Water control structures:

Designs for natural resource management on coastal floodplains

A review

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OVERVIEW

Water control structures are being used for Natural Resource Management (NRM) purposes in irrigation, drainage and natural waterway systems to manipulate the flow of water within the system with a view to improving the surrounding environment. These structures are used to manage the hydrological regime by modifying the direction or rate of flow of water, and / or to maintain a desired water surface elevation.

Water control structures can be designed to provide solutions to suit a range of natural resource management issues, including:

- Improving water quality;
- Acid Sulfate Soil (ASS) remediation and promoting reductions in iron and aluminium discharge;
- Reducing the generation and export of Monosulfidic Black Ooze (MBO);
- Minimising blackwater discharge;
- Improving fish habitat and fish passage;
- Addressing low dissolved oxygen content and eutrophication;
- Wetland enhancement;
- Increased agricultural and grazing productivity of backswamps;
- Reducing fire risk;
- Maximising frost control;
- Wetland hydrology restoration;
- Modifying the condition of bottom sediments;
- Enhancing weed control.

Due to variable site specific conditions, it is likely that no two structures or designs will be exactly the same. Should two structures appear similar, they may in fact be acting under significantly different conditions. The desired management outcome, along with a solid understanding of the hydrological and other environmental or biological processes of the system under consideration, is required for selection of an appropriate design. Current legislation and legislative instruments must also be considered when choosing structure design and functionality.

This review is not intended to be a comprehensive set of guidelines to be followed when installing water control structures, rather an insight into the various designs of structures, their functionality and some of the considerations necessary for implementation. Detailed engineering and scientific advice should be sought prior to each installation or modification.

This review has been prepared on behalf of the six Councils participating in the Urban Sustainability Program funded by the NSW Environmental Trust.

The diversity of available water control structures combined with a lack of information on their relative merits and constraints led to the development of this review.

CONTENTS

1. CULVERTS AND HEADWALLS

1.1 Culverts

A culvert is a conduit used to enclose a flowing body of water. They generally enable flow through an embankment, road or some other type of hydrological impediment. Culverts are constructed in various shapes such as round or corrugated pipes, ducts and square boxes and are available in a range of sizes. Construction materials are also variable and include concrete, polyvinyl chloride (PVC), steel, rock or aluminium structural plate. Dependant upon the specific requirements, a number of culverts may be installed adjacent to one another to maximise flow.

1.1.1 Impact of culverts on the waterway

Natural hydrological regimes can be significantly modified both within and immediately adjacent to culverts, which has the potential to cause the following impacts:

- Reduced hydraulic capacity, or choking of the system;
- Flow concentration resulting in scouring and increased erosive processes;
- Increased risk of stream flow blockage by floating debris;
- Increased risk of upstream floodwater intrusion;
- Reduced capacity for passage of aquatic fauna;
- Reduction in aquatic habitat in or adjacent the culvert;
- Disturbance of benthos during installation and the subsequent discharge of sediment, nutrient or acid sulfate product.

These factors should be considered along with legislative instruments when designing and implementing culvert junctions to minimise environmental impact.

1.1.2 Impact of culverts on fish passage

Fish passage through culverts is essential to allow breeding cycles and re-population of both estuarine and marine waters, and to provide adequate access to aquatic habitat and other resources. NSW legislation governs the installation and modification of culverts and other water control structures to ensure adequate mobility for aquatic species.

The most common fish passage problems associated with both pipe and box culverts are outlined by Fairfull and Witheridge (2003) and include:

- Excessive flow velocities within the culvert;
- Inadequate flow depth within the culvert;
- Excessive water turbulence;
- Debris blockage of the culvert;
- Excessive culvert length and a lack of aquatic habitat and 'rest' areas within the culvert;
- Inadequate lighting within the culvert;
- Excessive variation in water level across the culvert outlet (waterfall effect).

1.1.3 Pipe culverts

Image 1: single pipe culvert

Image 2: multiple concrete pipe culverts

Advantages

- Simple to install;
- Manufactured to required specifications;
- Easily cut or joined to a required length;
- Inexpensive;
- Strong and durable;
- Low maintenance;
- PVC pipes are flexible, tolerating some ground movements.

Disadvantages

- Generally only suitable for small applications subject to low flow rates;
- May become clogged with debris or sediment;

- Poor provision for fish passage. May require additional box culvert for enhancement of passage.

1.1.4 Box culverts

Image 3: concrete box culvert providing flow continuity of a channel under Nelson Bay Road

Image 4: Image combination of pipe and box culverts providing flow continuity under Port Stephens Drive

Image 5: sandstone box culvert (NSW RTA)

Advantages

- Can be used for large applications;
- Concrete boxes available as inverted ‘U’ shaped structures with a base, or ‘U’ shaped with a lid to suit requirements;
- Robust and durable;
- Less susceptible to damage through vandalism;
- Better provision for fish passage;
- Precast concrete units can be easier to install and installation can take place in most weather conditions.

Disadvantages

- The installation of concrete products is most often expensive, particularly in the event that structures will be cast in place;
- Adequate site accessibility is required for the delivery of materials and the construction process;
- The installation or removal of these structures can cause a heavy level of disturbance to the host waterway.

Considerations

An appropriate size and number of culverts should be selected for the application to ensure that flow efficiency throughout the system is not compromised. Despite the installation of multiple culverts, high levels of turbulence may be generated as the water in the system collides with the walls of culverts, compromising the efficiency of drainage through the culvert. It may therefore be more effective to install culverts of a greater width and hence opening cross sectional area, to reduce the amount of generated turbulence. If the operational invert of multiple culverts is not uniform across that system, those installed in the higher elevations may experience a lesser velocity of passing waters, particularly during low water level events. This may facilitate the deposition of sediment in the base of culverts, further compromising flows during later events.

During concrete pipe construction, polyvinyl chloride (PVC) liners may be mechanically embedded into the pipe wall to provide added resistance against corrosion. Due to their restrictive nature, pipe culverts should only be implemented in waterways that provide no natural fish habitat or are not expected to host fish species.

Regular inspection is required to remove any debris trapped by the culvert and to ensure that there are no blockages. Maintenance may be required in the case of appearing cracks, holes, dislodged joints and in the event of collapse.

1.2 Headwalls

A headwall is a structure installed at the end of a culvert in order to retain soil around and above the culvert ends and to protect against erosion at the culvert entrance and exit. A headwall may also direct the flow of water in to or out from culvert ends, or incorporate a water control gate. A range of materials can be used in the formation of a headwall including concrete, rock, gabion baskets, sandbags or logs, dependant upon budgetary constraints and the site specific requirements of the system within which it will be implemented.

Image 6: concrete headwalls train flows through a culvert and provide protection against erosive processes (K Russell)

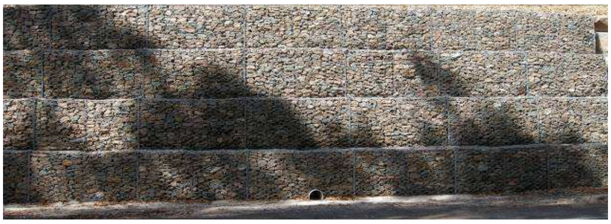

Image 7: gabion baskets may be used for the formation of channel headwalls

Image 8: sandbags can be filled with a concrete and sand mixture and stacked for cost effective headwall construction

Advantages

- Excellent retention of soil about structures;
- Provides for the direction of water flows through structures;
- Allows for the dissipation of erosive energy and the protection of the bank about a structure;
- Numerous range of suitable construction materials, and these are often readily available;
- May provide seamless incorporation of structures, particularly where cast in place concrete is moulded to suit.

Disadvantages

- Labour intensive;
- Adequate site accessibility required for the delivery of construction materials and the installation process;
- The installation or removal of these structures is often highly disruptive to the host waterway.

Considerations

Installation of these structures generally requires the addition of coffer dams at either end of the construction site, so that the waterway may be isolated at this point and the water pumped out for adequate site access. In particular, coffering-off is required when installing cast in place concrete structures

For adequate sealing capacity, each end of the headwall should be keyed into both banks of the host waterway at such a distance as to prevent water seeping through the soil around the structure. Failing this, it may be more appropriate to form a key by inserting sheet pilings into the banks or by excavating a pit and packing it with clay, adjacent to the headwall. Similarly, the headwall should penetrate the waterway floor at such a depth to prevent the seepage of water underneath the structure. The headwall should also be constructed to a height appropriate to provide tidal exclusion above the highest astronomical tidal invert.

When implementing gabion baskets in systems containing highly acidic or marine waters, the use of a smaller sized *blue rock* aggregate will provide a greater corrosive resistance.

2. ‘TRADITIONAL’ FLOODGATES

Floodgates are simple systems that can be hinged to the ends of culverts or headwalls to allow the flow of water in a single direction. The opening and closure of floodgates (or flapgates) is dependant on changes of the water level caused by rainfall, floods or tidal fluctuations. These will remain open or closed depending on the magnitude of the tides and the volume of water either side of the gate. When water pressure upstream of the gate exceeds the pressure of the downstream side, as well as the effective weight (restorative force) of the gate itself, the gate will open and allow the downstream flow of water through a culvert. Alternatively, the restorative force of the gate along with the hydraulic pressure of the downstream side will seal it against a vertical or near vertical face.

Floodgates have been installed for the purposes of preventing back-flooding of creeks and tributaries from the main river system. They have been effective in reducing the impacts of minor floods and have also been used to drain low-lying wetlands and coastal floodplains for agricultural purposes. The water level upstream of the floodgates is effectively lowered to the base invert of the structure, or the lowest water level.

Floodgates have been shown to give rise to a range of negative impacts due to their prevention of water exchange. These include:

- Stagnation and sedimentation upstream of the floodgates;
- Deterioration in water quality including dissolved oxygen levels, pH, temperature, affecting most forms of aquatic biota;
- Encouraging conditions for in-stream weeds;
- Reducing opportunities for fish passage;
- Draining wetlands and coastal backswamps which further lead to environmental (biodiversity) and agricultural (fewer nutritious pasture species, more peat fires and frost impacts) losses;
- Oxidation of ASS and export of acidic materials.

Gates can be designed to suit a wide variety of culverts, pipes and drains, and can be hinged to existing pipelines or box cells or constructed as complete self-contained units.

Floodgates can impede or prevent the migration of fish species by blocking their passage up and down stream. In many circumstances NSW legislation prohibits the blocking of fish passage or requires that permission be obtained from relevant authorities prior to implementing designs.

A range of modifications are now available to basic floodgate design, that enable controlled flows upstream during non-flood periods, offsetting the negative impacts previously described. These modification designs are explored during subsequent sections of this document.

2.1 Hinged Flap Gates – Traditional Floodgates

Used for the conversion of wetland environments into agricultural land. These are very efficient in draining upstream lands, preventing the intrusion of saline waters and back flooding during high tides and some minor floods. These lead to the development of freshwater systems, where they were previously saline / brackish. Only suitable for tidal gating of channels set back from main rivers and when complete tidal isolation is required. Flap gates, also known as reflux valves, only allow flow in one direction (downstream) for drainage purposes.

2.1.1 Top hinged

Image 9: top hinged flaps retrofitted to suit a box culvert and existing pipes

Image 10: top hinged flaps

Image 11: fibreglass gates with neoprene seal (Humes)

Advantages

- Naturally automated;
- Simplistic construction and installation;
- Requires little maintenance;
- Long lifespan;
- Gates manufactured from non-metal materials have no scrap value and will have no attraction to scrap metal thieves;
- Inexpensive cost of parts.

