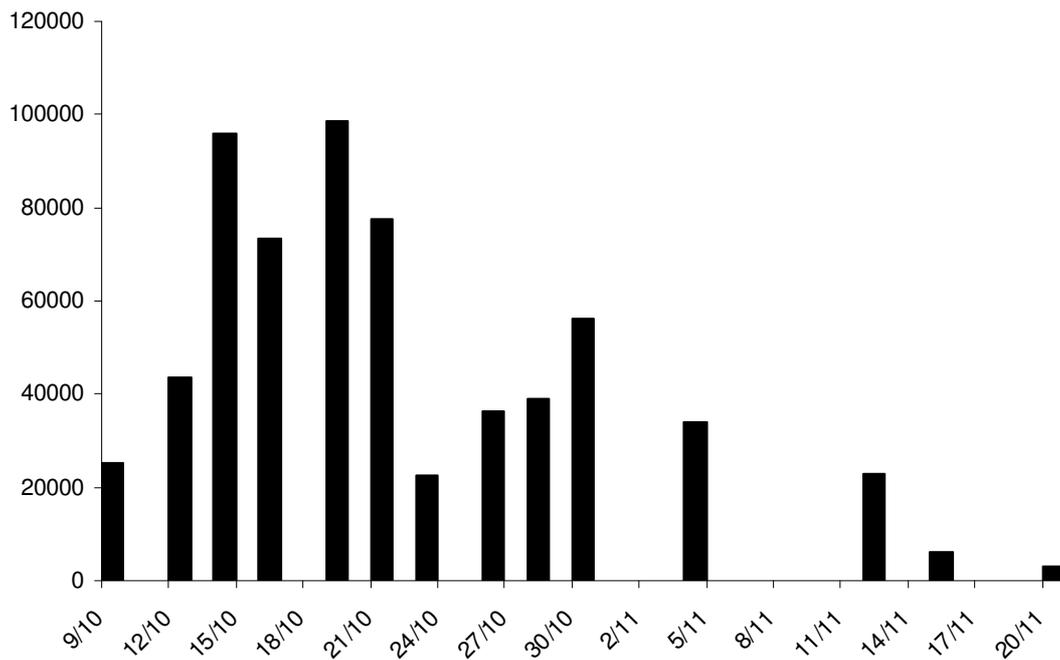


Figure 15. Petersen mark-recapture carp population estimates for each of the 14 sampling events which occurred in Lake Bonney between 9th October and 20th November 2009.

Table 2. Summary statistics for the Petersen mark-recapture experiment; estimated number and weight (and variance of estimates) of the total carp population in Lake Bonney from the 14 fishing events.

	Estimated	
	Number of fish	Weight (kg)
Average	45317	176601
St. dev.	30787	119976
Max	98582	384175
Min	3015	11750
Pooled data	39031	152104
Pooled data minus commercial harvest	25649	99954

Carp Screens

Grid mesh vs. jail bar carp screens

Observations confirmed that the grid-mesh fouled rapidly (< 24 hours, Figure 16 a - b), which restricted flow, and tended to trap entrained bony herring but not turtles or carp. In contrast, the jail bar screen had minimal fouling but did trap more entrained carp and turtles than the grid-mesh (Figure 16 c - d).

Vandalism was a problem for both screen types. In particular, rocks were thrown onto the screens from above, to the point where the screen mesh and frames were severely damaged, and individual bars (from the jail bar screen) were broken-free. This vandalism, in concert with the high-flows and fouling, eventually weakened and destroyed the screens. In one incident, a bar that had been broken-free was used to stab a turtle that got entrained in the flow. These disturbing observations highlight the importance of prohibiting public access, particular in highly populated areas.

