Appendices

Appendix 1

Review paper not presented at the Workshop
but included as a resource document

Screening Irrigation Offtakes in the Murray-Darling Basin to Reduce Loss of Native Fish

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EXECUTIVE SUMMARY

Fish protection screens are installed at irrigation diversions to prevent the entrainment of fish into the offtakes. Despite the heavy reliance of irrigation in the Murray-Darling Basin, to date there are no fish protection measures in place. This report identified different techniques available to screen irrigation diversions, and highlighted some of the important design elements. This included investigation of:

- Types and applications of fish screens
- Fish screen design
- Placement of fish screening structures
- Debris control measures

From these elements, recommendations on the most appropriate types of screens for irrigation diversions in the Murray-Darling basin have been made. This project demonstrates the process by which the most appropriate fish protection screen can be selected for a given situation. While there is information to guide the design of fish screens available, currently there is no information specific to the Murray-Darling Basin. There is a need to conduct a comprehensive study of native fish movements and biomechanics in the Murray-Darling system, in order to develop a set of design guidelines appropriate for the region. Without this, any preliminary screening attempts may prove to be ineffective.

ACKNOWLEDGMENTS

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1. Introduction

Fish protection screens are devices installed at surface water diversions to physically preclude passage of fish into the intake (WDFW, 2000). Screening irrigations offtakes to prevent the loss of fish has been a priority in many irrigation districts around the world for many years in response to a serious decline in fish numbers. To date however, fish screening practices have been non-existent in Australia. This is despite the fact that due to our climate we rely heavily on irrigation for our agricultural industry. This report seeks to identify different techniques available to screen irrigation offtakes to reduce the loss of fish, highlight important elements that should be considered in the design of fish screens and also to make recommendations on the basis of these findings. The Murray-Darling basin covers more than one million square kilometres, nearly one seventh of Australia, and is one of the largest catchments in the world. Approximately 80% of the flow in the Basin's rivers is diverted and currently there are no mechanisms associated with these diversions to prevent fish from leaving the rivers (MDBC, 2002). **Figure 1** shows the Murray-Darling Basin and areas of major irrigation within it.

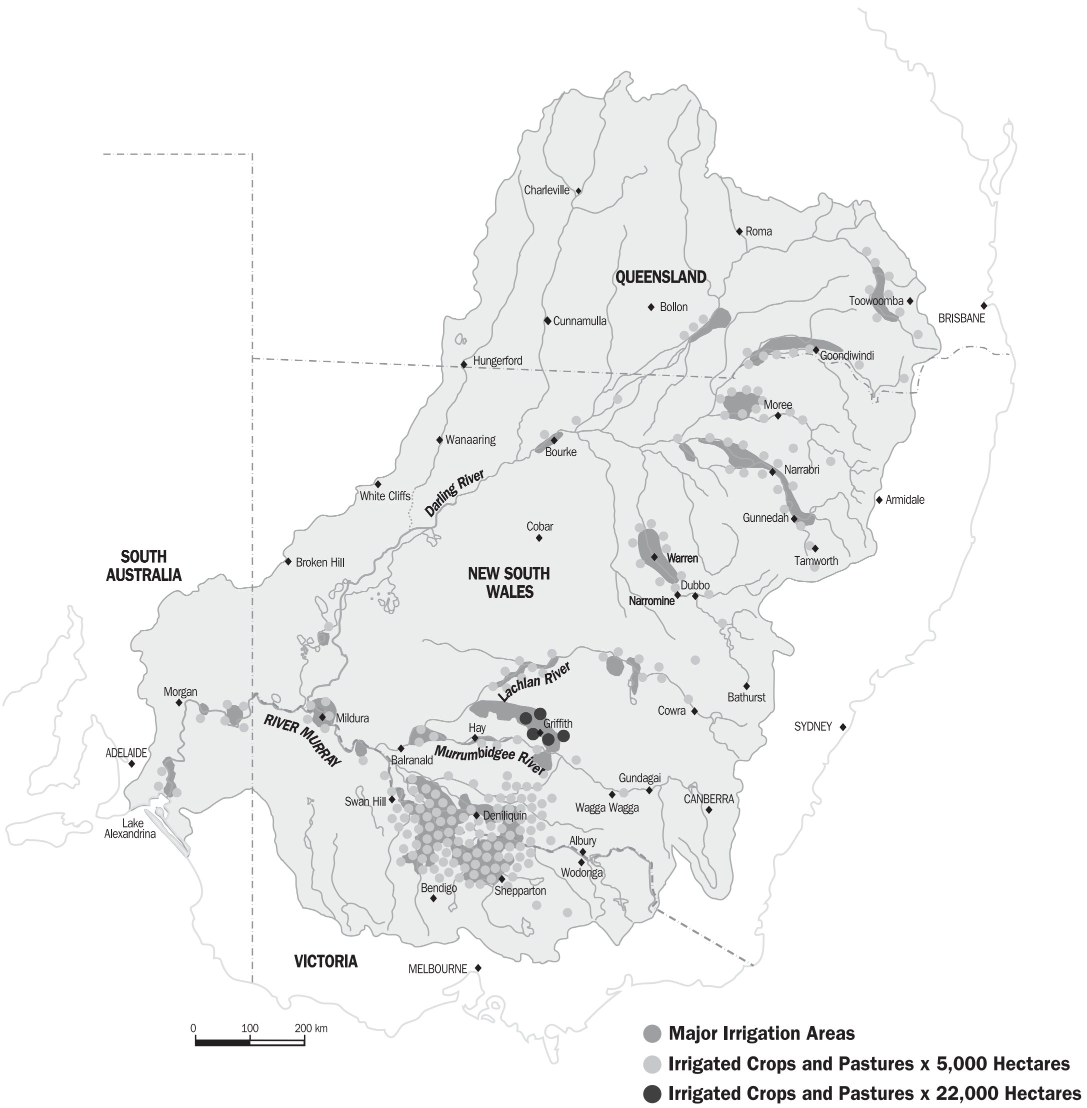

Figure 1 – Irrigation in the Murray-Darling Basin 1

Studies on fish movements in the Murray-Darling system have shown that many of the native species are quite mobile, especially in the summer months. Unfortunately, this coincides with the major irrigation season where the greatest volume of water is diverted into irrigation channels. Radio tracking devices have indicated that the native fish, and in particular juveniles, have a tendency to 'go with the flow' and follow the natural flow of the waterway. If this flow happens to enter an irrigation offtake then it is a fair assumption that any fish in that section of the water will all so enter the offtake. Research has concluded that, fish entrained into agricultural and municipal water diversions experience 100 per cent mortality (NMFS, 1994). To put this into perspective, it is estimated that of the native fish lost from the Basin's rivers each year, two-thirds of these are in fact killed in irrigation offtakes (MDBC, 2002).

2. Fish Screens – Types and Applications

A variety of different measures have been developed to prevent movement of fish from the parent body of water into irrigation offtakes (WDFW, 2000). Fish screens must be designed to protect the weakest swimming species of fish in their most vulnerable stage of development. This means that screens are designed to protect juvenile fish, because if a juvenile cannot make it past a screen then logically, a fully grown fish will not make it past.

Three main causes of injury or loss of fish at water intakes are; entrainment, impingement and predation.

- ***Entrainment*** – Occurs when as fish, either voluntary or involuntary, enters a water diversion
- ***Impingement*** – Where a fish comes into contact with a screen, trash rack or debris at the intake. This causes bruising, descaling and other injuries. If Impingement is prolonged or occurs at high velocities it causes direct mortality.
- ***Predation*** – Water intake increases predation by stressing fish and/or by providing habitat for fish and bird predators.

The majority of techniques employed to prevent entrainment, injury, or death of fish at irrigation offtakes involve the construction of a physical barrier to prevent fish passage. In order to achieve this, it is necessary to have a set of guidelines to which these structures must conform. These design considerations will be identified later in the report. This section aims to identify the most common fish screens in use and to describe their typical applications and limitations.

The following types of fish screening devices are used extensively in the USA as well as other parts of the world. As these devices have already undergone a large degree of testing and improvement, they will be the focus when looking at solutions to screening irrigation offtakes in the Murray-Darling Basin. These devices are:

- Rotary Drum Screens
- Vertical Fixed Plate Screens
- Vertical Travelling Screens
- Non-Vertical Fixed Plate Screens
- Pump Screens
- Infiltration Galleries
- Experimental Behavioural Devices

2.1 Rotary Drum Screens

The rotary drum screen is the most commonly used physical barrier in service for the protection of juvenile fish. It can be used for numerous applications but the most common function is in open channel flow situations, such as gravity irrigation channels. Using a single drum or multiples, rotary drum screens can be used to screen a wide range of diversions with flows from as low as 0.05 m^3/s up to 85 m^3/s or more (WDFW, 2000). This type of screen has undergone extensive biological testing, with the results generally showing better than 98% survival of juvenile fish (Nordlund, 1996). **Figure 2** shows a rotary drum screen in isometric view while **Figure 3** shows it from a side elevation.