Disadvantages

- Prevents flushing of upstream water body leading to stagnation, poor water quality and growth of in-stream weeds;
- Restricts fish passage and creates a barrier to passage during high tides;
- Floating debris can jam the gate open or shut, and hence requires regular inspection;
- No provision for manual control of gates without installing additional infrastructure;
- Hinge/pin material may be subject to corrosion and damage impeding or prohibiting action of the gate;
- Excessive drainage may result in a lowering of the groundwater table and subsequent oxidation of any potential acid sulfate material.

Considerations

The greater the weight of the gate, the more energy (head pressure) required to open it and keep it open. This is generally only a limitation in small systems, such as side drains feeding a major drainage channel. Lighter or more buoyant construction materials can be used to increase the opening periodicity of gates within systems operating under small hydraulic pressure. In larger systems, although the head differential at either side of a gated structure may be minimal, the hydraulic pressure acting upon any gates is significantly large, as it is generated by the entire water body upstream of the structure. This pressure can be so great that operation of tidal gates will not be limited by the use of heavy construction materials, within reason. Adequate clearance is required for the gate to swing.

Dependant on the size of the culvert and the design of the gate, more than one hinge may be required to provide lateral stability of the gate. This is important in the protection of hinges from damage. Hinge / pin material should be chosen carefully to reduce risk of corrosion.

2.1.2 Side hinged

Image 12: NSW Fisheries Floodgate Design Workshop (2002) Proceedings

Image 13: NSW Fisheries Floodgate Design Workshop (2002) Proceedings

Image 14: NSW Fisheries Floodgate Design Workshop (2002) Proceedings

Advantages

- Naturally automated;
- Requires small amount of energy (water pressure) to open gates. As a result, more robust materials can be used for the gate without compromising the efficiency of the structure;
- Once open, the gate will remain open until the tide recedes;
- Gates open wider than top hinged flap gates and for a greater period;
- Full depth of the water column is available for fish passage;
- Simplistic and more difficult to vandalise;
- Requires little maintenance;
- Long lifespan.

Disadvantages

- Floating debris can jam the gate open or shut, and hence requires regular inspection;
- Not suitable in large rivers – currents and boat wash can open gates;
- The structure or gate requires some form of component, such as a chock, that will prevent each gate from over opening during discharge. If over opening occurs, the hydraulic pressure experienced as the tide begins to rise can prevent the gate from closing;
- Restricts fish passage (less restrictive than top hinged gates) and creates a barrier to passage during high tides;
- No provision for manual control;
- More difficult and costly to build the support structure required to hang the gate;
- Water quality degradation may result in the system upstream of the structure due to stagnation.

Fish Passage

Fish passage is heavily restricted and is completely blocked during closure of the gate. The opening created as the gate opens may be insufficient to allow full passage to all species. Furthermore, the velocity of waters passing through the culvert may be too strong, prohibiting entry.

The application of this design is not expected to affect the passage of fish species as it is most likely to be installed in systems that are not of natural fish habitat or are sub-optimal for hosting fish, such as man made drainage channels.

Considerations

The top hinge should be fastened to the support structure closer to the culvert opening than the bottom hinge so that the gate develops a slight downward tilt. This provides the gate a restorative force and enables closure at the end of an ebb tide. Hinge / pin material should be chosen carefully to reduce risk of corrosion. Clearance is required for the gate to swing.

2.2 Elastomer Check Valves (Duck Bill Valves)

An alternative to tidal flap gates, the rubber check valve can be used to provide flow in one direction only through a culvert for floodplain drainage and flood and saline intrusion mitigation purposes. The valve is constructed from an elastomer with a vertical slot that is flexible yet quite stiff and closed in its relaxed position. This elastomer material is resistant to the corrosive effects of marine and highly acidic waters, a significant issue associated with most metallic structures. The valve can be mounted flush on a flat or curved headwall, or be clamped to culverts of varying shape, size or material. During backflow, the valve seals shut.

Image 15: elastomer check valves (Tideflex Technologies)

Image 16: elastomer check valves (Fuller Valve)

Image 17: elastomer check valves (Tideflex Technologies)

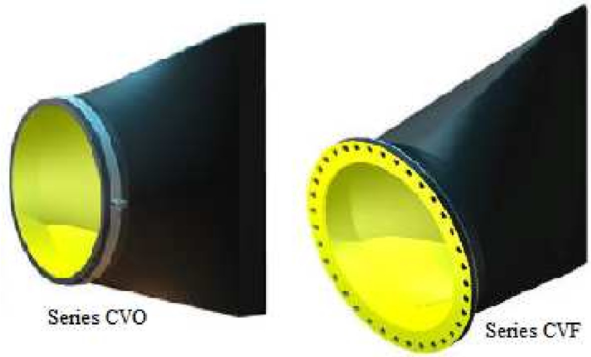

Image 18: elastomer check valves (Fuller Valve)

Advantages

- Self automated;
- Can be mounted to a variety of culvert configurations – bolted to headwalls or clamped to pipes;
- Can be installed at any angle including vertical;
- Smaller valves (~50 cm) can usually be installed by one person with simple hand tools;
- Corrosion resistant and outer wrapping resistant to ozone;
- Not as susceptible to jamming and will seal around entrapped floating debris during backflow. Can still operate when partially buried in sediment;
- Has no moving mechanical parts subject to wear and can last up to 50 years;
- Flexible nature reduces risk of damage from floating debris;
- Will not freeze closed in cold systems;
- No clearance is required for operation.

Disadvantages

- No provision for manual control of valve;
- Highly restrictive to fish passage;
- Water quality degradation may result in the system withheld behind the valve.

Fish Passage

Fish passage is limited to the direction of flow. However, the application of this design is not expected to affect the passage of fish species as it is most likely to be installed in systems that are not of natural fish habitat or are sub-optimal for hosting fish, such as man made drainage channels.

Considerations

A range of elastomers are available for construction of these valves. Ethylene Propylene Rubber (EPDM) is a material appropriate for water service and is available for food grade applications. Other elastomers have been created that provide added resistance against abrasion, hydrocarbon and oxidising chemical influence. Chloroprene Rubber – Neoprene is a material that inhibits marine fouling by preventing the growth of such organisms. The appropriate elastomer should be selected to suit site specific requirements and an occasional inspection for entrapped debris conducted.

3. MANUALLY OPERATED MODIFICATIONS

The controlled opening of floodgates is a key component of floodplain Natural Resource Management and can provide significant improvement of a number of environmental parameters.

Controlled flushing through existing structures and gates may be possible dependent upon their individual circumstances. Self contained units can be developed and implemented to a system as required. Such gates can be manually activated by hand or designs may incorporate more advanced technologies capable of providing self operation.

Automation is usually controlled by Local Council or the landholders of properties on which structures are placed, following guidelines to achieve management objectives designed by authorising bodies (such as Catchment Management Authorities or Government agencies).

The decision to open water control gates is not one that can be undertaken by a single landholder, due to the widespread impacts associated with hydraulic flow manipulation. This represents a requirement for a strategic approach to gate management. Consultation with neighbouring landholders and relevant natural resource authorities is required to determine appropriate management objectives and opening regimes. Where issues arising from salinity and acidity are likely, water quality monitoring programs may be required to further determine appropriate operation of gated systems.

3.1 Winched Tidal Flap Gates

Winching systems take varying forms and can easily be attached to existing culvert headwalls or installed at appropriate locations adjacent the culvert. Opening gates will allow tidal exchange to take place for the duration of the opening period and can allow large, rapid inflows of river water. Exchange rate is limited only by the capabilities of the culvert or by closing the gates once an appropriate objective has been reached.

Gantry lifting systems can be installed to headwalls or as extensions of the ends of pipes, or may even be fastened to crossings for ease of accessibility. Cable span lifting systems can be implemented in sites that are difficult to access with the use of pulleys, which provide increased mechanical advantage for winches. As a result, cables can pull open gates at distance.

Image 19: winched flap gates on a horizontal lifting gantry (K Russell)

Image 20: wire cable span system (Clarence Valley Council)

Image 21: upper left: thimble; upper right: Jarrett 600 Series hand winch; lower left: wire rope grip; lower right: 7x19 stainless wire rope configuration (Blackwoods)

Advantages

- Simple operation of mechanism;
- Easy to install;
- Cable span systems utilising pulleys can be installed in areas that are difficult to access;
- Managed flap gate opening regimes provides potential benefits to the quality of water, native vegetation and pasture productivity, in stream weed management, ASS remediation and enhanced fish passage;
- Entire water column is open to flows and fish passage, when actively managed;
- Easy to maintain.

Disadvantages

- Require ongoing intervention by operators for maximum potential;
- Can require additional OH&S infrastructure to provide safe, working access;
- Can be easily tampered with or vandalised. Locking winches helps, though cabling can be easily cut;
- Limited water level control – gates are either open or closed;
- Have a greater risk of overtopping the system whilst gates are open;
- Large downstream hydraulic forces can act against the action of winching systems leading to winch failure.

Fish Passage

As per traditional flap gates, passage is only possible during opening periods, and is governed by the aperture and culvert size along with the velocity of water passing through the culvert. A barrier occurs for the duration of closure.

Considerations

Winches should be chosen according to appropriate working load limits required to lift gates and suit the requirements of the system. Winches with braking systems can be used to provide the operator greater control when operating the gates.

The number and positioning of pulleys should be installed appropriately to allow maximum mechanical advantage and suit system characteristics. Connections should make use of thimbles and wire rope grips in order to minimise damage to wire rope as a consequence of bending.

Appropriate maintenance plans should be developed to ensure correct operational functionality and removal of entrapped debris.

3.2 Penstocks (Vertical Winches)

Penstocks are normally fitted to the structural framework of culverts and headwalls, or are constructed as self contained units. Penstocks function by operation of a sluice gate placed on the landward side of a culvert. Designs can vary, with penstocks consisting of a single gate controlling flow through the culvert (image: Watergates sp). The gate can be opened to a required height and will remain in position until it is reset.

This provides excellent water level control. The gate may be fully opened to allow rapid influx of river water or discharge of storm waters, or fully closed for full retention preventing exchange.

Image 22: single penstock (Clarence Valley Council)

Image 23: multiple penstocks mounted on a gabion basket headwall (Watergates sp)

Advantages

- Provide excellent water level control and flood protection;
- Adjustable and reliable;
- Low maintenance;
- Manual actuation systems less expensive. Provision for data logging equipment and automated actuation systems for development as a smart gate;
- Provide excellent sealing capacity.

Disadvantages

- Can be expensive;
- Manually operated designs require intervention;
- Friction can develop in the tracks whilst opening or closing gates;
- Vertical winching mechanisms may result in the gate jamming open during outflow. This can be overcome by use of a worm drive mechanism;
- Vertical space required above culvert for actuation system;
- Can require additional OH&S infrastructure to provide safe, working access.

Fish Passage

Passage is restricted to the size of the opening relative to the gate position and the velocity of water passing through the aperture. A barrier exists for the duration of gate closure.

Considerations

Penstocks often require space vertically above the culvert for actuation systems. The material chosen for construction of the gate should be strong enough to withstand impacts from floating debris and the natural forces of the system. As per sluice gates, vertical winching actuators may become jammed during outflow, so worm or screw drive mechanisms are advisable. The use of automatic actuators, such as electric motors and pneumatic systems, will significantly add to design and on-going maintenance costs. Ongoing maintenance is intensive, with actuators requiring regular attention to ensure correct operational functionality, and breakdown events can be expensive.

3.3 Sluice Gates

Sluice gates use a sliding panel to regulate flow through an aperture. Sluice gates can be designed to provide a vertical, horizontal or rotational direction of this action. The nature of this action not only allows tidal flushing but also provides excellent water level control as the aperture size can be adjusted as required to suit management objectives. Furthermore, the position of the aperture can be varied to further enhance water level control.

The action can be operated by a worm drive or by cable winches to suit the system in which it is to be installed. Smaller sluices can be developed to incorporate pneumatic operation of the gate.