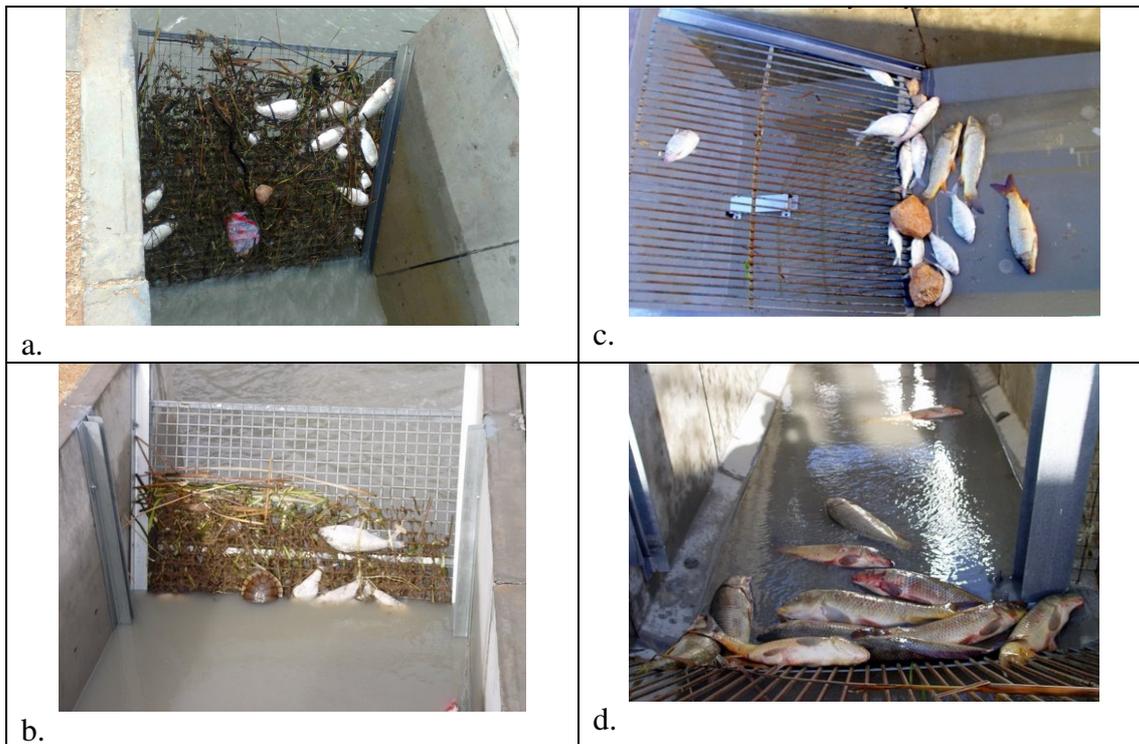


Figure 16. Pictorial representation of the function of a-b) the grid mesh carp screen and c-b) the jail bar carp screen. Photos were taken after approx. 24 hours of flow.

Carp Pivot Screens

The results from each pilot experiment support the use of carp pivot screens in high flow conditions and are provided separately:

1) The effect of the CPS on flow velocity ($m.s^{-1}$):

With the sluice gate fully open and the CPS set at 0° , flow velocity through the culvert was recorded at $1.87 m.s^{-1}$. The application of the CPS set at 90° slowed culvert flow velocity ($1.35 m.s^{-1}$) however this effect was less pronounced when the screen was set at its operating angle of 33° ($1.5 m.s^{-1}$; Table 3- No debris column).

2) The effect of fouling and screen angle on flow velocity:

The addition of 20 L of aquatic macrophytes had no effect on flow velocities for the angled screen (33° - all debris was forced to the water surface), while a decrease in flow velocity of $1 m.s^{-1}$ (from $1.35 m.s^{-1}$ to $0.35 m.s^{-1}$) was recorded through the vertical screen (90°) after the addition of the same volume of macrophytes (Table 3- Debris column).

Table 3. Summary statistics for the preliminary trial of the new carp pivot screen.

Screen angle	Flow velocity (m.s ⁻¹)	
	No debris	Debris
0°	1.87	n/a
33°	1.5	1.5
90°	1.35	0.35

3) The cleaning effect of lowering the CPS to 0°:

With approximately 40 L of macrophytes trapped on the screen, the flow rate was reduced from 1.5 m.s⁻¹ to 0.5 m.s⁻¹. Cleaning the CPS via lowering (to 0°) and raising (to 33°), led to the majority of debris being washed-off the screen, and remaining debris was forced to the water surface where it was easily removed with a rake. Post cleaning, the flow rate increased to 1.45 m.s⁻¹ (note: debris forced to the water surface was not removed before flow measurements were taken).

Additional observations indicated that entrained bony herring and turtles successfully negotiated the carp pivot screens (even with debris trapped at the surface) and that fouling was minimal (Gary Warwick, Pers. Comm.). However, as Lake Bonney carp had disappeared from the culvert area by the time of installation of the new CPS and carp deflector screens, we were unable to evaluate whether the deflector screens prevented carp from jumping the CPS. It was hypothesised that carp do not jump ‘with the flow’, and when jumping ‘against the flow’ (as per carp in Lake Bonney) they will jump into the carp deflector screen. This hypothesis remains to be tested.

DISCUSSION

WCSC - Design, construction, installation & monitoring

Within 6 months, the conceptual design, engineered design, fabrication, installation, commissioning, and the OHS&W assessment and confirmation of the Lake Bonney WCSC occurred. In addition, the resident carp population was quantified, the native fish population was assessed, two new carp screen designs were fabricated and evaluated, and new carp pivot/deflector screens were designed, engineered, fabricated, installed and commissioned.

Lake Bonney fish assemblage & response to filling

Carp

As observed in 2008, adult carp aggregated *en masse* near the inflow point to Lake Bonney within 6 hours of the onset of flow in 2009 (their passage out of the lake blocked by carp screens) and remained in the vicinity of the inflow point for almost 2 months. The aggregation was observed to spawn *en masse* within 24 hours of the commencement of flow and then intermittently thereafter, presumably taking advantage of water temperatures above 16°C and the inflowing fresh water (<1000 EC units) containing an array of chemical (Sorensen and Caprio 1998) and acoustic (Hawkins 1986; Popper and Carlson 1998; Amoser and Ladich 2005) cues. A reduction in the biomass of carp over time and the disappearance of aggregating carp on 20th November 2009 may reflect the completion of spawning and/or improved water quality within the lake (e.g. salinity near Barmera's town jetty reduced from 20,000-15,000 EC units during the inflow period; K. Marsland, SA MDB NRM Board, Unpub. Data).