Water passes through screen mesh that covers a rotating cylinder. The greatest advantage of a rotary drum screen is that due to its rotation, it continually removes any debris that may accumulate. The debris is picked up by the screen mesh and is deposited downstream side of the screen, leaving the screen clean. It is important to note that large pieces of debris will not necessarily be removed by this method and may need to be manually removed from the vicinity of the screen face.

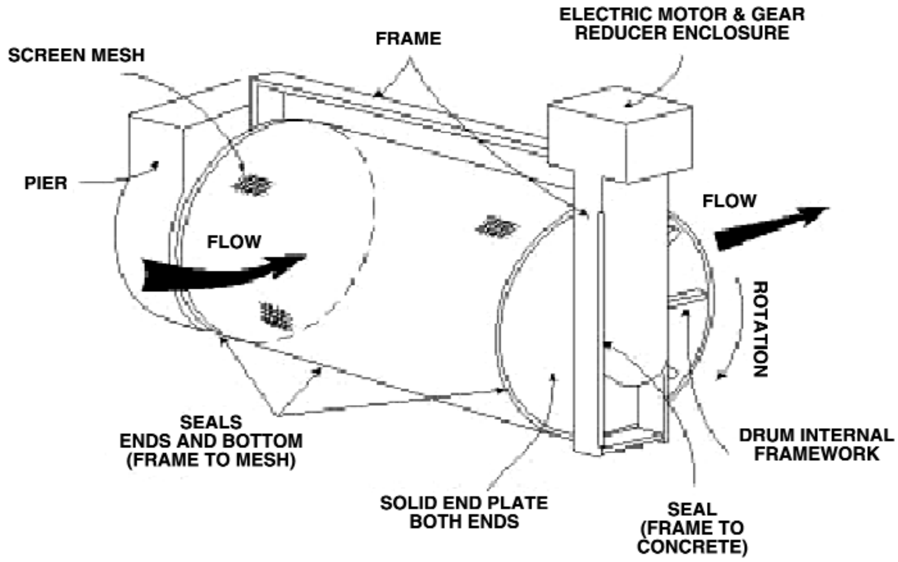

Figure 2 – Isometric View of Rotary Drum Screen (WDFW, 2000)

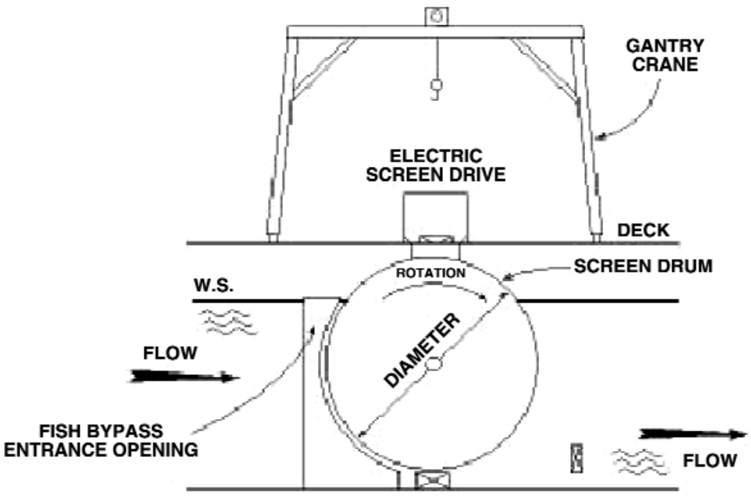

Figure 3 – Side Elevation of Rotary Drum Screen (WDFW, 2000)

A rotary drum screen operates by utilising a power system to permanently rotate the drum. Screen rotation can be achieved by a number of energy sources. These include;

- Electric Motor
- Paddlewheel
- Solar Drive
- Hydraulic Motor

In order for a rotary drum screen to remove debris, it must be properly submerged. Because of this submergence becomes a major design parameter for this type of screen. For successful operation, the screen must always have between 65% and 85% submergence (WDFW, 2000). This can be seen as a disadvantage of this type of screen as there is only a narrow range of submergence required for acceptable performance. Submergence greater than 85% dramatically increases the potential for fish entrainment and impingement on the screen. At a submergence level less than the desired minimum (65%), debris is not efficiently picked up on the face of the screen. Once again this greatly increases the chance of impingement to occur.

Another disadvantage of the rotary drum screen is that it requires on-going routine maintenance. Since the drum is continually rotating, wear on the side and bottom seals must be closely monitored, depending on site conditions. Silt accumulations in front of a rotary drum screen can wear seals quickly, so sometimes a sediment sill is incorporated into the design that allows for a deposition of sediment that can be removed on an annual basis (Nordlund, 1996). The failure (or leakage) of the seals can result in fish impingement. The mesh also requires a regular inspection for signs of wear or damage. At some locations it has been noted that mesh has experienced fouling due to algal growth. The problem of algae can be solved quite simply by using a mesh with growth inhibitor characteristics, such as phosphor bronze, or by installing additional cleaning mechanisms such as internal spray bars.

2.2 Vertical Fixed Plate Screen

The vertical fixed plate screen is also one of the most common screens used in practice. They have many diverse applications in that they are used for industrial, domestic and irrigation intakes, at both pump and gravity diversions. Much of their popularity comes from the fact they are relatively simple to tightly seal because the mesh is fixed directly to the structural frame. There are also no moving parts or wear surfaces between the screen mesh and structural frame resulting in less maintenance. **Figures 4 and 5** show an example of a vertical fixed plate screen arrangement in both plan and side elevations.

A major advantage of the vertical fixed plate screen is that it can be built in a canal with much less blockage of the canal cross section and flow compared to a rotary drum screen. This is because narrow columns can suffice for the supporting piers rather than having to accommodate the drum diameter. Also, for small diversions, vertical fixed plate screens can be installed on the bank of a river and therefore require no bypass.

The disadvantage of a vertical fixed plate screen is that removal of debris may be more difficult than with a rotary drum screen depending on the type of debris present. Because of this vertical fixed plate screens must incorporate a mechanical cleaning system for the removal this debris. Two common mechanical cleaners for vertical fixed plate screens include travelling brush cleaners and hydraulic back-spray systems. The best brush cleaners produce a small eddy behind the brush as it travels the length of the screen, allowing debris to be suspended until

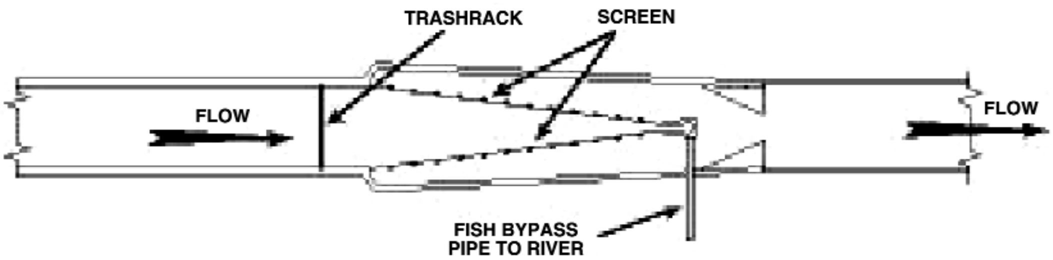

Figure 4 – Plan Elevation of Vertical Fixed Plate Screen (WDFW, 2000)

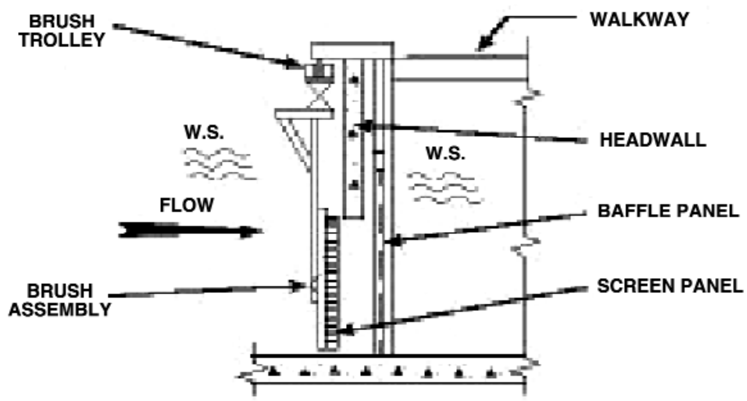

Figure 5 – Side Elevation of a Vertical Fixed Plate Screen (WDFW, 2000)

it is passed of the downstream end of the screen (Nordlund, 1996). The operation of the cleaning system is activated by a timing mechanism, a head loss detection unit or a combination of both.