Image 24: sluice gates operated by a screw drive (B Smith).

Image 25: sluice on a lockable chain system (S Walsh)

Advantages

- Fully adjustable for excellent water level control in non-flood events;
- Can be retro-fitted to existing gates or culverts;
- Designs are often inexpensive;
- Better provision for fish passage;
- The vertical action can be operated in all conditions and water levels;
- In winch activated systems, the handle may be removed to reduce the risk of unauthorised tampering or vandalism.

Disadvantages

- Friction can develop in the tracks whilst opening or closing gates;
- Requires manual operation, although less so than for winches;
- Requires manual closure during flood events;
- Can require additional OH&S infrastructure to provide safe, working access.

Fish Passage

Although the aperture size is a restriction on fish passage, the greater opening periodicity of the gate allows passage during both tide events. Passage is blocked completely for the duration of closure.

Narrow apertures combined with high head pressure can increase the velocity of water to a rate beyond those navigable by fish.

Considerations

The timing of gate operation is significant in respect to climatic conditions, agricultural cycles and tidal height.

The design may have a vertical limitation above the culvert to make room for operating mechanisms. Plans for achieving management objectives and ongoing maintenance should be developed to ensure correct operational functionality of sluices.

4. SELF-REGULATING TIDAL GATES (SRT)

A variation of the traditional top hinged flap gate, the self-regulating tide gate styles allow automated and regulated tidal flushing in the system whilst preventing inundation of low lying land during high tides and flood events.

These styles of gates maintain the primary flood mitigation design function, while enabling a controlled amount of tidal flushing during non-flood periods to offset the negative impacts highlighted previously.

4.1 Waterman / Nekton SRT

This style of tidal gate consists of a positively buoyant lid and counterbalancing arms, on top of which a series of floats are mounted. Due to the positive buoyancy of the gate, it floats above the water remaining open for most of its operation and allows unrestricted water exchange through the culvert during both tidal periods. The floats are installed at a height predetermined as the point at which upland flooding will occur. The gate will only close during an incoming flood tide when the water level reaches the floats, raising the counterbalancing arms and closing the gate. As the water level recedes, as do the floats and the gate opens again. The height of the floats can be set to suit flood management objectives.

Installed in systems with extremely low elevation, the Waterman / Nekton SRT should only be implemented for the mitigation of flood events.

Image 26: Association of State Wetland Managers, Inc

Image 27: Waterman/Nekton

Advantages

- Naturally automated;
- Provides excellent protection against flood waters;
- Adjustable action by setting float height;
- Self cleaning with tidal flushing either side of gate;
- Better provision for fish passage.

Disadvantages

- Light nature of gate material susceptible to damage from floating debris;
- Floats may collect debris resulting in compromised operation of gate;
- Damage or loss of floats will result in the door remaining open;
- No provision for manual operation;
- Gate may be jammed open or shut by floating debris.

Fish Passage

Although the culvert size is a restriction on fish passage, the greater opening periodicity of the gate allows passage during both tide events. A barrier only occurs with closure due to extreme water level events and for the duration of gate closure.

Considerations

The number and size of floatation devices must provide enough positive buoyancy to override that of the gate and allow closure during high water level events. The float height should be set to suit the system for adequate protection against flooding.

The design has a vertical limitation above the culvert as the counterbalancing arms require room to swing.

4.2 Saltshaker Floodgate

The saltshaker floodgate was a one-off construction, designed as a means to reduce the risk of iron monosulfide oxidation by allowing an input of salt water to drainage systems maintaining sufficient water levels to inhibit oxidation and allow natural neutralisation of acid.

The floodgate consists of a Teflon disc that can spin about a bolt through an existing or new floodgate. Holes are drilled through the disc and floodgate around the edge of the disc. A floating arm rotates the disc according to the water level and when the holes in the disc align with the holes in the gate, water passage is enabled. The opening mechanism may be manually controlled as desired to either allow or inhibit exchange as required. The floating arm can be set at a desirable height to allow a required amount of water exchange to suit management objectives.

Image 28: Fisheries Floodgate Design Workshop (2002) Proceedings

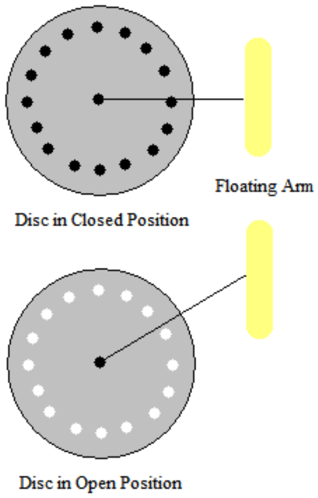

Image 29: schematic; saltshaker disc operation

Advantages

- Automated action;
- Can be manually controlled;
- Teflon material resistant to corrosion;
- Low clearance area required for operation;
- Adjustable float height for water level control.

Disadvantages

- Should damage to the floatation device occur, gate will close;
- Restrictive to fish passage.

Fish Passage

Saltshaker disc holes are generally small at around 20mm in diameter, presenting a barrier to fish passage for fish larger than these dimensions. The functionality of the parent gate will also determine passage and is likely to represent that of a top hinged flap gate. A total barrier occurs for the duration of closure of both the saltshaker and the parent gate.

Considerations

The floatation device must have enough positive buoyancy to allow rotation of the saltshaker. The materials and components used for the pivot points on both the disc and floating arm should be resistant to corrosion and allow good movement of the action.

4.3 Buoyant Lifting Floodgate (Automatic Floodgate)

There are varying designs, although these gates usually consist of a primary gate, either fixed or swinging as per a traditional top hinged flap gate, that includes an aperture. A secondary gate fitted with an adjustable floating arm pivots from the primary gate to provide opening or closure of the secondary aperture. This action is determined by the water level downstream of the system and the height of the float. When the water level drops below the float during low tide events, the weight of the float arm causes it to fall and the secondary gate to open, resulting in the exchange of water. This continues until the incoming tide lifts the float to its maximum height and causes the gate to seal. The gate is held closed by the rising action of the float and the back pressure applied to the gate once overtopped, providing protection against flood water.

This design is used in the rehabilitation of wetland environments that have been damaged by excessive floodplain drainage, often for the neutralisation of ASS contaminants by saline water. Buoyant lifting gates allow a degree of tidal flushing whilst providing flood protection.

Image 31: automatic floodgate retrofitted to a pipe culvert at Windeyers Creek (J Fredrickson)

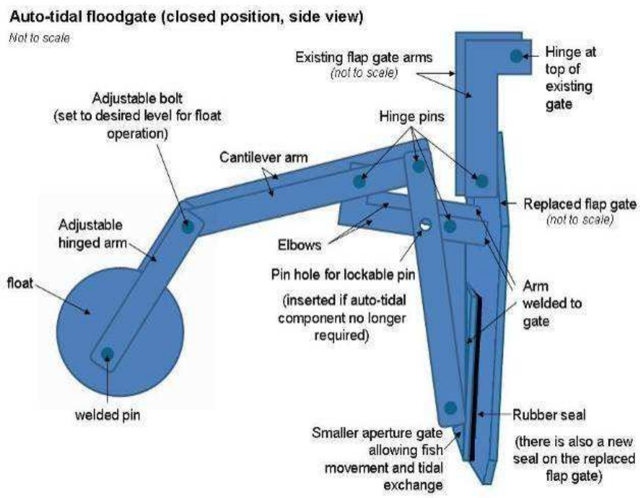

Image 30: Schematics: component construction and operation of the automatic floodgate (S Nichols)

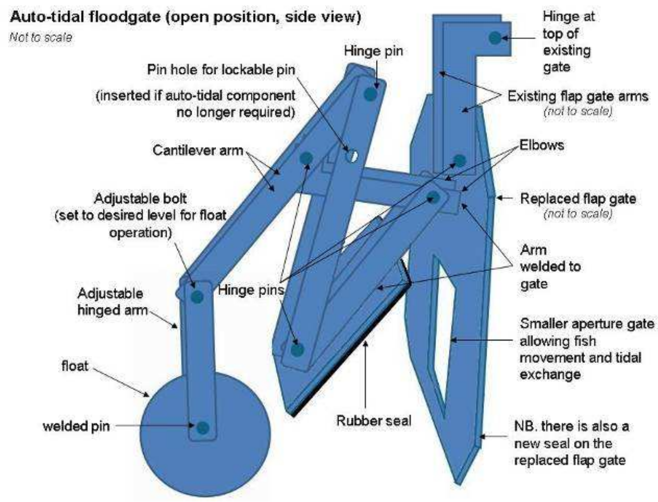

Image 32: Schematics: component construction and operation of the automatic floodgate (S Nichols)

Advantages

- Naturally automated;
- Good control of water level;
- Adjustable float height to determine amount of water exchange and maximum height of tidal influence;
- Flood secure as gate automatically closes with increasing pressure from rising outside water levels;
- The secondary gate can be secured as a failsafe mechanism;
- Self cleaning as tidal flushing occurs from both sides of gate;
- Has no vertical height limitations as the design is only as high as the culvert;
- Good sealing capacity of secondary gate provided by replaceable seal;
- Stainless steel or marine grade aluminium construction materials highly resistant to corrosion and provision of long working life;
- Better provision for fish passage.

Disadvantages

- The floatation device is more susceptible to collect debris, compromising the intended operation of the gate;
- Premature closure of the secondary gate may result as it is forced closed by excessive head pressures generated by increased water levels during high tide or flood events. This is a particular issue for gates installed in larger hydraulic systems;
- Dependant upon individual design specifications, should the float be damaged or removed, the secondary gate can remain open. Float failure in other designs can result in the secondary gate sealing shut and the device operating as per a top hinged flap gate;
- Due to constant operation over time, the positioning of the floating arm can change from its intended setting, requiring adjustment;
- Stainless steel construction expensive. Combination of aluminium plate and stainless steel components can significantly reduce costs.

Fish Passage

Although the culvert and aperture size is a restriction on fish passage, the greater opening periodicity of the gate allows passage during both tide events. Passage is blocked completely for the duration of closure.

Considerations

There is a potential for the secondary gate to slam with the influence of wavelets lifting and dropping the floating arm. A larger float may be used to overcome this. Clearance in the system is required for the floating arm and to allow swinging of both the primary and secondary gates.

4.4 Fibreglass Ballast Floodgate

Constructed from vacuum-sealed fibreglass, this style of modified floodgate floats open in the water column until the downstream head pressure increases (due to tidal or flood water increase) causing the gate to close.

Vacuum sealing assists in the removal of air bubbles during fibreglass hardening and provides greater resistance against pin-hole corrosion by interaction with highly acidic or saline waters. This method of fibreglass moulding offer a life expectancy of around 50 years in acid waters. Being fibreglass, it is also not susceptible to the destructive process of electrolysis known to affect aluminium in saltwater.

A PVC ballast tube is fitted along the base of the gate to enable ballast such as sand, rocks or water to be added via one of the three fitted screw caps. This allows for regulation of the point at which the gate will close by manipulating the restorative force.

This design supports excellent drainage of agricultural land and the protection against saltwater intrusion and flood events. The ability to control the restorative force of the gate by the use of ballast can provide some degree of tidal intrusion for the control of in stream weeds and neutralisation of ASS contaminants.

Image 33: fibreglass ballast gate in the Manning Valley

Image 34: fibreglass ballast gate in the Manning Valley (S Walsh)

Advantages

- Excellent resistance to corrosion;
- High positive buoyancy (default weight) provides greater span of opening and periodicity;
- Adjustable weight for the determination of opening periodicity;
- Long life span;
- Naturally automated;
- Low maintenance;
- Light weight yet durable;
- Inexpensive construction materials;
- Easily retrofitted to existing culverts or headwalls;
- Provision for manual operation.