The temporal decrease in the motivation of carp to migrate out of the lake suggests that targeted harvesting should be focused in the initial phase of each filling event. At the onset of filling in this study, however, when flow through the culverts was

maximised, carp were not able to negotiate the high velocity and high turbulence conditions (not measured) within the v-notch of the rock weir caused by a ≈ 1.5 m head-difference in water levels upstream and downstream of the weir. Indeed, the high velocity water and turbulence destroyed the v-notch within a few days, and on two other occasions after the v-notch had been re-made. It was only once the lake's water level rose and the head differential had reduced to ≈ 0.8 m (post-November 2009) that the integrity of the v-notch was maintained. However, by this time, the carp had disappeared.

The continued destruction of the v-notch weir resulted in an inability to maintain 'fish holding/harvesting' water levels when flow through the culverts was reduced to permit the upstream movement of carp. Thus, to maximise the harvesting potential of the WCSC in 2010, the construction of 'stepped' v-notch weirs (at least 2) is needed. With the head differential spread across multiple weir pools, water velocity and turbulence within each notch will decrease, thereby maintaining weir integrity and suitable fish holding/harvesting water levels within the culverts, as well as presenting less of a migration barrier to carp. Since similar carp behaviour was also observed in 2008, it seems reasonable to expect a similar response in 2010 (assuming a similar timing of filling). If that is the case, a pulsed flow to initially attract the carp from across the lake, followed by a relatively reduced 'trickle flow' might serve to maximise carp harvesting success whilst minimising carp spawning and recruitment potential (high salinities can have lethal effects on carp eggs and sperm; Whiterod and Walker 2006). However, this would only succeed if carp are able to reach the WCSC in the initial phase of filling via a stepped weir.

Native fish

In terms of large bodied native fish, bony herring were the only species recorded in high abundance. The very low or nil catch results for other large bodied native fish (Murray cod, golden perch, silver perch and catfish) suggest the abundance of these native species within Lake Bonney is currently very low. Previously, Murray cod and to a lesser extent golden perch, were both recorded in mortalities that occurred during a fish kill within Lake Bonney in 2008 (K. Marsland, SA MDB NRMB, pers. comm.). In addition, historical commercial catch data indicates that both species were once relatively common in Lake Bonney (Gary Warwick and Tony Smith, Commercial

Fishers, pers. comm.). Thus, although not in high abundance, the precautionary principle suggests future management strategies should account for the possible presence of these iconic native species.

Peterson mark-recapture experiment

The results of the Peterson mark-recapture experiment indicate that even after two large scale harvesting events (2008/09- 35 tonnes removed; 2009/10- 52 tonnes removed), a significant biomass of carp still exists within Lake Bonney (\approx 100 tonnes or 25,649 carp). While the 2009/10 commercial harvest did reduce the lake's adult carp biomass by an estimated 33%, this success may be masked by future carp recruitment stemming from carp spawning during September-November 2009 (indicated by young carp captured in the fyke nets set in December). The exact level of carp recruitment is thought to be relatively low (compared to the magnitude and duration of spawning observed) but this cannot be quantified until the young carp reach sexual maturity and become catchable at > 300 mm TL (via commercial fishers, or the WCSC).

Estimated WCHS catch

If the Lake Bonney wetland carp harvesting system was able to be operated during the 120 day (21st September 2009- 18th January 2010) inflow period, we are confident that it would have captured, at minimum, the carp biomass removed by the commercial fishers, which represented 33% of the population. It is speculated that a further 5-10 % of carp, which is estimated to have escaped the commercial fishing 'stop nets' or were present at times when the commercial fishers were absent, may have also been captured. Thus, it is estimated that a total of 38-43% of the population would have been captured by the cage if it was able to be operated.

Carp screens

The application of carp screens at Lake Bonney presented several key design challenges including the delivery of approx. $250-300$ ML d^{-1} of water through both culverts (approx. flow velocity of 1.87 ms^{-1}) to meet filling timeframes, entrapment of entrained aquatic fauna and debris in the inflowing water, carp attempting to exit the lake by jumping over the screens (as water levels increased), the requirement to keep

carp within the lake for targeted removal with the WCSC and, public access and vandalism.

The original grid mesh carp screen design fouled quickly, constricted culvert flow and trapped entrained bony herring but only a few turtles and carp. Whilst bony herring are not strong swimmers, the turtles may have been able to use the grid mesh as a ladder to climb over the screen, and carp may have been able to use the turbulence associated with the blocked screen to jump over the screens and into the lake. In contrast, the jail bar screens had minimal fouling and flow constriction, and trapped less bony herring but more carp and turtles than the grid-mesh. Without increased backwash and turbulence it appears carp were unable to jump the jail bar screen and, once exhausted, would lay sideways at the water surface which created a surface barrier that turtles could not negotiate. Although some bony herring got trapped on the jail bar screen, most could orientate vertically to pass between the bars. Regardless, because of the obvious problems associated with each screen type and their deterioration over time resulting from cheap construction and vandalism, it is recommended that such fixed screens not be used at Lake Bonney or at any similar site with high flows and unimpeded public access.