2.3 Vertical Travelling Screens

Vertical travelling screens are a widely used screening technique mainly utilised for pump diversions. There are two varieties of vertical travelling screens commonly used; panel type and belt type. The difference between the two types is in the screening mesh itself. Panel type screens have many discrete mesh panels that are hinged together, while a belt type screen is constructed of a continuous belt mesh. Similarly, both screens are driven by electric motors through a drive shaft at the top and rotate around a parallel idler shaft at the bottom (WDFW, 2000). This is illustrated in **Figure 6**.

The advantages of a vertical travelling screen are similar to those of a rotating drum screen in that the mesh rotates to remove debris to the downstream side of the screen. Other advantages include:

• Scope for installation on a river bank (therefore requiring no bypass)

• Civil Works are relatively minimal

• They can be installed in deep water

Because the screen lifts vertically, there is no limitation on minimum or maximum screen submergence to be effective (WDFW, 2000).

There have been a number of disadvantages of the vertical travelling screen that have become apparent. The main one stems from the fact that these screens were originally designed to keep debris away from pump intakes rather than protect fish. Although this original design has been modified, problems with current screens still exist. Many installations of these screens show high incidence of impingement and entrainment, due to improper alignment, mesh size and mesh seal problems (Nordlund, 1996). Mesh seal problems are difficult to identify, since the screen is often located in a sump.

2.4 Non-Vertical Fixed Plate Screens

Fixed plate screens do not always have to be orientated in a vertical direction. Other possible alignments include:

• Downward Sloping Flat Plate Screens

• Downward Sloping Contoured Plate Screens (Coanda Screens)

• Upward sloping Flat Plate Screens

Downward sloping screens can either be constructed as a flat plate or a contoured plate such as the Coanda screen. This design operates by allowing a percentage of the flow over the

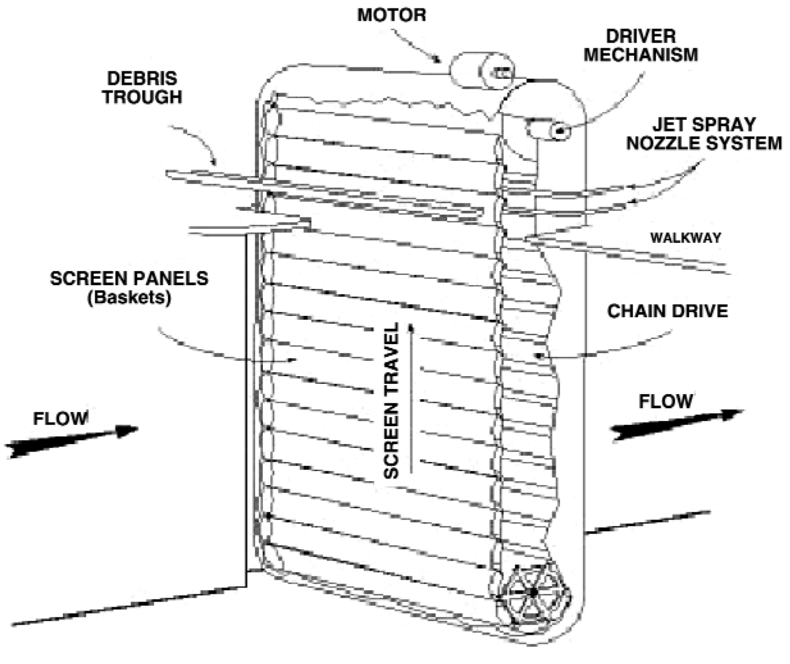

Figure 6 – Vertical Travelling Screen (WDFW, 2000)

screen to pass through it. The flow that passes through the screen falls into a canal situated below the screen, where it is routed to where it is required. Any fish or debris that are present in the original flow are passed over the screen with the remainder of the flow. **Figure 7** and **Figure 8** detail the non-vertical fixed plate screen and the Coanda screen respectively.

In terms of fish passage, downward sloping screens only function successfully if sufficient flow depth exists at the downstream end of the screen. This allows debris to be moved downstream where it won't pose a hazard to fish passing over the screen. The minimum flow over a screen face should be based on expectations of size and type of debris, size and condition of fish

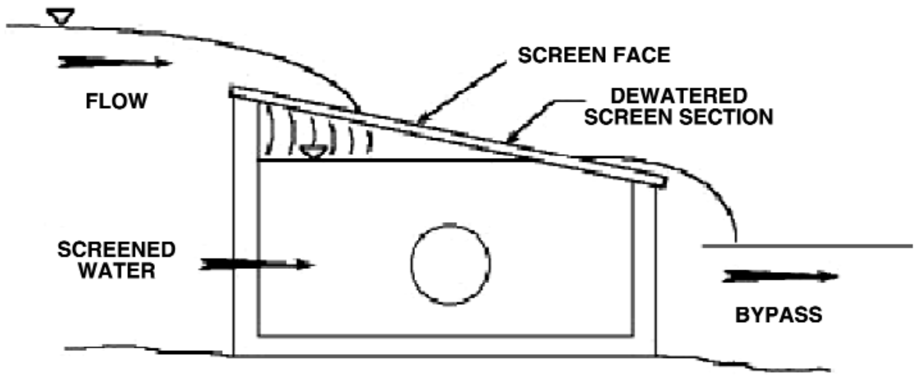

Figure 7 - Downward Sloping Flat Plate Screen (WDFW, 2000)

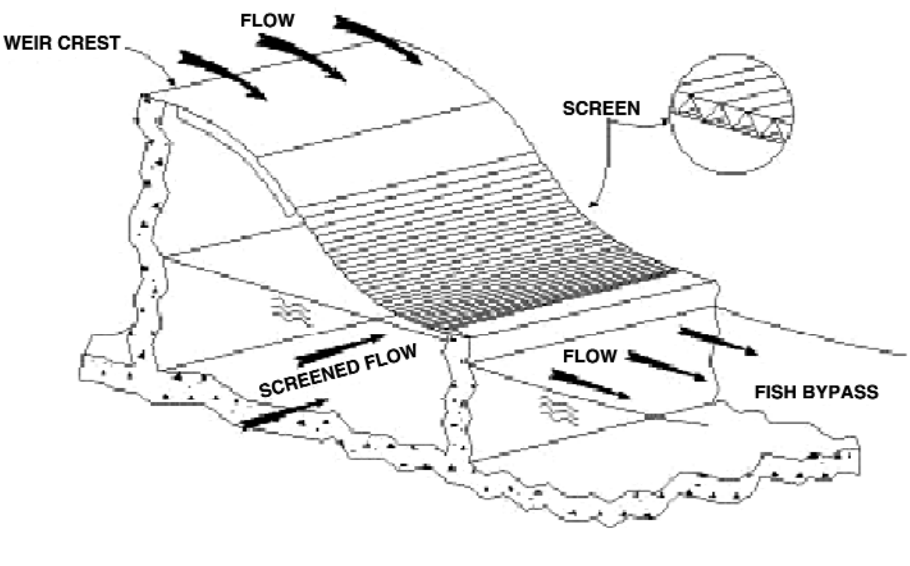

Figure 8 - Downward Sloping Coanda Screen (WDFW, 2000)

passing, and potential changes in flow that could reduce the depth to below the desired minimum (WDFW, 2000). For these prescribed minimums, substantial amounts of bypass flow is often necessary, and even the use of headgates to regulate flows. Downward sloping screens are generally used for gravity diversions however they do require up to a metre of head to operate successfully.

Downwards sloping flat plate screens can also suffer from non-uniform flow distribution across the screen. This is due to the water depth of the upstream end being greater than that at the downstream end. This non-uniform flow can make transition across the screen difficult for fish that tend to avoid regions of variable flow. Traversing through non-uniform flow can also disorientate or stun juvenile fish, making them an easy target for predators. The contoured plate on a Coanda screen helps to minimise this effect as the head driving flow through the screen is more uniform. However, the contour of the screen will only be optimal for a certain flow rate and a variation of the flow magnitude will create problems similar to that of the flat plate screen.

Upward sloping screens are the opposite of downward sloping screens in that their profile rises in the direction of the flow as seen in **Figure 9**.

As can be seen in the diagram above, water drops over the downstream end of the screen creating the fish and debris bypass. An advantage associated with this type of screen is that there is generally uniform flow distribution through the screen due to a uniform head differential throughout its area (Nordlund, 1996).

Unlike the downward sloping plate screen, the upward sloping flat plate screen does require an automatic cleaning device that can add significantly to the cost of the screen. If the doesn't remain clean, the weight of debris build up on the screen may cause structural failure. The operation of this screen is also very sensitive to the minimum bypass depth. Typically a depth of at least 30 cm is required to keep fish from rejecting the bypass (WDFW, 2000). This means that if the upstream water surface elevation is not high enough, the minimum bypass depth will not be achieved.