Disadvantages

- Large quantities of ballast may be required to overcome the high positive buoyancy of the gate;
- Should floating debris cause damage to the ballast tube, the high positive buoyancy of the gate may cause it to remain open, facilitating undesirable levels of tidal exchange.

Fish Passage

As per a tidal flap gate, fish passage is governed by the size of the aperture created by the open gate, the size of the culvert and the velocity of water passing through it. A barrier to passage exists for the duration of closure.

Considerations

Without the addition of ballast, the high positive buoyancy of the gate will cause it to float. As a result, the gate will remain open when waters either side of it are greater than the aperture it closes against. An appropriate ballast weight should be selected to provide the restorative force capable of achieving management objectives. In short, the less ballast added, the greater the opening periodicity of the gate, and vice versa.

Mounting the ballast tube on extended arms that hold the tube out from the base of the gate may maximise the mechanical advantage created by ballast. This will allow the use of less ballast to achieve the desired restorative force.

A ballast basket may be used as opposed to a ballast tube, allowing simplicity when adding or removing ballast. The basket may be constructed by moulding an open fibreglass box to the base of the gate. Ballast material, such as sandbags, may be added to or removed from the basket with ease. Holes may be bored into the base of the basket to allow flushing and prevent sediment accumulation.

Support ridges should be moulded along the edges of the gate to ensure rigidity.

Due to the light and buoyant nature of fibreglass, a chain hinge system may be used to allow a greater opening span.

4.5 Smartgates

Smartgates usually refer to gating systems fitted with advanced components that provide automatic actuation of gates when triggered. Self automation can be provided by a range of different mechanisms to suit numerous water control gate designs. Electrical motors activated by sensing data logging devices can replace manually operated winching systems and worm drives. Some designs may be activated by pneumatic or hydraulic systems. Circuitry can encompass telecommunication devices allowing a floodgate manager remote operation. Smart gate circuitry can be powered by solar systems for installation in remote locations.

Smartgates are particularly designed for systems which require a high degree of security in water levels and are often used for the rehabilitation of wetland environments that have been damaged by excessive floodplain drainage.

Image 35: smart gates installed in the Tomago Wetland (J Fredrickson)

Image 36: left: smartgate system; right: motor and sensory equipment (W Glamore, UNSW)

Advantages

- Fully automated based on a data logging and sensory equipment;
- Provides greater accuracy of control as floodgate operation is constantly monitored – particularly advantageous in highly dynamic waterways or remote locations;
- Automation may be provided by electrical, pneumatic or hydraulic actuation systems. These systems may also be manually overridden as required;
- Solar cells provide a power source in remote situations;
- Components can be retrofitted to many existing applications;
- Operational programs may be developed for automated control to accomplish a range of management objectives;
- Can be modified to allow for larger apertures;
- Telemetry systems can send information from sensory systems to a floodgate manager's mobile telephone;
- Better facilitation of fish passage whilst apertures are open;
- Floodgate action can be controlled remotely.

Disadvantages

- Costs of damage and vandalism can be expensive.

Fish Passage

Fish passage is restricted by both the size of the culvert, the opening of the aperture as determined by the gate and the velocity of water passing through the gate. A complete barrier exists for the duration of the gate closure. Smartgates operate about a larger aperture, facilitating better fish passage whilst gates are open. Debris screens can also provide an obstacle for fish passage.

Considerations

All electrical circuitry and instrumentation should be located well above the potential flood height invert in lockable and durable weather-proof shelters.

5. FIXED LEVEL RETENTION STRUCTURES (WEIRS)

Fixed level retention structures are incorporated into a water system when adjustment of the sill invert will not be required after installation. Weir retention structures can guarantee a minimum water level in the system behind the structure at a desired invert to satisfy management objectives. Permanent retention can assist in the rehabilitation of wetlands, ASS affected areas and highly saline waterways.

Fish passage about fixed level retention structures

Passage is only possible when water levels become high enough to overtop the weir. If a particular design includes any water control gates, passage will be governed by the size of the aperture of gates and the velocity of waters passing through. During all other events, and upon closure of any gates, a barrier to passage exists. These designs are suited to areas of extremely poor water quality where fish habitat value is minimal.

General considerations of fixed level retention structures

Bank stabilisation at the edges of the structure is also advisable for the alleviation of erosive processes. Similarly, stabilisation at the base of the structure will assist in preventing erosion by undercutting.

For adequate sealing capacity, the structure should be constructed at a length appropriate to allow each end to be keyed, or extended, into both banks of the host waterway at a minimum distance of 1.5m as to prevent water seeping through the soil around the structure. It may be more appropriate in some situations to excavate a trench the required length for the key and repack it with clay, or utilise a sheet piling product. Similarly, the height of the weir should provide adequate length so that when it is driven to the operational invert, it penetrates deep enough into the waterway floor to prevent leakage underneath the structure. Assessment of localised hydraulic conductivity of soils can assist in identifying these values.

Ideally, a retention structure should be situated at the toe of the levee where there is a naturally lower hydraulic conductivity in the soil. This will help to reduce the groundwater seepage loss around the weir.

Dependant upon the operational invert and associated tidal regime, fixed level retention structures can act as a barrier to both fish passage and intruding saline waters.

5.1 Sheet Piling Weir

The construction of pile weirs takes place by driving them into the waterway to the required height. This can be done by means of an excavator or similar device. Pilings can be manufactured from a range of materials to suit the requirements of the system, including recycled plastics and vinyl for increased resistance against corrosion. Individual pilings can be cut to the required length.

This weir design is excellent for use in sensitive environments where minimal disturbance to the system is required, such as ASS areas. These structures may be utilised for the remediation of ASS regions or wetland rehabilitation works where the prevention of excessive drainage is required. Sheet piling is also commonly used to coffer-off sections of waterways for construction of cast in place concrete headwalls or culverts.

Image 37: v-section plastic sheet piling weir (Vonmac)

Image 38: solid plastic sheet piling weir with water control gates (Vonmac)

Image 39: vinyl sheet piling weir (S Murphy - Clarence Valley Council)

Image 40: solid plastic sheet piling weir incorporating drop boards for added functionality (Vonmac)

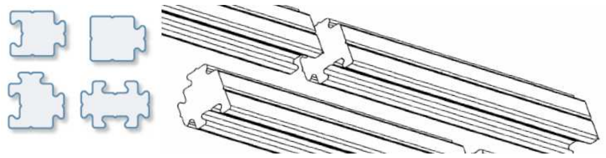

Image 41: Vonmac's Plastpile connectivity (Vonmac)

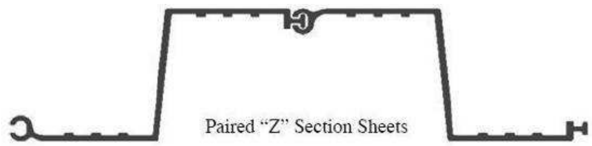

Image 42: sheet piling connectivity (Crane materials International - supplier to Pilequip Australia)

Advantages

- Guarantees minimum water level retention capacity providing excellent water level control;
- Interlocking Plastipile (Vonmac) provides excellent sealing capacity;
- Structure can be constructed to any length as required by interlocking as many pilings as necessary;
- Plastipile structures can be created to follow more than one direction, or to a desired with, by interlocking specially shaped pilings;
- Pilings can be custom made to a required shape;
- Can incorporate water control gates;
- Flexibility provides resistance against impact and a toleration of ground movement;
- Sheet piling installation may be linear or curved;
- Possible construction materials include corrosion resistant vinyl or recycled plastic;
- Easy handling and installation, as piles may be buoyant and lightweight and driven using an excavator;
- Minimal disturbance to the system of implementation as piles are merely driven into the ground – no digging;
- Relatively easy to remove from a waterway with minimal disturbance. Once removed the structure may be reused at a similar site;
- Low cost as concreting, earthmoving and coffering-off not required;
- Low maintenance.

Disadvantages

- Not adjustable without modification of original installation;
- May require the addition of rock fill for additional structural support;
- Sheet piling often results in some leakage.

Considerations

Piles should be of an appropriate length to allow them to be driven to the required invert at a depth that provides adequate support for the weir to withstand the forces acting upon it from the waterway. Plating piles or addition of rock fill can enhance support of the structure.

Piles should be driven with the male lock leading as the female lock has a tendency to fill with soil and hinder driving if used as the driving edge.

Although pile driving may be completed by any competent contractor or excavator operator, it may be beneficial to employ a localised consultant of the supplier to ensure correct and efficient installation.

The Plastipile product is manufactured by Vonmac of South Australia, who will oversee the installation to required specifications. Vonmac has a history of environmental applications with this product and will conduct geotechnical surveys as required. The cost of these structures will be highly variable, based on the scope of the project, scale of the host system, required number and length of pilings and geotechnical assessment. Freight will be calculated by the volume of Plastipile required and the location of the shipping destination from the production centre in Adelaide. As a result, freight may significantly add to costing.

5.2 Permanent Weir (Fixed Sill)

These structures create a partial blockage of the channel, retaining water level at the height of the structure during outflows. These structures can be constructed from a range of materials including earth and compacted clays, sandbags, concrete, steel or rock fill.

Image 43: permanent sill weir (Clarence Valley Council)

Image 44: concrete weir with flap gates for the prevention of saltwater intrusion. Compacted clay base covered by thin layer of concrete to reduce material costs.

Advantages

- Guarantees minimum water level retention capacity;
- Low maintenance requirements;
- A large range of construction materials are available to suit budgetary requirements and needs;
- Less susceptible to unauthorised adjustment of the desired invert;
- Can incorporate water control gates to allow greater management of water exchange.

Disadvantages

- Less flexibility with manipulating water levels;
- May be difficult to remove from waterway;
- Installations such as those involving set in place concrete can be labour intensive and cost prohibitive;
- The installation or removal of these structures can cause significant disturbance to the host waterway.

5.3 Stainless Steel Sheet Weir

This design follows the concepts of the sheet piling weir, however it is comprised of a single stainless steel sheet driven into the waterway to the required invert. This can be done by means of an excavator or similar machinery. Stainless steel sheets can be cut to size and welded together as required to achieve an appropriately sized single sheet for insertion.

Like the sheet piling weir, this design is excellent for use in sensitive environments for the prevention of excessive drainage. It is often a cheaper alternative to sheet piling with less intensive installation.

Image 45: stainless sheets welded to size and folded for support

Image 46: sheet weir installed behind a culvert for ASS remediation in the Manning Valley

Advantages

- Simplistic design;
- Naturally automated;
- Easily sized to suit application;
- Provides excellent water level retention;
- Sheets 3mm in thickness are considerably rigid and will cut through roots during insertion;
- Minimal disturbance to system during insertion or removal;
- Resistant to the corrosive effects from marine and highly acidic waters;
- Long lifespan;
- Low maintenance.

Disadvantages

- Generally only suitable for low volume drains;
- No protection against flood waters above the maximum sill invert;
- No provision for manual operation;
- Operational invert is not easily adjusted after installation – requires machinery such as an excavator.

Considerations

Folding a section at the top of the sheet to form a sill will provide added horizontal structural support. Reinforcing steel rod, or a similar material, may be folded and welded to the top of the fold to provide an anchor point to assist with mobility.

5.4 Pre-Fabricated Stainless Steel Weir

This design is driven into the waterway in a similar fashion to that of the Stainless Steel Sheet Weir, although it is superior in strength and durability and can be utilised in larger scaled applications. The v-section construction and added thickness of stainless sheeting provides increased rigidity, reinforcing the solid sills that hold them in place.

The designs presented in the images below comprise elevated walls either side of the operational invert that embrace a flap gate, facilitating protection against saltwater intrusion. This allows for drainage of agricultural land to the operational invert of the weir whilst withholding saline waters below the maximum high tide invert.