The new CPS (designed specifically for the high flow conditions at Lake Bonney) minimised flow constriction and the entrapment of entrained debris and fauna while providing a simple pivot/removal mechanism to enable easy cleaning and maintenance. In addition, the position of the CPS within the culvert (underneath the WCSC walkway), its heavy gauge construction and the ability to easily remove the screens between filling events should also minimise deterioration and vandalism. Although the key design element of permitting entrained fauna (particularly carp) to pass over the top of the screen was successful, this strategy might receive some negative attention from the general public. As such, it is recommended that educational signage detailing the requirement, design and function of the CPS be installed at the culvert. This signage should state that carp are positively rheotactic (Smith *et al.* 2005) and, having passed the screen, will orientate into the flow and move back toward the WCSC. Although further research is required to fully assess the utility of the new CPS (see below), the preliminary trial suggest these screens are well suited to high flow conditions.

Future considerations

Site requirements:

- The construction of stepped weirs (consisting of at least two v-notch weirs) that can withstand high flows during filling but maintain acceptable ‘fish holding/harvesting’ levels within the culverts during the low flow conditions is needed to trap and harvest carp as they attempt to migrate from the lake. The maximum current-velocity experienced at each v-notch should not exceed 0.8 m.s⁻¹. It is highly recommended that the development and installation of the proposed weir be conducted through consultation with professional engineers as well as scientists from SARDI Aquatic Sciences.
- The access door to the WCSC needs to be modified so that it opens above the newly installed walkway mesh.

Required future work:

- Evaluation of the wetland carp harvesting set-up, and the harvesting success of the WCSC under environmental flow conditions in 2010.
- Assessment of the long term function of the new carp pivot screens and carp deflector screens in high flow conditions e.g. their maintenance requirements, entrapment of entrained fauna, and ability to prevent the passage of carp >250 mm TL.
- Determination of the appropriate current velocities through the culvert(s) to permit carp access to the WCSC.
- Carp demonstrate a peak in spawning at the onset of increasing temperatures in early-spring (Vilizzi 1998; Smith & Walker 2004; Smith & Walker 2004), coinciding with the timing of flow delivery to Lake Bonney, and as there is limited aquatic vegetation (spawning habitat) within the lake, carp recruitment stemming from this first spawning (before the majority of carp are harvested) could potentially be minimised with a corresponding application of lime, as has occurred successfully in Lake Sorell, Tasmania (Chris Wisniewski; Inland Fisheries Service, Tasmania, Unpub. Data). Liming could occur from the onset of observed spawning for a nominal period, and thereafter hatch-dates of carp recruits could be evaluated to compare survivorship between ‘treatment’ and ‘non-treatment’ weeks.

- Finally, it is important to note that when/if the lake is reconnected to the river at pool level in the future, a new culvert that adheres to the Board's 'Your Wetland: On-Ground Works' manual should be considered for installation, to better accommodate water delivery, river/wetland connectivity and the passage of native fish. Complementary monitoring would validate this requirement.

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Thanks to all of the staff from SARDI Aquatic Sciences and Artec Engineering that were involved in getting the MKII WCSC set-up designed and installed and who were instrumental in overcoming the various design/site problems encountered along the way. Darren Jones (Artec Engineering) deserves special recognition for his exceptional workmanship, enthusiasm and determination. Also, thanks to Kelly Marsland and Brad Hollis from the SA MDB NRM Board and the commercial fishers Malcolm Wilksch, Gary Warwick, Damien Wilksch and Tony Smith for their help and support. Paul Brown and Anne Gason (Victoria Department of Primary Industries) provided useful input into the design of the Peterson capture-mark-recapture experiment. Finally, thanks to Dr Katherine Cheshire, Dr Dale McNeil, Sandra Leigh, Kylie Hall, Wayne Fulton and Heleena Bamford for providing constructive comments on earlier versions of this report. The SA MDB NRM Board, the Invasive Animals CRC and the MDBA funded this work.

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Appendix A

Draft Standard Operating Procedure (SOP) for the Wetland Carp Separation Cage (WCSC)

NOTE: This SOP is to be updated following the first operational trials of the WCSC planned for mid-late 2010

Design, installation and monitoring of a prototype Wetland Carp Separation Cage set-up

Standard Operating Procedure – Wetland Carp Separation Cage (WCSC)

Division Name: SARDI
Group Name: Aquatic Sciences, Inland Waters
Brief task description: Fish Separation Cage
Approved By: Ben Smith

SOP No: Leave for the moment
Date of last Revision: 30/10/09
Date for Review: October 2012
Review By (Author): Leigh Thwaites