2.5 Pump Intake Screens

Pump intake screens are basically a variety of screens built at the end of a pumping intake to prevent fish and debris from being sucked into the pump. The most common design of these screens is either a box or cylinder, with the walls constructed from screen mesh and the suction pipe entering into one of these walls.

An advantage of pump intake screens is that there are many different screen configurations that are commercially available meaning they do

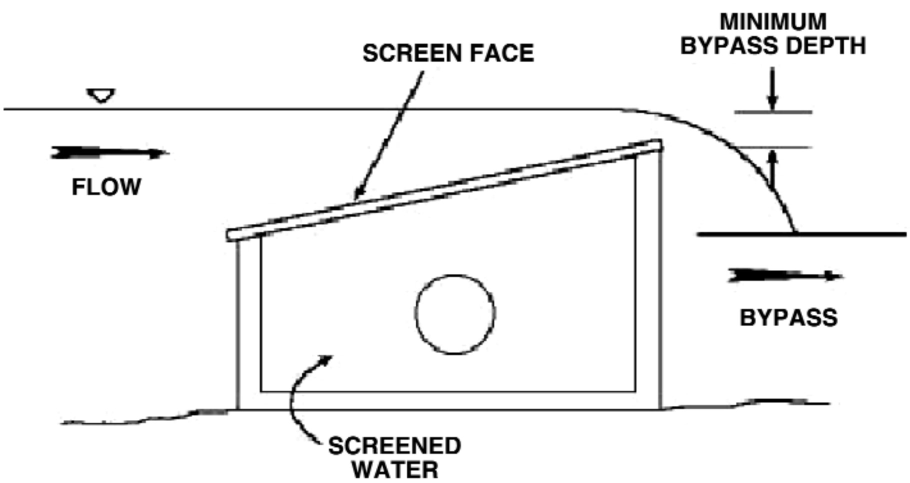

Figure 9 - Upward Sloping Flat Plate Screen (WDFW, 2000)

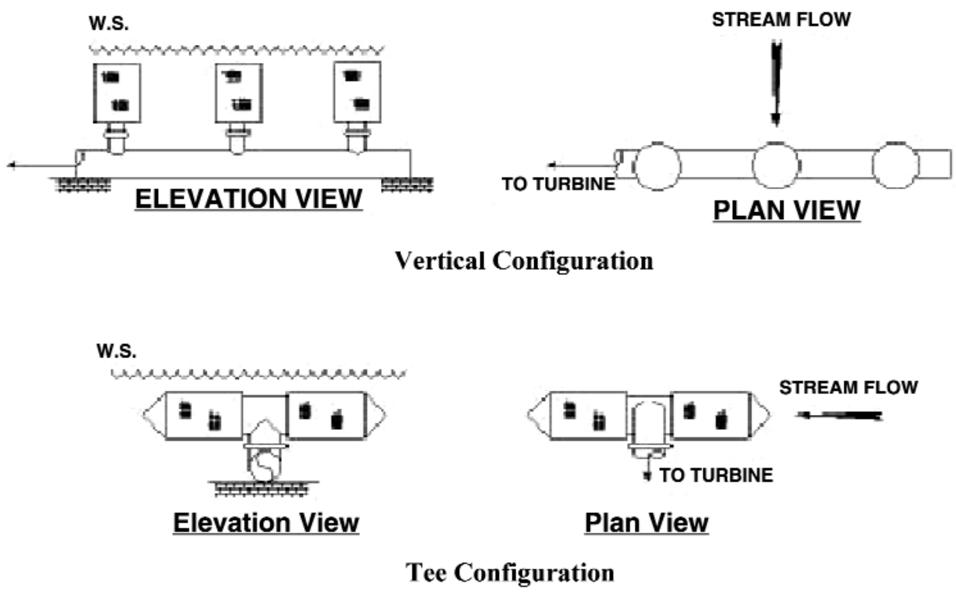

Figure 10 – Configurations of Pump Intake Screens (WDFW, 2000)

not require custom construction. The flow range of these screens is approximately 0.03 m^3/s to over 2 m^3/s. The area of the screen must be large enough so that the flow velocities entering the screen are not too great, to minimise the chance of fish impingement. For large flow intake applications, it is possible to place a number of screens in series as demonstrated in **Figure 10** to reduce the velocity at the screen face.

The disadvantage of pump intake screens is that they are quite susceptible to clogging from debris. Because of this there have been a number of different systems developed to automatically clear the screens of debris.

These include:

• Fixed spray bar, rotating screen

• Fixed screen, rotating spray bar

• Internal air burst

The first two of these cleaning systems are reasonably self explanatory. The internal air burst operates by backwashing the screen with a burst of air. This has been used with quite a large degree of success but care needs to be

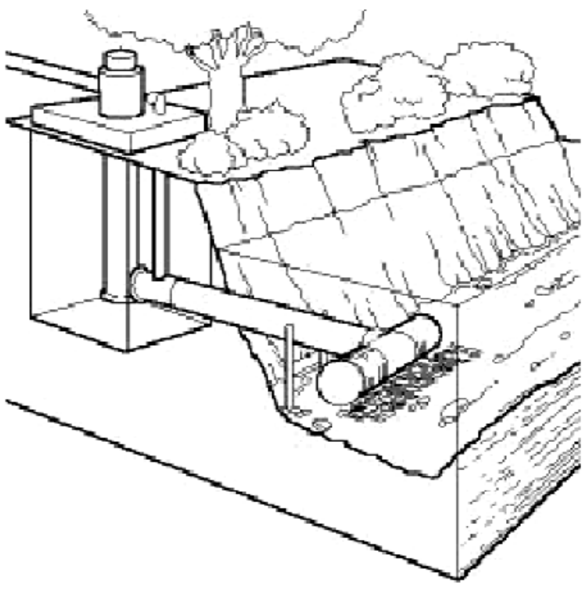

Figure 11 – Tee Configuration Pump Intake Screen (WDFW, 2000)

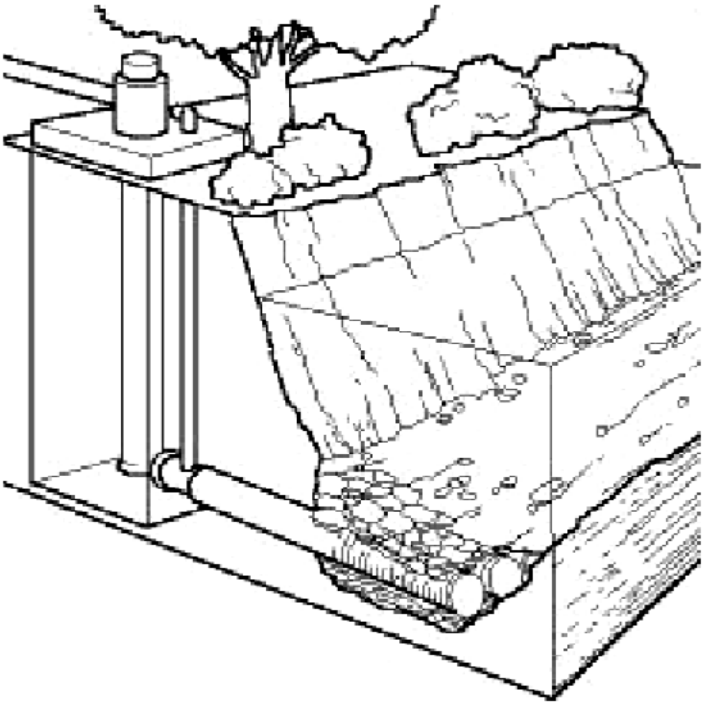

Figure 12 – Layout of an Infiltration Gallery (WDFW, 2000)

taken to ensure that it removes debris accumulation from the bottom of the screen which is sometimes overlooked.

Pump intake screens have the option of being a permanent submerged structure or they can be designed to be retractable for ease of maintenance. Either way they can be used in a variety of water depths, from shallow to very deep. Regardless of the depth of installation it is advantageous for there to be significant flow to carry debris away from the pumping site. This will increase the effectiveness of other the debris removal measures mentioned above. **Figure 11** shows a typical pumping site fitted with a cylindrical tee pump intake screen.

2.6 Infiltration Galleries

Infiltration galleries consist of perforated pipe manifolds or single pipes buried perpendicular to the stream channel approximately one metre below the stream bed (OFWO, 2002). Water infiltrates through the stream bed and into the pipe system where it is drawn away to be used. The pipes must be installed in a steep section of a river such as slight rapids, which is maintained free of fine sediment due to the hydraulic action of the stream. For example they must be installed in a location where the bed is regularly scoured and thereby cleaned, rather than in a depositional area such as an artificial pool. The section of stream also needs to comprise very coarse bed material to ensure adequate flow to permeate. Infiltration galleries are usually associated with pump diversions; though can be used at gravity diversions where there is adequate head available to drive the flow (WDFW, 2000).