This design is ideal for use in sensitive environments closer to estuarine systems that require additional structural support.

Image 47: pre-fabricated stainless weir with tidal exclusion gate in Port Macquarie

Image 48: rope fixed to tidal exclusion gate facilitates more efficeint capacity for drainage by allowing greater opening span and periodicity during discharge

Advantages

- Naturally automated;
- Prefabricated to size suitable for application;
- Robust and rigid;
- Provides excellent water level retention;
- Minimal disturbance to system during insertion or removal;
- Resistant to the corrosive effects from marine and highly acidic waters;
- Long lifespan;
- Pictured designs provide tidal exclusion;
- Can be designed to include various flow control gates;
- Low maintenance.

Disadvantages

- No protection against flood waters above the maximum sill invert, which is only a consideration should this invert exist lower than that of the natural levee;
- Operational invert is not easily adjusted after installation – requires machinery such as an excavator;
- Requires occasional inspection for entrapped debris or damage.

Considerations

During installation, trenches may be excavated on either bank using a 300mm bucket to reduce the amount of effort required by machinery to drive the weir in place. Upon reaching the required invert, rocks may be used to fill the trenches and concrete added to finalise the fill and bind the rocks in place. This secures the weir assisting in the prevention of vandalism, as tampering with the structure will not be possible without the use of heavy machinery.

Music note seal can be installed to the edge of the tidal exclusion flap in order to enhance sealing capacity.

5.5 V-Notch Weir

As the name suggests, this design is a modification of the fixed sill weir that incorporates a 'V' shaped notch in the top centre of the structure. These designs are often utilised in order to calculate stream flow and discharge within the host system. The angular alignment of the v-notch can be set during installation to the most appropriate angle that will best suit calculation parameters. As these structures are effective in determining discharge and mass flux of water about a waterway, this data can assist in determining the rate of mass flux for a particular parameter in question, such as acid flux throughout an ASS system. An understanding of the mass flux of a parameter about a system is much more valuable than merely knowing the concentration of the parameter at a particular point. This data is often vital when formulating a remediation strategy.

Image 49: v-notch weir (W Glamore, UNSW)

Advantages:

- Naturally automated;
- Provides excellent water level retention below the v-notch;
- Excellent provision for stream flow and discharge calculations;
- Angular alignment of the v-notch can be set as to provide the most effective angle for stream flow calculations;
- In small systems, use of construction materials such as marine ply may be easily installed to the required elevation or removed from the system with minimal disturbance;
- Provision for the operational invert to be adjusted once installed, by blocking or cladding the required portion of the v-notch;
- Low maintenance.

Disadvantages

- Best suited for lower volume systems;
- No protection against flood waters above the maximum sill invert;
- If the installation is permanent, a lack of tidal flushing below operational invert can cause depreciation in water quality upstream of structure;
- More intensive installations involving set in place concrete can be intensive to both labour and cost.

Considerations

Designs can be made from numerous construction materials to suit the intended application and stream size. Smaller, temporary structures can be constructed simplistically from materials such as marine ply, as variations to the single sheet pile weir, or larger, more permanent installations can be achieved with set in place concrete casting.

Discharge about a v-notch weir is directly related to head (H). H in a v-notch weir is a measure of the height of water above the base of the v-notch. The v-notch allows large changes in depth to be noticed with small changes in discharge, and this allows for an accurate determination of H.

Numerous discharge calculations exist and many are best suited to particular applications or specific v-notch angular alignments. The most appropriate calculations and designs should be selected for each installation.
By constructing a weir with the angular alignment of the v notch set about 90º, discharge can be calculated using the following formula (W. Glamore, UNSW Water Research Laboratory):

Q = 0.266 x cB x (2g)0.5 x H1.5

Where, Q – discharge, or rate of flow, m3/sec
B – width of the weir at the flowing rate (across the channel)
C – discharge coefficient, average 0.62
G – gravitational constant, 9.81ms-2
H – height of water over the base of the v-notch, measured 4xH upstream of the weir

Note – height and width measurements in metres

6. ADJUSTABLE WATER RETENTION STRUCTURES

6.1 Drop-board Culvert (Overflow Escape)

Also known as flashboard risers, these culverts function as per a weir, retaining a specified volume of water behind the culvert during outflow. Construction usually consists of a concrete headwall to which boards may be added or removed along railings to achieve a desired water level. Water can over top the structure during high tide or storm events filling the rear of the system where it is withheld upon receding.

Drop-board culverts can be incorporated to existing structures, thereby reducing the number of additional structures required within the waterway, such as weirs.

These structures provide excellent water level control which can be utilised in the remediation of ASS, by ensuring potential acid concentrations remained waterlogged. Furthermore, the groundwater table may be raised providing vegetation greater accessibility to water and enhancing productivity.

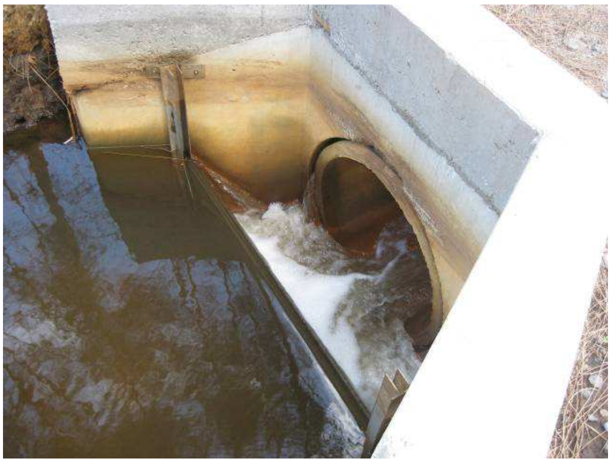

Image 50: drop-board culvert retrofitted to suit existing culverts in Anna Bay (K Russell)

Image 51: drop-board culvert retrofitted to suit existing culverts in Anna Bay (K Russell)

Image 52: precast drop-board culvert (Goondiwindi Precast)

Advantages

- Provides excellent water level control;
- Adjustable to desired water level;
- Construction can be retrofitted to existing culverts, removing the requirement for installation of further structures in the waterway;
- Concrete structures can be precast or set in place dependant upon design, scope of the project and site access;
- Designs can be manufactured inexpensively.

Disadvantages

- Often result in some leakage;
- Boards may be difficult to remove under significant head pressure;
- Manually operated;
- Smaller structures generally only suitable for low volume drains;
- No protection against flood waters above the maximum sill invert;
- Easily tampered with or vandalised which can result in the unauthorised lowering of the operational invert;
- May require additional OH&S infrastructure for safe working access;
- Restrictive to fish passage.

Fish Passage

Passage is only possible when water levels become high enough to overtop the drop boards. During all other events, a barrier to passage exists.

Considerations

Structures may only be set in place when there is adequate access to the site for the supply of concrete, and for construction itself. This method of concrete construction requires the isolation and subsequent drainage of the waterway at the construction site. These activities are often labour intensive and expensive.

Precast structures do not require waterway isolation for installation, although rock-fill is required to form a more robust base to enhance support of the structure.

Stabilisation of watercourse banks with rock-fill may be required to enhance erosion control, and the installation of an apron extending from the base of the structure may be beneficial in the alleviation of undercutting.

6.2 Lay-flat Gate (Tilting Weir)

As the name suggests, the lay flat gate closes vertically against a culvert and opens horizontally. When vertical, water passage is prevented in both directions. As it is laid horizontally towards downstream, water transfer is allowed and water can overshoot the gate. Upon receding water will be withheld behind the structure at the invert provided by the gate height. When fully horizontal, water transfer is allowed in both directions and is governed only by the dimensions of the culvert. The base invert of the culvert usually aligns with the watercourse floor in most designs allowing manipulation of water level about the full depth of the watercourse. This horizontal action requires little space above the gate for operation. Constructed from marine grade aluminium or stainless steel, lay flat gates can be retrofitted between existing concrete walls or piers, or constructed as stand alone units to suit system requirements.

These structures provide excellent water level control within the system which can assist in management of the ground water horizon, ASS remediation and the manipulation of tidal or storm waters.

Image 53: single celled lay-flat gate in Partridge Creek, Port Macquarie

Image 54: single celled lay-flat gate (AWMA)

Image 55: fully automated and solar powered multi celled lay-flat gates (AWMA)

Advantages

- Provide excellent water level control, flood protection, drainage or tidal exchange capacity;
- Provides excellent sealing capacity;
- Fully adjustable to maintain desired water level about the entire depth of the watercourse;
- Can be retrofitted to existing headwalls or piers;
- Manual actuation systems less expensive. Provision for data logging equipment and automated actuation systems for development as a smartgate;
- Greater opening expanse provides greater passage for debris;
- Better provision for fish passage;
- Can be used in conjunction with undershot gates;
- No vertical limitation above culvert for actuation.

Disadvantages

- Expensive. Installation of concrete supporting structure both intensive and expensive. Automatic actuation systems and data logging equipment significantly adds to costing and ongoing maintenance;
- Ongoing maintenance can be intensive and expensive;
- Manual operation requires human intervention;
- May require additional OH&S infrastructure to provide safe, working access.

Fish Passage

A barrier to passage exists for the duration of gate closure. While open, fish passage is only possible when water levels are high enough to overtop the gate. When fully open, passage is restricted only by the dimensions of the culvert and the velocity of water.

Considerations

For adequate sealing capacity, each end of the structural concrete should be keyed into both banks of the host waterway at such a distance as to prevent water seeping through the soil around the structure. Failing this, it may be more appropriate to extend the structure into the banks by inserting sheet piling or by excavating a pit and packing it with compacted clay.

The costs associated with the installation of these structures can often be expensive due to the incorporation of advanced components in the design. Dependant upon the design, ongoing maintenance costs may also be expensive. Although expensive, the cost of these structures will usually be relative to the scope and requirements of the project, where guarantees are required for specific objectives.

6.3 Drop-board Weir (Stop Log / Flashboard Weir)

Construction usually entails installation of a concrete support structure that creates a partial blockage in the system, although rock-fill or other materials may be used. The centre of the structure usually comprises a gap with a railing system moulded into each end for the provision of dropboards to determine the operational invert of the weir.

These structures provide excellent water level control within the system which can assist in management of the ground water horizon and the remediation of ASS, by ensuring potential acid concentrations remained waterlogged. Furthermore, the groundwater table may be raised providing vegetation greater accessibility to waters and enhancing productivity.

Image 56: installation of precast drop-board weir (S Walsh)

Image 57: installation of precast drop-board weir (S Walsh)

Image 58: installation of precast drop-board weir (S Walsh)

Advantages

- Provides excellent water level control, drainage or tidal flushing;
- Adjustable to desired water level;
- Low maintenance;
- Designs are often inexpensive;
- Concrete weirs can be precast or set in place dependant upon site suitability.

Disadvantages

- Often result in some leakage;
- Boards may be difficult to remove under significant head pressure;
- Manually operated;
- Restrictive to fish passage;
- No protection against flood waters above the maximum sill invert;
- Easily tampered with or vandalised which can result in the unauthorised lowering of the operational invert;
- May require additional OH&S infrastructure for safe working access.

Fish Passage

Passage is only possible when water levels become high enough to over top the weir. During all other events, a barrier to passage exists.

Considerations

Structures may only be set in place when there is adequate access to the site for the supply of concrete, and for construction itself. This method of concrete construction requires the isolation and subsequent drainage of the waterway at the point of installation. These activities are often labour intensive and expensive. Precast structures do not require waterway isolation for installation, although rock-fill is required to form a more robust base to enhance support of the structure. Stabilisation of watercourse banks with rock-fill may be required to enhance erosion control.

For adequate sealing capacity, each end of the structural concrete should be keyed into both banks of the host waterway at a distance of at least 1.5m to prevent water seeping around the structure through the soil. Failing this, it may be more appropriate to extend the structure into the banks by inserting sheet piling or by excavating a pit and packing it with compacted clay.