Item No	STEPS <i>List the steps required to perform the task in the order they are carried out.</i>	HAZARDS / RISKS <i>Against each step list the hazards / risks that could cause injury or damage to equipment or the environment.</i>	SOLUTION <i>List the remedies required to either eliminate or control the risk/s for each step.</i>	PROTECTIVE EQUIPMENT <i>(see below) Please specify</i>				
1	Special notes	<p>This document details the Standard Operating Procedure (SOP) for the SARDI Wetland Carp Separation Cage (WCSC).</p> <p>WCSC operation requires the operators to work outdoors, adjacent to water, to use a towing vehicle and trailer, and a 3-phase generator.</p> <p>Note the WCSC site is to be accessed from the side access road to avoid personnel traversing the adjacent highway. The WCSC is to be operated by two trained persons at all times.</p> <p>Operators are to ensure First Aid kit is onsite and they can summon emergency assistance in the case of an emergency.</p> <p>Personal using this equipment must be familiar with and understand the requirements of the following Safety Instructions:</p> <ol style="list-style-type: none"> 1. General Safety- <ol style="list-style-type: none"> a. Sun protection (refer to PIRSA SOP 118) b. Manual lifting c. Working safely near water 						
1 Eye Protection	2 Breathing Protection	3 Head Protection	4 Hearing Protection	5 Hand Protection	6 Foot Protection	7 Protective Clothing	8 Face Protection	9 Other (Please specify)
								

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			<ul style="list-style-type: none"> • Ensure fencing and handrails in place 	
3	Pre-Inspection: Wetland Carp Separation Cage (WCSC) check	<ul style="list-style-type: none"> • WCSC failure (structural integrity) • Crushing hands, arms and fingers • Amputation hands, arms and fingers • Electrocutation 	<ul style="list-style-type: none"> • Check plant for all aspects of safe operations including footings, guide runners, door slides hoist chain, lock-out pins, cage, safety guarding, power board, earth stake etc, are free from corrosion, cracks, warping, wear and debris. • Check that AA batteries in control pendant and carry spare batteries • Check for tampering and vandalism of site. WCSC 	
4	Position trailer for harvest	<ul style="list-style-type: none"> • Reversing into WCSC (WCSC failure- structural integrity) • Run over by trailer and/or vehicle (broken bones, lacerations or death) • Reversing off vehicle ramp. • Jack-knife trailer 	<ul style="list-style-type: none"> • Second person to remain in visual and vocal contact with driver and direct reversing vehicle • Check trailer height to ensure it fits under fish guides • Ensure safety bollards are in place 	
	Pre-Start: Generator	<ul style="list-style-type: none"> • Electrocutation 	<ul style="list-style-type: none"> • Equipment should be serviced according to 	

1 Eye Protection	2 Breathing Protection	3 Head Protection	4 Hearing Protection	5 Hand Protection	6 Foot Protection	7 Protective Clothing	8 Face Protection	9 Other (Please specify)

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5	(also refer to PIRSA SOP 157)	<ul style="list-style-type: none"> • Asphyxiation • Burns • Inhaling fumes • Fuel ignition • Manual Handling 	manufactures manual <ul style="list-style-type: none"> • Inspect power board, earthing point and all cable connections to ensure working order • Attach generator earth cable to generator and earth stake • Check petrol level • Do not refuel in confined space or near ignition source (naked flame) • Check oil level • Attach generator power cable • Report any faults to manufacture and Lock out tag machine • Ensure two persons are available to load and unload generator. 	
6	Starting generator	<ul style="list-style-type: none"> • Electrocutation • Asphyxiation • Burns • Hearing damage 	<ul style="list-style-type: none"> • Ensure all step 5 solutions have been conducted • Refer to manufactures recommendation for starting 	Hearing protection

1 Eye Protection	2 Breathing Protection	3 Head Protection	4 Hearing Protection	5 Hand Protection	6 Foot Protection	7 Protective Clothing	8 Face Protection	9 Other (Please specify)

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8	During WCSC operation	<ul style="list-style-type: none"> • Amputation • Crushing • Flying debris • Electrocutation • Gantry failure 	<ul style="list-style-type: none"> • Both operators to stand behind red line • The control pendant operator must account for all on-site personal before operation and ensure no other persons have entered the site • Ensure generator earth cable is attached • A vocal alert warning must be made before raising and lowering the trap • When lowering cage ensure trap is fully lowered with minimal strain on hoist chain 	Eye protection
8a	Faults in WCSC operation	<ul style="list-style-type: none"> • Amputation • Crushing • Flying debris • Electrocutation • Gantry failure 	<ul style="list-style-type: none"> • If any fish catch or jam in the cage use a long pole with a gaff to remove them. Under no circumstances should operators enter the cage or place their hands or limbs in to the cage. • If hoist or generator fails during operation, 	

1 Eye Protection	2 Breathing Protection	3 Head Protection	4 Hearing Protection	5 Hand Protection	6 Foot Protection	7 Protective Clothing	8 Face Protection	9 Other (Please specify)

Design, installation and monitoring of a prototype Wetland Carp Separation Cage set-up

Standard Operating Procedure – Wetland Carp Separation Cage (WCSC)	
Division Name: SARDI Group Name: Aquatic Sciences, Inland Waters Brief task description: Fish Separation Cage Approved By: Ben Smith	SOP No: Leave for the moment Date of last Revision: 30/10/09 Date for Review: October 2012 Review By (Author): Leigh Thwaites