The advantage of infiltration galleries is that when they are successfully placed in the right location, the stream hydraulics manages the debris and sediment without the need for an expensive cleaning system. They are extremely successful in screening fish as the screen is simply made up of the stream bed which the fish cannot, and have no desire to, penetrate.

The disadvantage of infiltration galleries is the risk associated with them becoming clogged with sediment or other types of debris. Once an infiltration gallery becomes clogged with sediment, it is very difficult maintain because it is buried in the stream bed. The best method to maintain them is firstly by placing them in the correct location in the stream to begin with, and secondly to make allowances for the system to be reverse flushed with either pressurised water or air.

The failure rate of infiltration galleries is high; approximately 50% (WDFW, 2000). This failure rate is generally the result of poor understanding of the technical design requirements of an infiltration gallery, coupled with installation at an unsuitable location. **Figure 12** shows the layout of an infiltration gallery at a pump diversion.

2.7 Experimental Behavioural Devices

Fish behavioural devices have been experimented with since the 1960's as a substitute for physical barrier screens (EPRI, 1986). This has been brought about by the high cost often associated with conventional screening techniques. At diversions of high flow (10-15 cubic metres per second or greater), the low velocity requirement and structural complexity can drive the cost for fish protection and the associated civil works to over a million dollars (NMFS,1994).

A behavioural device, as opposed to a physical barrier, requires a deliberate response on the part of the fish to avoid entrainment. The philosophy behind these devices is to either attract or repel fish, depending on the specific desire for the area in which the device is placed. This is achieved by the device transmitting a signal to trigger a behavioural response from the fish, usually noticeable agitation. Unfortunately, to date using these startle investigations to develop effective fish guidance systems has not been effective (NMFS, 1994).

Experiments show that there is a large variation in response between individual fish of the same size and species. Because of this, it cannot be predicted that a fish will always move towards or away from a certain stimulus. Evidence also shows that even when such a movement is desired by a fish, it often cannot distinguish the source or direction of the signal and therefore may not swim in the required direction.

One of the factors to explain the poor performance of behavioural devices is that many do not incorporate a controlled set of hydraulic conditions to assure fish guidance, as do the physical screening systems. This means that the devices can encourage fish movement in directions that actually contrast with the expected natural response. Because of this, the fish gets mixed signals about what direction to move. Another concern is that of repeated exposure in that over a length of time a fish may no longer react to a signal that initially was an attractant or repellent.

In addition to the unpredictable response of an individual fish, it is expected that behaviour variations will occur due to size, species, life stage, and water quality conditions. In strong or accelerating water flows, the swimming ability of a fish may prevent it from responding to a stimulus even if it attempts to do so.

The main motivation for choosing to install behavioural devices is for the purpose of cost saving. This is because much of the cost in conventional systems is for the physical structure needed to provide proper hydraulic conditions. Ironically, implementing a behavioural device with its own structural requirements may lessen much of its cost advantage.

Present scepticism over behavioural devices is supported by the fact that few are currently being used in the field and those that have been installed and evaluated seldom exhibit consistent guidance efficiencies above 60 per cent (NMFS, 1994). Given this, until improved technology is obtainable it would be difficult to recommend the use of this system.

3. Fish Screen Design

In the design of fish screens, it is important to keep the project in perspective and not loose sight of the main aims. Fish screening is an issue due to the fact that people have to divert water for irrigation. Therefore, the primary design considerations of any fish protection device are based upon hydraulics. The screen must allow a sufficient quantity of water to pass through with minimal head loss, while still providing conditions that prevent entrainment, impingement, or predation of fish.

Protection criteria have been developed in accordance to these requirements, and if carried out correctly can successfully protect fish whilst posing no threat to the operation of the irrigation offtake. These criteria are quite conservative, and are based on protecting the weakest swimming species, at their most vulnerable time, under adverse environmental conditions.

The most critical aspects of a successful fish protection screen are based on control of conditions around the screens. This section is to examine the conditions from the perspective of fish protection. These critical design considerations are:

- Approach Velocity
- Screen Size
- Screen Materials
- Sweeping Velocity and Screen Orientation
- Fish Bypass System

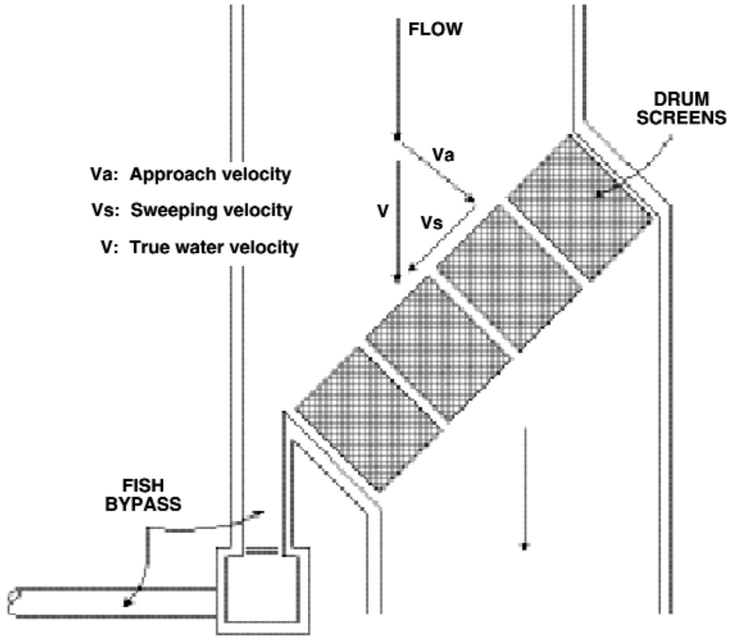

Figure 13 – Velocity Vector Components (WDFW, 2000)

3.1 Approach Velocity

The primary objective in the design of fish screens is to match the swimming ability and behaviour of fish, to the hydraulic characteristics of the screen and civil works design, to minimise the probability of contact with the screen (WDFW, 2000). This means that the screen design must ensure that the velocity of the water flowing towards the screen is low enough so that fish can voluntarily prevent themselves becoming impinged on the screen. Because of this, approach velocity is one of the most critical characteristics when designing fish protection screens.

Before setting design limits on the approach velocity, it is necessary to define what it actually is. The true water velocity approaching the screen can be broken up into vector components as shown in **Figure 13**. The approach velocity is the component the flow perpendicular to the orientation of the screen. In other words, this is the component of the flow that actually travels through the screen. The other component flows parallel to the screen face. This is known as the sweeping velocity and will be discussed later.

Juvenile fish must be able to swim at a speed equal to or greater than the approach velocity for an extended length of time to avoid impingement on the screen (WDWF, 2000). It is therefore necessary that a study on fish biomechanics be conducted in order to determine the sustained swimming speed of the weakest swimming species of fish present, to use at a design parameter. This study would be quite complex as there are a number of factors apart from individual fish species that affect their speeds. Some of these factors include; water temperature, fish size, dissolved oxygen content, and water quality. This study is beyond the context of this project.

To give an estimate of the allowable magnitude of the approach velocity, a comparison is made to a fish species found in the USA. In the case of juvenile pacific salmonoids, nearly 100% of fry (fish less than 40mm in length) are protected if approach velocity is less than 0.122 metres per second (Nordlund, 1996). This value is the accepted design value for most parts of the world. The only time this varies, is if studies prove that fish of this size and swimming ability are never present near a particular offtake, and that only stronger swimming species are present.

To determine the approach velocity, simple trigonometric relationships are applied to the flow velocity of the canal and the vector components are determined.

This is shown in Equation 1 below.

$$V_a = V \text{ sine } Ø$$

Where: V_a **= Approach Velocity (m/s)**
V = Canal Velocity (m/s)
Ø = Angle between Screen Face and Canal Flow Line

Equation 1 – Approach Velocity

3.2 Screen Size

The size of the screen is one of the most important factors to consider when designing fish screens. It is screen size that dictates what the approach velocity on a canal will be based on a particular design flow rate. The relationship between approach velocity, screen size and flow rate is shown in Equation 2 below.

$$A = Q / V_a$$

Where: V_a = Approach Velocity (m/s)

Q = Design Flow Rate (m^3/s)

A = Effective Screen Area (m^2)

Equation 2 – Required Screen Area

As Equation 2 showed, the screen area calculated is the effective area. This takes into account the area covered by seals and other potential obstructions and any area that is not submerged. The effective area is therefore the gross area of the screen, not the open area of the mesh. Because of this it is important that the design considers the area of submerged screen throughout the entire range of diverted flows. Design must also consider the possibility of a percentage of the screen face becoming ineffective due to blockages caused by debris.