6.4 Self-Regulating Tilting Weir

The self tilting weir was designed for the remediation of ASS pollutant discharge by allowing a minimum water level to be maintained constantly at a desired elevation upstream of the structure. The intention of maintaining this water level is to withhold the groundwater table so that ASS material remains inundated and therefore contained within the soil profile, preventing the mobilisation of this material during low water level events.

The design incorporates a moveable gate about an aperture at the top of a weir. The movement of this gate is governed by tidal amplitude by means of a set of floats on the downstream side of the structure. Wire ropes are attached to the gate on the upstream side, the length of which are set to guarantee a desired minimum water level behind the structure. The gate may be raised or lowered about the aperture, by adding or removing specialised blocks as required under the gate.

As the water level increases on the downstream side, the gate lowers and allows tidal ingress to pass through the aperture. During egress the floats lower causing the gate to rise, holding back water and preventing the mobilisation of ASS products from the soil profile below that elevation.

Image 59: water transfer through self tilting weir (W Glamore, UNSW Water Research Laboratory)

Advantages

- Provides excellent water level control;
- Gate adjustable to desired elevation;
- Self automated;
- Structural concrete precast for more effective construction and installation.

Disadvantages

- Floating debris may damage or jam operation of gate;
- Gate height may be difficult or inappropriate to adjust under significant head pressure;
- No protection against flood waters above the maximum sill invert;
- Easily tampered with or vandalised which can result in the unauthorised lowering of the operational invert;
- May require additional OH&S infrastructure for safe working access.

Fish Passage

Passage is only possible when water levels become high enough to over top the weir or during transfer through the aperture. During all other events, a barrier to passage exists.

Considerations

The floatation devices must be adequately buoyant to counteract the weight of the gate. The use of stainless steel products is recommended for fixtures and wire rope fittings for better protection against corrosion.

6.5 Overshot – Undershot Penstock (Head and Discharge Gate)

This style of penstock operates as per a vertically winched penstock, although it has two vertical sluices operating within a robust external frame. The use of a second gate allows greater vertical manipulation of water passage. As the base invert of the culvert usually aligns with the watercourse floor in most designs, manipulation of water level can occur throughout the full depth of the watercourse. When fully closed, the lower sluice seals flush with the base of the culvert, and the base of the upper sluice aligns with the top of the lower sluice.

Adjustment of the upper sluice provides flow regulation through the top half of the gate, while the lower sluice can prevent or allow drainage under the gate. Furthermore, both gates can be removed from the system allowing complete exchange governed only by the dimensions of the culvert. Can be retrofitted to existing culverts or headwalls or constructed as self contained units. Multiple bays can be implemented as required.

This level of flow control can be used to satisfy a range of management requirements and can be used in the remediation of ASS and resultant impacts, the management of mosquito breeding, in stream weeds and water quality, and for the enhancement of riparian vegetation and wetland or agricultural productivity.

Image 60: left: over/undershot gate (Watergates sp); right: closed over/undershot penstock (AWMA);

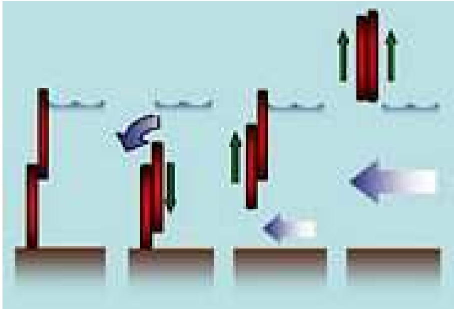

Image 61: schematic; operation of over/undershot penstocks (AWMA)

Advantages

- Provide excellent water level control, flood protection, drainage or tidal exchange capacity;
- Can be constructed to retrofit existing culverts or headwalls;
- Adjustable and reliable;
- Low maintenance;
- Excellent sealing capacity;
- Manual actuation systems less expensive. Provision for data logging equipment and automated actuation systems for development as a smartgate;
- Removable handles on manual actuation systems to help alleviate unauthorised tampering.

Disadvantages

- Manual operation requires human intervention;
- May require additional OH&S infrastructure to provide safe, working access;
- Friction can develop in the tracks whilst opening or closing gates;
- Construction can be expensive.

Fish Passage

Passage is restricted to the size of the culvert, the size of the opening relative to the sluice positioning and the velocity of water passing through the aperture. A barrier exists for the duration of gate closure.

Considerations

Penstocks often require space vertically above the culvert for actuation systems and operation of sluice gates. Gates should be designed and reinforced to withstand in stream forces and impacts from floating debris.

6.6 AWMA Sidewinder

The sidewinder gate operates as if it were a sideways penstock. Opening gates will allow tidal exchange to take place for the duration of the opening period and can allow large, rapid inflows of river water. Exchange rate is limited only by the aperture size created by the gate or by closing any gates once an appropriate objective has been reached. With excellent sealing capacity, closure of the sidewinder gate provides efficient water retention properties, and the protection against ingress of flood or saline tidal waters.

Image 62: sidewinder gate installed for SunWater QLD (AWMA)

Advantages

- Requires no space above culvert for actuation systems;
- Excellent sealing capacity;
- Fully adjustable;
- Excellent flood protection and tidal exchange capacity;
- Can be retrofitted to existing headwalls;
- No obstruction of waterway by supports and frames;
- Less friction acting on tracks;
- Greater or full depth of the water column provides more efficient fish passage and water transfer;
- Manual actuation systems less expensive. Provision for data logging equipment and automated systems for development as a smartgate;
- The manual action handle can be removed to reduce the risk of unauthorised tampering.

Disadvantages

- Manual operation requires human intervention;
- May require additional OH&S infrastructure to provide safe, working access;
- Poor water level control without expensive automatic actuation systems or constant manual monitoring.

Fish Passage

Fish passage will be restricted by the size of the aperture as determined by the positioning of the gate and the velocity of water passing through. A barrier to passage exists for the duration of gate closure.

Considerations

Gates should be designed and reinforced to withstand in stream forces and impacts from floating debris.

6.7 Swivelling Elbow Culvert

This design consists of an elbow shaped pipe section that may be rotated about a lubricated O-ring fitting. The elbow is affixed to the end of a culvert. Raising or lowering the elbow determines the upstream or pond water level. When vertical, the greatest depth will be maintained according to the length of the riser pipe. When horizontal, the culvert will drain the system, provided that the pipe joint is installed level with or below the system floor. All water above the operational invert created by the position of the elbow has the potential to be discharged.

The swivelling elbow culvert is utilised for the rehabilitation or preservation of wetland environments. It allows a controlled amount of water to be retained within the wetland environment to achieve a range of natural resource management outcomes.

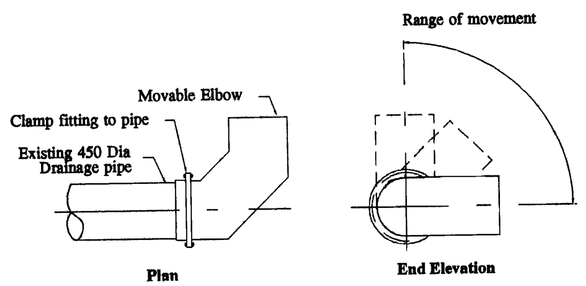

Image 63: Patterson and Smith (2000)

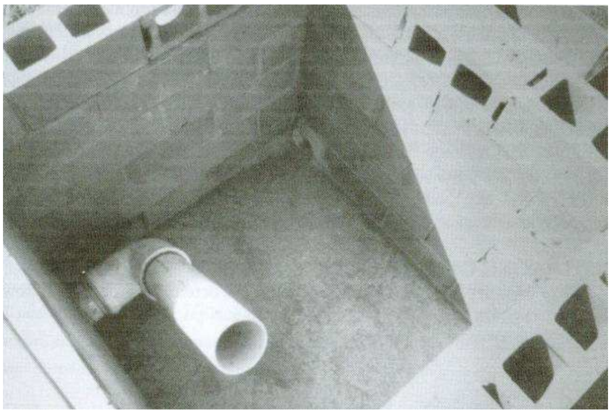

Image 64: swivelling elbow culvert with riser pipe set in a trench (Hammer, 1997)

Advantages

- Inexpensive parts and manufacture;
- Naturally automated;
- Adjustable to the length of the riser pipe;
- Simplistic design;
- Simple to transport and assemble. Can be installed in remote regions or sites with limited accessibility;
- Excellent water level regulation.

Disadvantages

- Generally only suitable for low flow systems. Pipe diameters greater than 250-300mm may be impractical to rotate;
- Requires manual intervention to adjust operational invert;
- Debris may accumulate in the elbow compromising operation. Damage or movement due to debris impact can alter the position of the elbow and hence the operational invert;
- Vulnerable to vandalism or unauthorised tampering.

Fish Passage

Due to the enclosed nature of piping and the culvert, darkness may prevent passage. The velocity of passing waters and the length of the culvert may also impede or prohibit passage. Furthermore, water levels either side of the culvert may be insufficient to allow entry or exit.

The swivelling elbow culvert is often utilised to manipulate water elevations about levees. As a levee offers no provision for fish passage, the use of a swivelling elbow structure is not expected to impact upon passage.

Considerations

Designs may be highly variable and can be constructed inexpensively from PVC piping and accessories readily available at local hardware, plumbing and irrigation stores.

A short length of wood or similar object may be inserted to the end of the elbow to provide greater leverage to assist rotation, should the elbow be stiff. A short chain or similar material may be used to fasten the elbow in position.

A headwall should be fitted with an apron extending underneath the elbow to prevent undercutting.

Generally, the discharge is equivalent to the diameter of the pipe and additional inflow with greater depths and higher hydraulic pressures only increases the velocity of the outflow (Hammer, 1997). Increased velocity translates into increased volumes, but the capacity to accommodate substantial increases is obviously limited (Hammer, 1997).

7. COMPARISON OF DESIGN ELEMENTS

Structure Design	Tidal Exclusion	Tidal Flushing	Flood Protection	Water Retention	Natural or Tidal Automation	Manual Automation	Self Automated	Adjustable Water Level	Fish Friendly	Good Seal Capacity
Hinged Flap	✓		✓		✓					
Elastomer Check Valve	✓		✓		✓					✓
Winched Flap	✓	✓	✓	✓	✓	✓			✓	
Sluice	✓	✓	✓	✓		✓		✓	✓	
Penstock (Vertical Winch)	✓	✓	✓	✓		✓	✓[1]	✓	✓	✓
Waterman/Nekton SRT		✓	✓		✓			✓	✓	
Automatic Gate	✓	✓	✓	✓	✓	✓		✓	✓	
Fibreglass Ballast Gate	✓		✓		✓					
Saltshaker Gate	✓	✓	✓	✓	✓	✓		✓		
Smart Gate	✓	✓	✓	✓		✓	✓	✓	✓	✓
Permanent Weir		✓[2]		✓	✓					
Sheet Piling Weir		✓[2]		✓	✓					
Stainless Steel Sheet Weir		✓[2]		✓	✓					
Pre-Fab Stainless Steel Weir	✓			✓	✓					
V-notch Weir		✓[2]		✓	✓			✓[1]		
Drop-board Culvert		✓[2]		✓	✓	✓		✓		
Drop-board Weir		✓[2]		✓	✓	✓		✓		
Lay-Flat Gate	✓	✓	✓	✓		✓	✓[1]	✓	✓	✓
Penstock (Over/Undershot)	✓	✓	✓	✓		✓	✓[1]	✓	✓	✓
AWMA Sidewinder	✓	✓	✓	✓		✓	✓[1]		✓	✓
Swivelling Elbow Culvert				✓	✓	✓		✓		

✓[1]: Optional design element
✓[2]: Above operational invert only

8. GENERAL CONSIDERATIONS OF STRUCTURE DESIGN

8.1 Comprehensive Engineering and Scientific Advice

The construction of culverts, headwalls and floodgates requires a substantial understanding of the site specific processes occurring within the host system. There are often very specific guidelines that must be followed when designing these structures. Advice should be sought from qualified personnel or consultants as required for each installation or modification.