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			place Lock-out pins and tags in appropriate position on gantry and notify the responsible Manager to arrange repairs by the manufacturer	
9	Stopping generator	<ul style="list-style-type: none"> • Electrocutation • Asphyxiation • Burns • Hearing damage • Eye damage 	<ul style="list-style-type: none"> • Refer to manufacturers recommendation for stopping • Do not touch exhaust system • Ensure generator is in a well ventilated area 	

1 Eye Protection	2 Breathing Protection	3 Head Protection	4 Hearing Protection	5 Hand Protection	6 Foot Protection	7 Protective Clothing	8 Face Protection	9 Other (Please specify)

Appendix B

Draft user guide for the operation of the Lake Bonney wetland carp harvesting system

Scope

This user guide describes the Wetland Carp Harvesting System (WCHS) sited at Lake Bonney and its intended use. The Lake Bonney WCHS is the first of its kind, and therefore, this user guide is specific to it. Further, this user guide is brief, general in nature and in draft form because the cage has not yet been trialled. This guide should be consulted with reference to the draft Standard Operating Procedures (SOP) for the WCHS outlined in Appendix A, and video guidelines available from the Invasive Animals Cooperative Research Centre (IA CRC) or SARDI Aquatic Sciences (Invasive Species Sub-Program).

The IA CRC “Guidelines for the selection and implementation of carp management options at wetland inlets” report (Smith *et al.* 2009) should first be consulted to determine the suitability of any proposed site for the installation of carp management options, including WCHS.

Introduction

The Wetland Carp Harvesting System (WCHS, Fig 1) was developed by SARDI Aquatic Sciences, to catch carp >250 mm (total length, TL) emigrating from Lake Bonney during the delivery of 26 GL of environmental water from 21st September 2009 to 19th January 2010. The WCHS comprises a Wetland Carp Separation Cage (WCSC, including the cage, gantry, hoist and generator) and associated infrastructure, namely carp pivot screens and carp deflector screens. It is positioned in one of two box culverts in Chamber’s Creek. Both culverts have sluice gates, which control the delivery of water and which may disconnect the lake. The

Lake Bonney WCHS is fully compliant with all Australian design and OHS&W legislation and is designed to lift 1.5 tonne of carp per haul.



Figure 1. Photograph of the Wetland Carp Harvesting System at Lake Bonney, incorporating the Wetland Carp Separation cage, gantry, hoist, carp pivot screens and carp deflector screens. Completing the infrastructure are sluice gates (out of view, river [left] side of culverts), walkway mesh, handrails and security fencing.

The Wetland Carp Separation Cage (WCSC)

The WCSC incorporates central jumping and pushing trap elements, separating a 'holding zone' and a 'carp cage' (Figure 2). The jumping trap element is a height adjustable mesh barrier extending and maintained approximately 15 cm above the water's surface (at 'pool level') that carp must jump. It incorporates a non-return slide on the river side of the barrier to prevent carp from jumping the barrier in the reverse direction. The pushing trap element consists of a series of weighted one-way steel 'fingers', hinged from individual sleeves over a supporting shaft (the sleeves maintain the gaps between fingers and negate the lateral movement of fingers) suspended within a frame. The gap between the 'fingers' (31 mm) and 'finger' weights are minimised to allow the easy passage of carp ≥ 250 mm TL out of the lake. To 'push through' the one-way element, carp must push (lift) at least one finger far enough to create a gap that will allow it to either swim directly underneath the lifted finger or

between the lifted and adjacent fingers. Once a carp has pushed through, the finger(s) then fall shut, preventing carp from pushing back through the fingers.

Whilst most carp that enter the 'holding zone' will proceed to either jump or push their way into the 'carp cage', some will remain in the holding zone and need to be sorted from large-bodied native fish, which must be returned to the water. All adult carp that pass the trap elements, via jumping or pushing, are contained within a holding cage to enable removal. The cage is lifted, and the zones emptied, via infrastructure (gantry and hoist) designed to mechanically lift and automatically funnel captured fish into trailer mounted fish bins.

Cladding at the rear of the cage (mesh; vertical jail bar design, with a 31 mm aperture between bars) is designed to permit the unimpeded passage of small and medium sized native fish, while preventing the passage of carp ≥ 250 mm TL (Thwaites *et al.*, 2009; Hillyard *et al.*, in press)