There are some situations where the water level of the canal must be raised as it approaches a fish screen in order to provide sufficient screen submergence. An example of this is in the use of rotary drum screens that have a low tolerance of submergence levels as mentioned earlier.

3.3 Screen Materials

Many different types of materials have been developed for the use for fish protection screens. This report will focus on the three most common materials; perforated plate, profile bar and woven wire. For each of these materials, design criteria have been established based on protecting

Table 1 – Criteria for Screen Face Material Based on Juvenile Fish Size (WDFW, 2000)

	Fry Criteria (Fish less than 60mm)	**Fingerling Criteria** (Fish greater than 60mm)
Perforated Plate (maximum opening diameter or slot width)	2.38mm	6.35mm
Profile Bar (maximum width opening)	1.75mm	6.35mm
Woven Wire (maximum opening in the narrow direction)	2.38mm	6.35mm
Minimum Open Area %	27	40

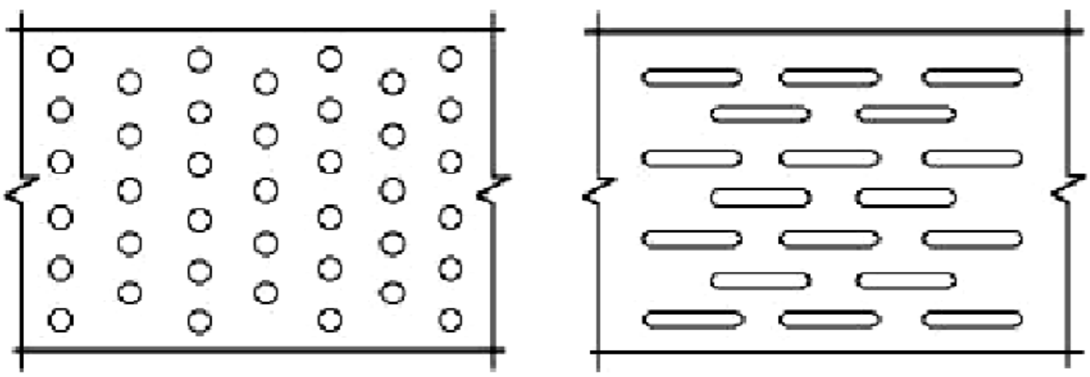

Figure 14 - Perforated Plate

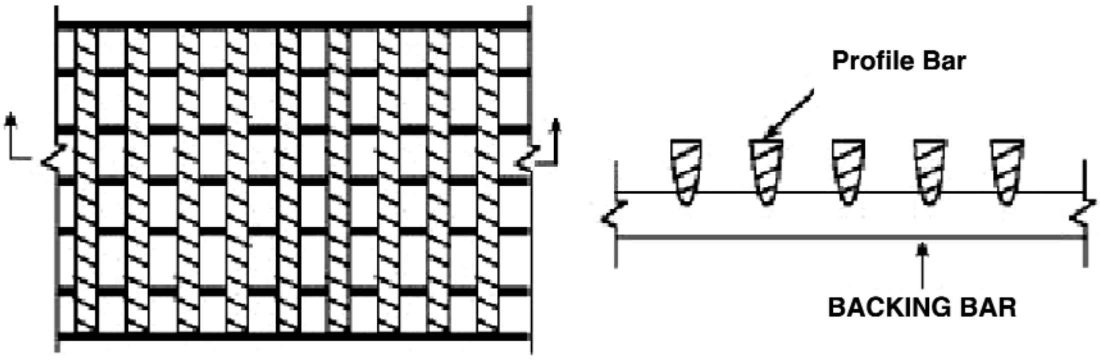

Figure 15 - Profile Bar

juvenile fish. These criteria relate to the maximum opening dimensions to prevent entrainment as well as minimum open areas to ensure that water can pass freely through the material. **Table 1** presents these criteria.

Perforated plate is constructed from sheet metal, with a number of holes or slots drilled into it. The plate is generally either stainless steel or aluminium for corrosion protection and can come in a variety of thicknesses. Thick plate is generally used when there is a high probability of large debris striking the screen, however as the plate gets thicker, the head loss across it becomes greater. **Figure 14** shows two different configurations of perforated plate.

Profile bar is constructed of parallel stainless steel bars welded to a structural backing. It is the strongest of all the screen materials, but also the most expensive. Profile bar is a common commercial product with a variety of bar geometries, sizes, and slot widths between the bars (WDFW, 2000). Profile bar can also be constructed in a cylindrical arrangement for use in pump screen applications.

In use, profile bar can be orientated either vertically or horizontally, depending on the type of cleaning system used in conjunction with it. For example, if a brush cleaner was utilised to clean the profile bar, then it would have to travel in at same direction as the orientation of the bars. **Figure 15** shows a schematic of the profile bar.

Woven wire mesh, as the name suggests, is constructed from wire that has been woven together to form a permeable mesh. It is quite versatile and because of this is one of the most common screen materials used. It versatility comes from its ability to be constructed out of varying gauge wire depending on conditions. If there is only small debris present at a screen site then the mesh can be of fine grade. Conversely, if large sized debris is present, a more heavy duty gauge of wire may be necessary. An example of a woven wire mesh can be found in **Figure 16**.

3.4 Sweeping Velocity and Screen Orientation

As mentioned previously, the water flow in a canal can be separated into two directional vectors. The sweeping velocity is the component of the true water velocity that runs parallel to the screen face as seen in **Figure 13**. This

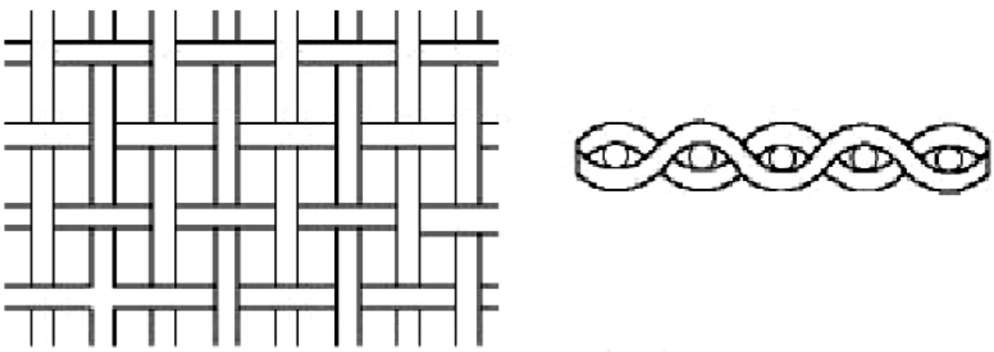

Figure 16 - Woven Wire Mesh

sweeping velocity is extremely important as it is responsible for guiding fish across the face of the screen to the bypass. To guide fish to a bypass, the sweeping velocity component should be as least as great as the approach velocity (WDFW, 2000).

Sweeping velocity is determined by the orientation of the screen relative to the direction of the true water flow in the canal. Therefore, in order to meet the criteria of sweeping velocity being at least equal to approach velocity, the screen should have a maximum angle of 45 degrees to the canal flow. If the angle of the screen is reduced to below 45 degrees, then the sweeping velocity component becomes larger than the approach velocity. This is sometimes a requirement depending on the conditions of the site and the type of fish being screened.

For screens installed directly on the river bank at the entrance of a diversion, it is the natural flow direction in the river that provides the sweeping velocity. However, at time of low flow or high water extraction, the flow of the river can vary to the point where the majority of the flow is actually in the direction of the approach velocity. If a screen is susceptible to this occurrence, a guide wall may have to be constructed to create geometry similar to that on an angled screen in a canal. This will alter the sweeping velocity to conform to the guidelines mentioned above.

3.5 Fish Bypass System

A fish bypass system is a flow route designed to transport both juvenile and adult fish from the face of the screen back to the river and is necessary if the screen is not located in the river itself (WDFW, 2000). Screens located in on the bank at an offtake diversion do not require a bypass system, as the fish always remain in the main waterway. While the actual design of a fish bypass can be quite complicated, the diagrams shown in **Figures 17 and 18** illustrate the major components of a system in a straightforward manner. This example shown is for a drum screen installation.