8.1.1 Engineering advice

To correctly design and install these structures, extensive engineering calculations are required to determine forces, understand hydraulic processes and allow consideration of super-critical flows. It is essential to have a comprehensive knowledge of these elements to ensure that the structure operates as intended.

Hayes *et* al, 2000 discuss wetland engineering procedures in detail with section five focusing on the design of water control structures and erosion control. Section four of the publication covers geotechnical aspects, describing soil handling and earthwork techniques including excavation and containment of dredged material.

8.1.2 Hydrological assessment

A hydraulic assessment is required for all water control structure installations or modifications and provides an understanding of the distribution, abundance and passage of water about the site. Assessment will help ensure that works do not unintentionally affect the land adjacent a system by altered flow rates, or result in increased erosive or scouring processes within the system. Assessment can also identify the expected velocity of water through structures, which can assist in the design of fish friendly modifications. Assessment can also be used to determine an appropriate setting for the operational invert or to calibrate adjustable structures.

A hydraulic assessment will typically include catchment size and land elevation surveys, K_{sat} assessments, watercourse profiling, assessment of system water level during both dry and wet periods, operation and efficiency of present water control structures or in-stream blockages, the extent of tidal ingress and egress, along with invert assessment of side or feeder drains, to determine the capabilities and limitations of the system.

The above elements can be combined in a complex computer model to simulate the effects that the installation of a water control structure will have on the parent system. Modelling can also be utilised to fine tune structural design.

8.1.3 Saturated hydraulic conductivity (Ksat) and Darcy's Law

K_{sat} of soil is a measure of the rate at which water passes throughout the soil profile under saturated conditions. Lal, 2006 provides that K_{sat} varies from soil to soil and even within the given soil, as it depends upon soil properties such as fineness, clay content, solid particle orientation, organic matter content and water content. K_{sat} is an important soil hydraulic property that affects water flow and the transport of dissolved solutes (Zeleke and Si, 2005).

Darcy's Law is an equation that can be used to quantify the amount of water passing through an aquifer and hence can be used to determine localised groundwater seepage. In Darcy's Law, K_{sat} is a variable forming the coefficient of permeability. Darcy's Law takes many forms, and the most appropriate form should be chosen when conducting seepage calculations. Darcy's Law can be expressed as (Sara, 2003):

$Q = KiA$ Where,
- Q – volume of discharge
- K – hydraulic conductivity
- I – hydraulic gradient
- A – cross sectional area

The installation of a water control structure can have significant impact upon localised groundwater interactions. These impacts will be dependant upon the influence of the structure in conjunction with the parameters of Darcy's Law. For example, installing a structure that facilitates tidal flushing in a system with a catchment possessing a high or extreme rate of K_{sat} can result in saltwater infiltrating the soil profile, and this can result in detrimental consequences such as reduced wetland vegetation and pasture productivity. Therefore, site specific knowledge about the maximum water conducting capacity of soils is crucial in understanding and modelling several surface and subsurface processes (Zeleke and Si, 2005).

There are numerous methods and calculations for determining saturated and unsaturated hydraulic conductivity, such as infiltration and pit bailing methods, and the most appropriate method should be selected to suit site specific conditions. The pit bailing method has been described by Bouwer and Rice, 1983 and Boast and Langebartel, 1984. Furthermore, Johnston and Slavich (2003) describe a

simple, semi-quantitative field method for assessing the likely range of K_{sat}, and this is available at: http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0009/168408/hc-field-test-instructions.pdf
Surface water and ground water aspects of wetland hydrology are discussed in detail in Hayes *et al*, 2000.

8.1.4 Acid sulfate soil (ASS) assessment

It is important when implementing structures in coastal systems to assess the presence and extent of ASS material in the catchment adjacent the system. This assessment typically includes analysis of soil profile cores taken throughout low lying regions adjacent to the system in order to determine the depth to any present acid sulfate layers. Soil samples are also taken for analysis to reveal detailed information regarding the acidic content. Detailed guidelines for the remediation of ASS in coastal floodplains of NSW are described in Tulau, 2007.

Retention structures are often used for the remediation of ASS conditions by holding the groundwater table above ASS layers. Where the primary function of the system is to drain agricultural land, the operational invert must be positioned at an elevation that will not compromise the capacity of the system to drain the surrounding catchment. Where this is intended the invert of the structure should ideally be set, where possible, at a height sufficient to inundate all acid sulfate layers. The actual achievable invert will be determined by the capacity of the system or an agreement reached with the landholder prior to implementation.

By setting the operational invert of the structure at a height capable of inundating the Potential Acid Sulfate Soil (PASS) layer, the exclusion of oxygen will prevent any further acid production as a consequence of oxidation. The inundation of the upper Actual Acid Sulfate Soil (AASS) layer will prevent the mobilisation of any oxidised and acidic product via groundwater discharge into the system. Inundation of the AASS layer without compromising the efficiency of the drainage system is often not possible, due to the relatively shallow occurrence of this layer in the soil profile. In this circumstance, the overall capacity of the drainage system would need to be enhanced to support the addition of a structure at these inverts.

The period whereby groundwater derived acidity is able to discharge into an adjacent waterway or drain is known as the acid export window. The acid export window is determined by the height difference between the top of the AASS layer (i.e. acidified soil, often also the surface soil in ASS backswamps) and the daily low tide level in the backswamp drain (Tulau, 2007). In accordance with Darcy's Law, rates of groundwater seepage to drains will be dependant upon the magnitude of effluent groundwater gradients, the hydraulic conductivity of acid soil horizons and the area over which seepage occurs (Johnston *et al*, 2004), so this will govern the duration and extent of discharge and therefore the mass flux of acid products.

Many previous cases have noticed that the final 10% of the hydrograph discharging from this acid export window contains the greatest concentration of ASS contaminants. In these instances, the circumstances suggest that the best achievable remediation strategy may therefore be the installation of a groundwater retention structure at an elevation above this sector of the hydrograph. However, due to the unique site specific conditions in effect at each site, this is not always the case. A comprehensive scientific assessment is required to determine the actual conditions occurring on site and the most appropriate remediation strategy.

It is also important to note that by installing any fixed level retention structure in an ASS system, the point of installation will create a barrier to saltwater intrusion, preventing the passage of saline waters upstream of the structure. This can impede or prevent the natural neutralisation of acid products by saltwater and result in a proliferation of in-stream weed species. Stagnation can also cause significant depreciation of water quality, particularly in dissolved oxygen content.

8.2 Material Choice for Structure Design

A range of materials are available for use when constructing water control structures, and these materials must be chosen to suit the particular conditions of the system in which it will be implemented and in accordance with budget availability.

8.2.1 Supporting structures

Concrete is commonly used due to its excellent strength, durability and erosive resistance. Concrete also has excellent water sealing capacity and provides good protection against bank erosion. Construction can be moulded to suit any design and allow efficient union with water control gates. The cost of constructing concrete supports can be quite expensive as construction is labour intensive and the cost of concrete itself is quite high. Concrete construction may be precast or set in place, dependant upon site specific requirements.

Image 65: cast in place concrete construction is intensive to both labour and cost

The binding agent of concrete is susceptible to attack from highly acidic waters and prolonged interaction with these waters can cause deterioration of the structure. High performance concrete products have been developed that provide additional protection against aggressive environments. Such products are capable of withstanding attack from sulfates or marine chlorides and depending on the application can provide a lifespan of around 50 years. These concrete mixtures often have the ability to cure underwater.

The dense packing and collaboration of rocks can also be used to construct support structures. Rock walls can also be used for the provision of further support to existing structures or the protection against bank erosion. The use of rock in this manner can be a disadvantage in some instances as it can provide vandals with a ready supply of material to construct unauthorised weirs or otherwise tamper with the structure. Binding the rock in some manner, such as loosely pouring a small quantity of concrete over the structure, may help to alleviate this. If the chosen aggregate (rock) is small enough, it may be installed in gabion baskets.

Although rock is more resistant to acidic influence it is more susceptible to erosion and can be hard to bind or incorporate water control gates. Earth may be packed around pipes and culverts to provide simplistic and cost effective supporting structures but this design is also susceptible to erosion.

8.2.2 Gate construction

Most unprotected metals are prone to corrosion or rusting during interaction with water, particularly marine and brackish waters or those with high acid concentrations. Galvanising or painting unprotected metals is a common method of providing protective coatings to combat corrosion. Due to constant interaction with water, coating these metals may not be a feasible solution as chemicals from the paint or actual paint particles may be leached to the system causing environmental harm. As a result, aluminium or stainless steel products are popular construction materials due to their natural corrosive resistance, although designs may also utilise carbon steel, titanium, fibreglass, plastics, wood and rubber, or a combination of these materials.

Image 66: recycled plastic construction material (Photo: S Walsh)

The weight and buoyancy of a water control gate is often a determining factor of its functionality, particularly in tidally automated gates where the natural processes of the system operate the gate. A material of appropriate weight and buoyancy must be chosen for the design or the structure may not function as intended. Floatation devices may be attached to gates to increase buoyancy as required. Consideration must also be given to the permeability of a chosen material as water logging can significantly affect the weight and buoyancy of the gate and implicate functionality.
A material of appropriate strength must also be chosen to withstand impacts from floating debris.

8.2.3 Component selection

Improper hinge design or installation, or the corrosion of hinge material, may significantly increase friction and hence the restorative force of the gates or the activation of floatation devices.

Furthermore, waterborne debris may damage hinges or floatation devices adding to the restorative force or preventing the gate from functioning. Stainless steel and bronze materials provide greater resistance against corrosion.

8.3 Regular Inspection and General Maintenance

Regular examination is required to check the condition and operation of all structures and devices, and for the build up of debris. Floating debris may accumulate within or about culverts and apertures, preventing or impeding the passage of water. Furthermore, this debris may also cause damage to structures or compromise the operation of gates or components.

Periodic maintenance is required to ensure hinges and actuation systems are functioning appropriately, and that any adjustable control arms are operating at the correct setting.

8.4 Importance of the Operational Invert

The operation of water control structures is governed by the hydrology of the host system in conjunction with natural tidal cycles. This cycle directly controls fish passage and water chemistry and indirectly influences a variety of biological factors (Giannico and Souder, 2005).

The operational invert of a water control gate is effectively the bottom sill or base of the culvert to which the gate is attached. Similarly, the operational invert of fixed level retention structures will be the invert of its sill, or the base sill of any incorporated gates in the instance that they are in operation. All waters below the operational invert will be withheld behind the structure and all waters above have the potential to be discharged, dependant upon the magnitude and duration of low tide events and the influence of any control gates.

The exchange of water about these structures is provided above this operational invert and will be dependant upon natural tidal cycles and the upstream hydrology of the waterway. Greater control of water exchange is provided by manually operated or self regulating designs, which allow the operational invert to be adjusted as determined by the positioning or closure of gates.

There may be a significant difference in the elevation of the low tide experienced between king and neap tidal cycles. The positioning of the operational invert within this ranging elevation will determine the drainage capacity of the upstream system. If the operational invert is too low, the frequency of conditions required to provide adequate drainage may be insufficient. Conversely, if the operational invert is too high, excessive drainage may result. As the same cyclic differences in elevation are noticed in high tide events, similar consequences can apply to the amount of exchange experienced during high tide events or level of flood protection provided by a structure.
In particular, these factors apply to designs that are controlled exclusively by natural tidal regimes.