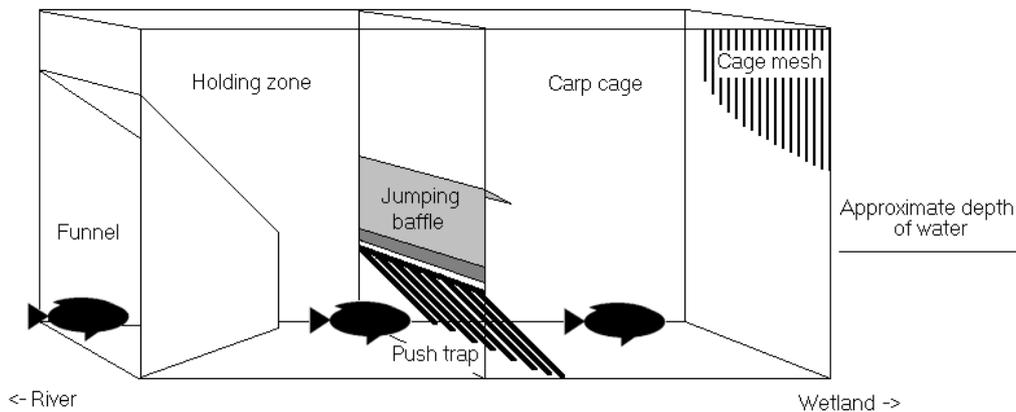


Figure 2. Schematic representation of the WCSC showing the entrance funnel, holding zone, jump/push trap element, carp cage and jail bar cladding with 31 mm aperture (cage mesh). Photograph of the WCSC set-up showing the two doors of the cage operating independently to allow each cage section to be emptied separately (with the holding cage door opening first).

Carp Pivot Screens & Carp Deflector Screens

Carp Pivot Screens are based on the original jail bar design and have 10 mm diameter bars spaced at 31 mm apart. They were specifically designed by SARDI Aquatic Sciences for application at Lake Bonney, where there are high flows ($>1.5 \text{ m}\cdot\text{s}^{-1}$) and vandalism. The carp screen is held in position by a 'pivot frame' which is fabricated from C-section. This frame is hinged and bolted to the base of the culvert. Using a braked-winch, the pivot frame holding the jail bar screen can be set at any angle (0-90°) or can be raised and locked in a vertical position (90°), where it can act as traditional carp screen. The jail-bar screen can also move vertically in the pivot frame to act as the gate for the WCSC or to be completely removed from the culvert for maintenance (Figure 3). All components were hot-dip galvanised to avoid corrosion.

Carp Deflector Screens were also designed for application at Lake Bonney, to work in conjunction with the carp pivot screens to prevent carp in the lake from jumping the carp pivot screens whilst they are in their operating position e.g. lowered to the water surface, yet allow entrained debris and fauna (i.e. carp, turtles, bony herring) to be washed over the top of the screen. The carp deflector screens were positioned out of the water, $\approx 15 \text{ cm}$ above the top of the pivot screen. This nominal distance is less than the mean depth ($>15 \text{ cm}$) of carp expected to jump vertically over the screens, and greater than the mean width ($\approx 9 \text{ cm}$) of large-bodied fauna expected to wash over the screens on their sides (Hillyard *et al.*, in press). While it was not ideal to allow some carp into the lake, it was unavoidable due to the conflicting requirements of containing the existing population of carp, whilst dealing with other operational constraints;

- A desire to maintain near maximum flow volumes through both culverts, to deliver the 26 GL of water in the desired time frame of three months.
- Resultant high-velocity flows ($\approx 1.87 \text{ ms}^{-1}$) for $>90\%$ of the filling event.
- Fouling due to entrained debris and fauna.

As carp are positively rheotactic (Smith *et al.*, 2005), it is anticipated that entrained carp washed over the screens, should subsequently orientate back into the flow and be vulnerable to capture in the WCSC.