There are a number of design considerations that must be taken into account if the bypass system is to operate successfully by returning fish back to the main waterway at a safe location, with minimum risk of injury. These major design considerations can be summarised into the following points:

- Entrance Geometry
- Entrance Velocity
- Bypass Conduit
- Return Delivery

The geometry of the entrance to the bypass system is one of the most important and critical component of the entire screening system. This

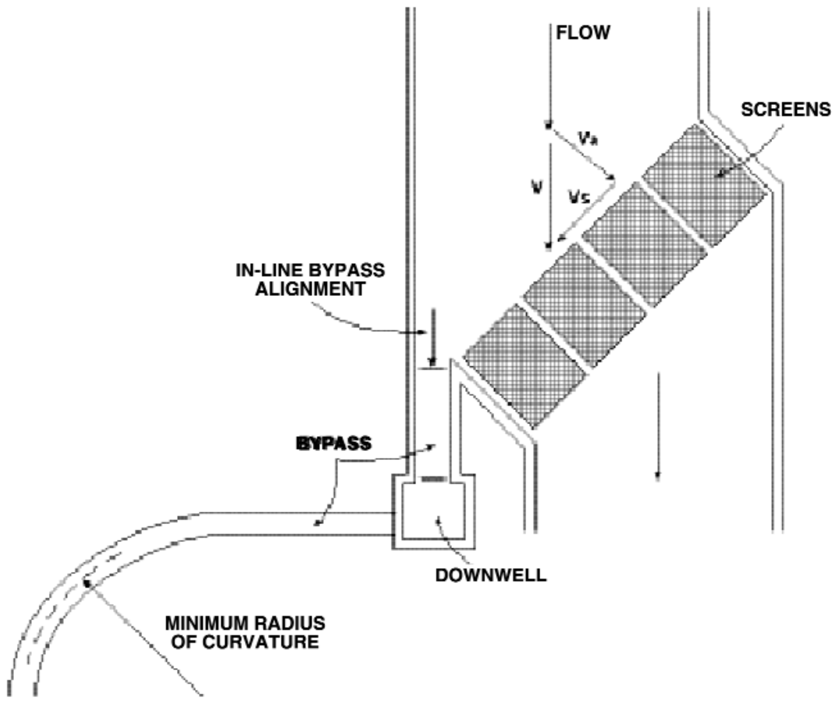

Figure 17 – Plan View of Fish Bypass System at Drum Screen Installation (WDFW, 2000)

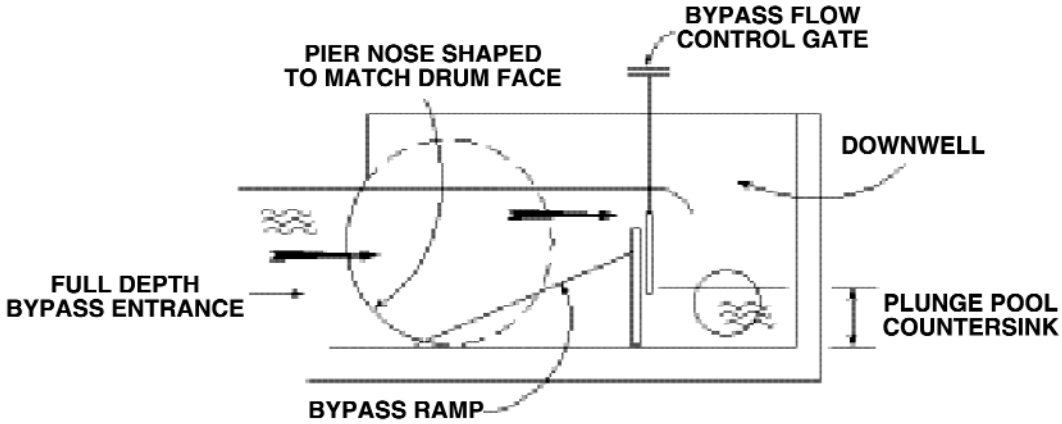

Figure 18 – Elevation View of Fish Bypass System at Drum Screen Installation (WDFW, 2000)

is because every fish that enters the offtake and is successfully screened must enter the bypass system in order to get back to the main stream. The entrance must be designed so that fish freely enter the bypass without delay. To achieve this, the geometry of the screen must be carefully designed so that adverse hydraulic conditions are not present that may hamper fish passage.

Juvenile fish often delay or avoid passing through areas where the velocity decreases or increases rapidly (WDFW, 2000). Because of this the entrance velocity of the bypass must be considered carefully in design. It is widely accepted that for optimum performance of the bypass, the velocity of the flow at the entrance should be about 10% greater than the true velocity approaching the screen. This must be the case for all flow rates experienced in the offtake. Despite the need for this additional velocity, the increase must be gradual if the fish are to fully accept the bypass.

The bypass conduit is responsible for transporting any fish and debris present back to the river. The conduit can comprise of pipes or channels with the emphasis on creating an environment free from turbulent flow. Additional criteria as specified by in fish screen protection guidelines (WDFW, 2000) include:

- Bypass hydraulics should be open channel flow; bypass pipes should not be pressurised
- Depth of flow in a bypass must be greater than 230 mm
- Minimum bypass pipe diameter of 600 mm
- There should be no extreme bends in the pipes
- Bypass system sampling stations should not impair normal operations of the screen facility.

The final component of a bypass system is the outlet where fish are returned to the main waterway. The outlet should protect fish from two factors; direct injury due to the impact when they enter the water, and predation. The impact velocity is the velocity of the bypass pipe as it strikes the water in the river. If this is too great, then shear occurs between the fish and the receiving water, and descaling can occur.

The outlet must be located in designed in such a way that it deters predators. The selection of an outlet site is based on their being suitable velocity in the receiving stream to enable fish to move quickly away from predators. Care needs to be taken to find a balance between helpful velocity and turbulent flow that can disorientate fish, allowing them to become easy prey.

If a bypass is designed to these above design considerations, then there is every chance that it will be successful and accepted by the fish.

4. Placement of Fish Screening Structures

The choice of location for an irrigation diversion is generally based on the convenience of the irrigator. In many cases this chosen location can make it difficult for screening. Considerations may include whether to screen water directly from the river or in a canal diverted from the river. This is because the point of withdrawal is important for the hydraulic aspects of the screen, as well as for the protection of juvenile fish.

This section is going to look at the placement of screening structures at the following locations:

- Streams and Rivers
- Canals
- Lakes and Reservoirs

4.1 Streams and Rivers

Optimally, and where physically practical, the screen should be constructed at the diversion entrance with the screen face parallel to the stream flow (NMFS, 1997). The foremost reason behind this is that it causes the minimal interference with the fish, and thus the greatest survival rates. Another reason is that it is generally the most economic solution as alternative screening systems require complicated bypass systems to return fish entrained into the offtake back to the river.

There are a number of factors that may prevent the installation of a fish protection screen at a diversion entrance. The most common reasons include excess river gradient, the potential for damage by large debris (for example logs during a flood), large amounts of sedimentation, or inappropriate flow conditions (WDFW, 2000). The screen face must be aligned with the adjacent bank, which in some cases may require minor works to achieve this. This is done to prevent eddies in front, upstream, and downstream of the screen. While it is preferable to locate the fish screen at the diversion entrance, if the conditions are not suitable then in the long term it is better not to try and force this placement as the screens will not work effectively.

4.2 Canals

If it is impractical to locate the fish screen on the bank at the diversion then a screen can be installed in the diversion offtake. Because the flow into the offtake is taken directly from the main stream, screens located in canals require a bypass system to collect entrained fish and safely return them to the river. Due to the need for this bypass it is necessary to locate the fish protection screen as close as practical to the diversion entrance to minimise the time fish spend in the bypass. To prevent impingement of fish onto the screens, the angle of the screen to the flow should be adequate to guide fish towards the bypass entrance (NMFS, 1997).

4.3 Lakes and Reservoirs

Observations and research have shown that when in lakes or reservoirs, juvenile fish spend the majority of their time in shallow water near the shore. On the basis of this, the most practical diversion outlets should be located offshore and at reasonable depth where there are the least number of fish present. Where possible, intakes should be located in areas with sufficient sweeping velocity to minimise sediment accumulation in or around the screen and to facilitate debris removal and fish movement away from the screen face (NMFS, 1997).

Often there is a requirement for very large flows to be diverted out of lakes and reservoirs, as this is the reason many of them were constructed in the first place. This must be taken into account when designing an appropriate fish protection screen to ensure that the effective screen area is large enough so that screen velocities are minimised. If this is not done, fish impingement onto the screens may become a large issue. Using very large, but low velocity, offtakes can also help maintain the high flows required in an environment when there is often very little head available.

5. Debris Control

Debris found in the natural waterway can have a large impact on the effectiveness and operation of a fish screen. The debris can be large such as tree branches or as small as sediment or algae. It is important both for the protection of fish and the hydraulic performance of the irrigation offtake, that an adequate cleaning system is in place to remove debris efficiently and completely from the screen mesh. Failure to incorporate an adequate mesh cleaning system can cause catastrophic failure of the screen assembly (Nordlund, 1996).

The primary concern of inadequate screen cleaning is that debris may build up on the screen face. This reduces the effective area of the screen resulting in an increased flow through the remainder of the screen. Increased flow leads to higher approach velocities and a greater chance of impingement on the screen. A second concern is that debris build-up in the trash racks, fish bypass, and screen face change the hydraulics of the system. Irrigators do not receive as much water due to these blockages and fish have a higher mortality rate due to increased velocities and impingement with the screen face and debris.

To prevent this from taking place, a number of fish screen cleaning systems have been developed. The most common of these include:

- Trash Racks
- Manual Screen Cleaning
- Brush Cleaning
- Jet Spray Cleaning
- Air Burst Cleaning

5.1 Trash Racks

Trash racks are placed upstream of fish screens to collect larger debris that might damage the screen or get blocked in the bypass system. Typically, a trash rack is a frame of bars slanted vertically at approximately 45 degrees to the flow, with bars spacings of 150-250mm (WDFW, 2000).

Juvenile fish require a bar spacing of at least 100mm to safely pass through the trash rack, so this forms the minimum allowable bar spacing. It is important to remember that the role of the trash rack is to prevent large debris damaging the screens, not to prevent passage of fish. If the bar spacings are too small them they will collect more debris, not only enhancing the problems of fish passage, but also having a negative impact of the hydraulics of the intake.

Trash racks must be cleaned and have any debris removed on a regular basis. At screening sites that are very large, it may be necessary to use trash racks with an automatic rack cleaning device. These devices are quite commonplace, even in Australia, where they are currently utilised in most waste water treatment plants to clean the primary screens.

5.2 Manual Screen Cleaning

Manual screen cleaning is generally used for small screens or in instances where there is insufficient debris load to require an automated cleaning system. Manual cleaning involves removing debris from bypass entrances and trash racks, as well as the screen face itself.

If a manually cleaned screening system is to be installed, it is important to take this into account in the screen design stage. Because the screen is only getting cleaned at specific times, it is inevitable that a degree of debris build-up will take place. Due to this, the total screen area should be larger than normally required to take into consideration the loss of effective area due to blockage. If this is not done, increased velocities due to reduced flow area can cause juvenile fish to become impinged onto the screen face.

5.3 Brush Cleaning

Brush cleaning systems are similar to the mechanical rakes used to remove debris from the trash racks. They consist of a series of brushes that continually travel over the screen on a conveyor system. It is important to ensure that the brushes are orientated so they efficient clean the entire screen. For an effective clean, the brushes must also travel in the direction that the screen is orientated. For example, for a vertical fixed plate screen, brushes must travel in a vertical direction or parallel to the screen face. Brush cleaners are one of the most common cleaning systems used in practice and have a good reputation for performance. A disadvantage with them is because they encompass moving parts, they also require a certain degree of maintenance.

5.4 Jet Spray Cleaning

Jet spray, or water jet, cleaning systems have been used with success for fixed plate screens, pump intake screens, vertical travelling screens and as additional cleaners for drum screens at sites with particularly heavy debris load (Nordlund, 1996). They work by spraying high pressure water onto the back side of the screen, dislodging any debris present. Depending on the type and amount of debris present, different jet pressures are required. A standard range of pressures commonly used is 200-700 kPa.

5.5 Air Burst Cleaning

Air burst cleaning systems are similar to jet spray systems only they use compressed air rather that water to blow the debris off the screen. Since being developed, it has mainly been used as the cleaning system for pump intake screens. Air burst systems have a variable record, working very well in some sites, less so in others. The main criticism with this system is that it has a tendency to only clean the upper portion of the screen. This makes sense as after release, the air bubbles will naturally and quickly raise towards the surface.

5.6 Power Systems for Cleaning Systems

Apart from manually cleaned screens, any mechanical cleaning system is going to require a power source in order to operate. The type of power system used for a particular site should be based on the physical constraints that the site possesses. The main priorities of any power system are that it must be capable if delivering the required amount of power, in the most cost efficient manner, with a very high degree of reliability. The most common power systems include;

- Electric Motors
- Paddle Wheels
- Hydraulic Motors
- Solar Power

Electric motors are the most preferred option for power systems. This is because they are by far the most reliable, and are reasonable inexpensive to run and maintain. Unfortunately however, many screening sites are situated in remote areas, thus a significant distance from the power grid. It is under these conditions that alternative sources of power are required.

Paddle wheels or water wheels are a reliable source of power in many locations. They are dependent on the flow of the water for operation so are only suited to certain locations. An advantage of using a paddle wheel is that after construction there in very little cost associated with operation. Hydraulic motors are also powered by paddle wheels but have the advantage that the paddle wheel can be placed away from the screen. For example it can be installed in a location where there are higher flows and therefore better operating conditions. With hydraulic motors, hydraulic lines connect the motor to the screen.

Cleaning systems driven off solar power are becoming increasingly popular as solar technology progresses. As solar energy can only be collected during daylight, these systems use solar energy to charge batteries that operate the cleaning systems. Battery charging systems are readily available for reasonable costs that allow operations for up to 48 hours without sunlight.

It is important to note that the above mentioned power systems are not just restricted to operating the cleaning systems. In many instances these systems are used to power the operation of mechanical screens as well as the cleaning systems.

6. Conclusions

As the report detailed, there have been a number of different solutions designed to prevent fish becoming entrained into irrigation offtakes. Each of these solutions has their advantages and disadvantages, and there is no one screen that can be used universally. The environment in the Murray-Darling basin is not ideal for the screening of fish. The water has a high degree of turbidity and possesses a large quantity of fine sediment that will easily clog fine grade screens. Despite this, there are a number of screens that could be adapted to suit the conditions. **Table 2**, gives the suitability of each of the screening methods described in the report, and offers suggestions as to what measures need to be taken to ensure they work successfully.

Not only does the *type* of screen need to be considered when determining a course of action, but careful thought must also take place on the *design* of these fish protection screens. At present there is limited information to guide this design for Australian conditions. There is a need to conduct a comprehensive study of the movements and biomechanics of native fish in the Murray-Darling Basin. It is only on the outcomes of this study, that a set of guidelines and design parameters be determined for the effective screening of fish. Without these guidelines, any future fish protections works may not be as effective as they potentially could.

There is a need for public education to enhance awareness on the topic of screening irrigation offtakes for the purpose of protecting fish. As studies in this report have pointed out, there is a large problem of fish mortality in these offtakes. Despite this, when the Murray-Darling Basin Commission approved a fish management plan that listed its objectives to deal with the problem of depleting native fish populations, screening irrigation offtakes was not mentioned.

Table 2 – Conclusions on Screen Suitability

Screen Type	Suitability for use in the Murray-Darling Basin
Rotary Drum	• Very Suitable. • One of the most commonly used screens, therefore large amount of technical information available for design purposes. • May not require a separate cleaning system. • Can handle quite large flows (80 +m^3/s) • Suitable for use in canals or directly at diversion.
Vertical Fixed Plate	• Very Suitable. • Simple design and construction. • Requires automated cleaning system • Suitable for use in canals or directly at diversion.
Vertical Travelling	• Suitable for use at pumping sites, especially for deep extraction. • Better alternatives available for gravity surface diversions. • Maintenance can be difficult due to access to screen.
Non-Vertical Fixed Plate	• Average suitability. • Require a significant amount of head. • Upward sloping screens require mechanical cleaning system. • Fine sediment build up may occur in drop canal below screen face.
Pump Intake	• Very suitable. • Pump diversions do not alter environmental conditions as much as surface diversions. • Requires automated cleaning system
Infiltration Galleries	• Not suitable in the majority of the Murray-Darling system due to sediment and unsuitable flow conditions. • May be used in some tributary streams in the high country where sediment loads are low and appropriate hydraulic conditions prevalent.
Experimental Behaviour Devices	• Not recommended due to testing evaluations showing poor performance in screening fish.

The project was also able to identify some limitations of the screens recommended. Properly designed, they are quite capable of screening both adult fish and juveniles down to about 40mm in length. However, some of the native fish spend a portion their life cycles as floating eggs or tiny larvae, which even in a screened offtake would experience entrainment. This is another example of where research needs to be conducted so that conclusions can be drawn on the best practices to extract water, while protecting all stages of the fish's lifecycle.

The problem of screening offtakes in the Murray-Darling is quite unique due to the diversity of flow situations that occur. They vary from small diversions to service a single farm to the offtake at Mulwala that has a maximum flow rate of up to 115m^3/s. To date, fish screens have only be developed for flow rates a little over 80 m^3/s so there are a lot of opportunities for advancement in this field.

Looking into the future, water demands for irrigation are not going to decrease. In fact, as people strive to increase agricultural productivity, the requirement for water is likely to increase. This increase in water demand is only going to add to the pressures already experienced by our native fish populations. The technology is available to successfully screen irrigation offtakes in the Murray-Darling Basin to reduce the loss of our native fish, but without implementation the benefits of this technology will never be appreciated.

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