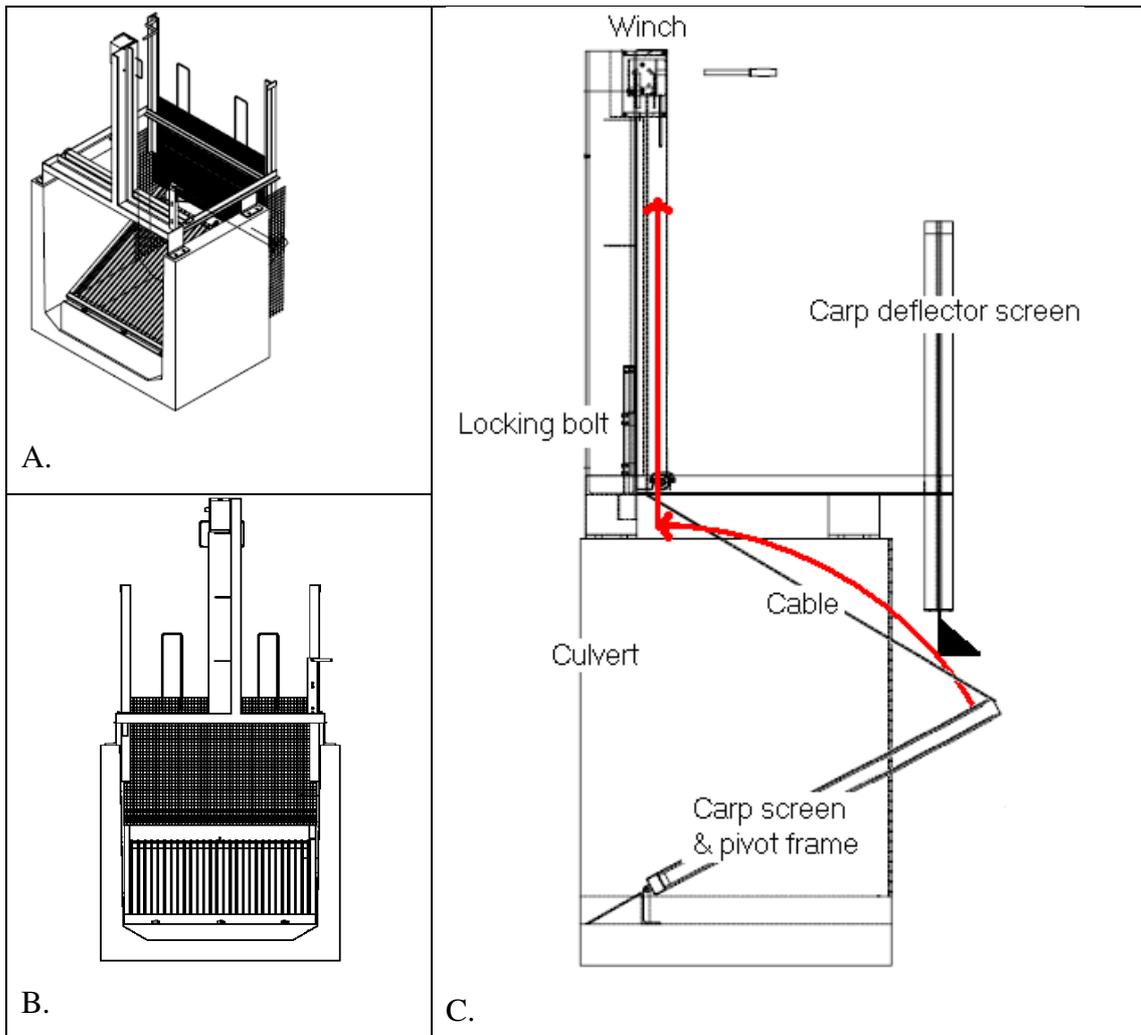


Figure 3. Workshop drawings of the carp pivot screen: A) Screen at 33°, B) screen in culvert fitted to the camber at the base of culvert C) showing the multi-function of the carp pivot screen—the red line indicates the direction of movement.

Operation of the WCHS

NOTE: This user guide must be read and used in conjunction with the entire SOP for the WCHS (Appendix B), before and during cage operation.

Arriving at the site

- Reverse your car and trailer into the southern side of the compound, and position the trailer centrally and below the funnels. Be careful not to reverse the trailer into the gantry structure – a second person providing directions will prevent this.
- Undertake a site and hazard assessment, ensuring that there are no hazards e.g. tripping, slipping, biological (snakes).
- Inspect plant for all aspects of safe operation, and ensure there are no obvious corrosion or vandalism issues.

Connecting WCSC to 3-Phase generator.

- The 3-phase generator can be operated out of the tray of a utility vehicle, to avoid excessive handling (the generator is >120 kg).
- Open all doors/windows (if applicable) for good ventilation, and ensure that no items are blocking the air intake or exhaust. Also ensure that flammable items are >1 m from the exhaust.
- Connect the 3-Phase and Earth cables to generator, then to the hoist power box on eastern side of the gantry.
- Check power box for spiders.
- Keep hoist power 'off' until the generator is started

Preparing cage and carp screens for operation

- Raise carp deflector screen, to enable carp pivot screen to be raised into a vertical position where it will act as a 'door' for the WCSC.
- Remove T-piece protecting the winch cabling.
- Add winch handle and raise carp screen to the vertical position.

- Start generator according to manufacturer's instructions and turn the hoist power to "on". NOTE: The hoist is operated by a remote pendant. The remote's 'safety-off' switch should be checked on every operation and reset when the control is turned on. Then, use the "Up" and "Down" buttons to raise and lower the cage, respectively. There are two speeds for the hoist: slow (1 m.s^{-1} , up/down buttons half depressed) and fast (4 m.s^{-1} , up/down buttons fully depressed).
- With all personnel standing at the front of the trailer (well away from the cage as it is operated), use the hoist remote control to raise the cage off the 'safety pins'. The remote operator should then remove the safety pins from the gantry structure and return to the front of the trailer.
- Completely lower the cage to the operating/fishing position.
- Raise the carp screen, so that the base of the screen is just out of the water and fish from the lake are able to access the cage (the screen can be completely removed for cleaning/maintenance).

Checking cage

- Using the hand-winch, fully lower the carp pivot screen into the vertical position, to hold carp back while the trap is being raised.
- Raise the cage using the hoist remote. Notice that as the cage is raised, the two doors open automatically and separately. The door to the 'Holding Zone' opens first; allowing native fish to be separated from carp and returned to the water. Otherwise, carp from this zone and the 'Carp Cage' should fall directly into the trailer for immediate transport and processing.

Re-setting the cage

- Using the hoist remote, fully lower the cage.
- Using the hand-winch, raise the carp pivot screen to enable fish to access the cage.

Packing up – leaving the trap out of the water

- At the completion of fishing, the cage should be raised out of the water so that the safety pins can be re-positioned. Then, slowly lower the cage onto those pins - the holding position.
- Re-set the carp pivot screens by winding them down until the top of the screen is positioned a few centimetres above the water surface (creating no turbulence).
- Replace the T-piece, which protects the winch cable and prevents people from tripping when the cage is not in operation.
- Replace carp deflector screen.

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