As the extent of tidal fluctuations, landscape elevation, hydrological parameters and structural design will be specific to each site, it is suggested that the operational invert will be unique for every water control structure. The operational invert is essentially calibrated by determining a point of equilibrium within all expected tidal elevations that will provide the required functionality of the structure. Other factors, such as the elevation of potential acid sulfate layers, may also influence the operational invert, and consideration of these factors may be required by legislative instruments.

8.5 Costs Associated with Installation

The costs associated with installing or modifying water control structures will most often be highly variable for each application, and due to the unique site specific requirements and the desired objective, it is not unusual to notice varying costs even when installing a number of the same structures within the one system.

There are many factors that influence the cost of structural design, including:

- Structure type;
- Chosen construction material;
- Size and number of structures required;
- Sealing capacity;

- Actuation systems, such as pneumatic, hydraulic, electric, buoyant and manually operated systems;
- Chosen components, such as hinges, rigging equipment, GSM modems, data logging equipment, sensory systems and power supply;
- Construction of a supporting structure or other infrastructure to allow safe working access to actuation systems, fish passage, debris protection;
- Modifications to existing structures or parent gates;
- Cost of manufacture, freight, and
- Erosion control, and
- Expected ongoing maintenance costs.

Installation costs will also be highly variable and this will be determined by structural design, ease of site accessibility and the condition of the construction site. This is particularly true with respect to concrete, as cast in place structures may be labour intensive, requiring isolation of the host system at the point of installation through the construction of coffer dams and the use of pumps. The grade of concrete used will also influence construction costs.

As significant engineering and scientific advice is required for each installation, these elements will further influence costs. Geotechnical, hydraulic and ASS assessments are usually necessary to develop remediation strategies and management objectives. These elements go hand in hand with structural design and field calibration, to ensure that structures operate as intended.

The above mentioned factors must be considered for each application. Even though many factors may compound to result in an expensive project, the associated costs will usually be relative to the scope of the project.

8.6 Debris Control (Trash Racks)

Debris accumulation at culvert inlets can have detrimental effect upon the operation of water control structures and, or, result in inadvertent adjustment of hydrological flows. Damage to structures or components of gated systems can be expensive, and failure of these systems can significantly alter management objectives. Debris control structures provide a means of protecting structures from impact or jamming the operation of gated systems by intercepting debris, shielding the structure.

These structures may not be suitable for use in some situations. In particular, systems isolated from tidal exchange and subsequently prone to excessive growth of in stream weeds. These weeds may accumulate in debris control structures where they can become entangled and difficult to remove.

Debris may also be controlled using non structural measures. Debris management is often a cost effective alternative to the installation of further structures and can be implemented when the use of these debris control structures is inappropriate. This method aims to reduce excessive debris input into the waterway and is achieved by clearing litter, fallen trees and branches from the waterway and the floodplain and maintaining these environments. A Debris Management Plan may be devised and incorporated as part of a final Plan of Management for associated water control structures.

Image 67: square mesh debris shield (Photo: W Glamore, UNSW)

Image 68: steel debris rack (Photo: Bradley *et al*, 2005)

Advantages

- Designs often inexpensive;
- Easily installed in or removed from the waterway;
- Reduced expense associated with damage to water control structures;
- Reduced failure of automated structures by operational jamming by debris.

Disadvantages

- Added cluttering of waterway;
- Fowling by aquatic organisms may accumulate within debris shields and be difficult to remove, particularly by plant species;
- Greater maintenance may be required to remove entrapped debris or fouling;
- Fish passage may be hindered or prohibited by designs or encompassed fouling.

Fish Passage

Dependant upon the design, where restrictions are generated by the size of mesh, fish passage may only be compromised with congestion by debris or excessive fouling. Designs will need to provide adequate passage for those applications expecting to encounter fish species.

Considerations

The type and estimated quantity of debris expected to be encountered by the debris control structure will determine the required design. Land use maps, topographic mapping and elevation modelling can be utilised to estimate the type and quantity of debris. Regular maintenance and removal of entrapped debris is required to ensure correct operation.

8.7 Modifications for Improved Fish Passage

Many of the designs outlined in this document have been developed for use in environments that do not naturally provide habitat for fish species, or are incapable of hosting fish, such as some man made drainage channels, many of which contain highly acidic waters. These structures are often used to improve the quality of waterways in which they are implemented, and usually expect to have no impact upon fish passage. In the event that structures are to be installed in fish habitat, modifications can be made to existing gates or incorporated in new designs.

8.7.1 Permanent holes

Permanent holes can be cut into gates so that there is always provision for fish passage. Provided that these holes are left unobstructed, the only restriction to passage will be the aperture size and the velocity of water passing through it.
This modification method may be impractical for most applications, particularly where gating is required to prevent saltwater intrusion or retain a predetermined level of water behind the gate.

8.7.2 Fish flaps (pet doors)

Image 69: open fish flaps attached to penstocks in Swan Creek (Clarence Valley Council)

Submerged flaps may be incorporated into water control gates for the facilitation of fish passage without compromising the functionality of the structure as per permanent holes. Fish flap devices operate in a similar manner to that of the automatic floodgate. The automatic floodgate closes as the water level raises the float outside of the gate, preventing excessive upstream tidal exchange. However, a fish flap device will open under these conditions and will close upon the receding tide, allowing water retention behind the structure.

8.7.3 Fishways (fish ladders)

Image 70: rock ramp fishway installed about Higgin's Causeway in Gloucester

Fishways are structures that may be manufactured on or around obstructions such as weirs or causeways to facilitate the passage of fish without compromising the functionality of a structure. Fishways are normally utilised on large scale applications. Passage is provided by allowing fish to swim through gaps or slots into a series of ponds. Each pond increases in elevation gradually, by some 100mm, starting from the waterway bed until the ‘ladder’ reaches the invert of an obstruction. The ridges separating ponds control the velocity of passing waters. Points of low velocity flows occur behind these ridges, allowing fish to rest and rebuild ‘burst speed’ energy. Fishway pools should be constructed to recommended gradients of 1:20 or 1:30.

Further information and differing design types can be found on the NSW DPI Fishways website:

http://www.dpi.nsw.gov.au/fisheries/habitat/rehabilitating/fishways#Types-of-fishways

9. NSW LEGISLATIVE CONSIDERATIONS FOR DESIGN IMPLEMENTATION

A consenting authority, most often the Local Council, is usually required to grant development consent prior to conducting on ground works. Along with consent, an approval or permit from a State or Commonwealth Government body may also be required, dependant upon the nature, location and scale of the development. The following is an overview of legislative instruments that may apply to the implementation of water control structures. These and any other instruments relative to site specific works must be reviewed and their requirements met when planning and conducting works. It is important to note that the following is merely a summary based on relevant legislative instruments current at the time of writing (September, 2009) and that the actual instruments in force or their requirements may differ from what is included in this section.

When determining legislative requirements it is best to begin by reviewing the prevailing Local Environment Plan. Should processes lie outside those presented by the LEP, reference can be made to more appropriate instruments as determined by the individual circumstances of the works. The processes presented in these referred instruments will then supersede the LEP.

9.1 Environmental Planning and Assessment Act 1979 (EP&A Act 1979)

The *EP&A Act 1979* has been developed to establish a general framework for environmental planning and assessment in NSW. Part 3 of the Act presents the framework for the creation and application of Environmental Planning Instruments (EPI), such as State Environmental Planning Policies (SEPP). Part 4 describes the processes required to attain development consent under an EPI or other Acts of Parliament. When consent is not required by any EPI or other Act, Part 5 prevails and provides the processes for attaining consent or completing any required environmental assessment of impacts relating to the development.

If the development will require consent, then a Development Application (DA) must be completed and approved as provided by Part 4 of the *EP&A Act 1979*, prior to undertaking works. The application for development consent process is outlined in s. 78A-81. The DA should address all aspects presented within these sections and identify any likely impacts of the development.

If development consent is not necessary, Part 5 prevails. Although consent may not be required, environmental impacts of the proposed works may still need to be assessed.
Assessment in the form of an Environmental Impact Statement (EIS) will be required for works that will have a significant impact on the environment. However, if an EPI determines that works are permitted without consent and will be of minimal environmental impact, the works are defined as *exempt development* under s. 76 (2), and an EIS will not be required. Assessment in the form of a Review of Environmental Factors (REF) can be completed to determine the scale of environmental impact expected by the works, and hence any requirement for the submission of an EIS.

The conditions set out in Part 5 of the Act, may require that some other approval is to be obtained by further legislative instruments or Acts. For example, if the works were to have an impact upon threatened species or communities, approval may then be required as determined by the Threatened Species Conservation Act 1995.

Furthermore, Part 5a provides the processes for development by or on behalf of the crown.

9.2 State Environmental Planning Policy (Infrastructure) 2007

Certain development types completed by or on behalf of a public authority are defined as *exempt development* by *SEPP (Infrastructure) 2007,* and are therefore permitted without consent. Types of exempt development often applying to works associated with water control structures include:

- Soil conservation works, for the management of acid sulfate soils, soil salinity and, or, erosion;
- Flood mitigation work;

- Works on land reserved or declared under the *National Parks and Wildlife Act 1974*, the *Marine Parks Act 1997* or the *Fisheries Management Act 1994*, on the provision that the works complies with the functions of the mentioned Acts.

9.3 State Environmental Planning Policy 14 (Coastal Wetlands)

SEPP 14 – Coastal Wetlands aims to ensure that the coastal wetlands are preserved and protected in the environmental and economic interests of the State, as given by Clause 2. Many coastal catchments and floodplains lie within land gazetted as SEPP 14 coastal wetland. These boundaries are represented in a series of maps held in the office of the Department of Planning. The boundaries presented within the maps should be surveyed as necessary to ensure that the on ground boundaries correspond with map lines, and that works are indeed enclosed within SEPP 14 wetland.

Council consent and concurrence from the Director-General (Dept. of Planning) is required for any works proposing to fill, clear, drain or construct a levee within land SEPP 14 bounded wetland. Any such proposal requires the accompaniment of an EIS.
The implementation of a new water control structure or the modification of an existing structure may indirectly result in the clearing of vegetation due to intolerance of changes to the chemical composition of waters supplied to the wetland. Although not a direct influence, any clearing of vegetation constitutes the requirement for consent and the submission of an EIS.

Works carried out to rectify a breach of the *SEPP 14 – Coastal Wetlands* policy are defined as *restoration works*, and are exempt from the submission of an EIS. Such works require council consent and concurrence from the Director-General, along with the submission to council of a Restoration Plan.

9.4 State Environmental Planning Policy 71 (Coastal Protection)

The objective of *SEPP 71 – Coastal Protection* is to preserve and protect the coastal zone and associated attributes. Any proposed development contained within a *sensitive coastal location*, as defined in s. 3, requires that the DA be forwarded to the Director-General (Dept. of Planning) for comment. The following *sensitive coastal locations* may often apply to works associated with water control structures:

- Land within 100m above the mean high water mark of the sea, a bay or an estuary;
- Coastal lakes;
- Ramsar listed wetlands of international importance;
- World Heritage areas;
- Marine parks or aquatic reserves;
- Land within 100m of *SEPP 14 coastal wetlands*, land reserved by the *National Parks and Wildlife Act 1974* or any of the above;
- Residential land.

9.5 Regional Environmental Plan (REP)

Regional Environmental Plans are created under the *EP&A Act 1979*. These plans have been established to provide a framework for detailed local planning by councils. REPs cover issues such as urban growth, commercial centres, extractive industries, recreational needs, rural lands and heritage and conservation for development control by affected councils.
Section 36 of the *EP&A Act 1979* provides that any applicable provisions provided by a governing SEPP will prevail over the REP.

9.6 Local Environmental Plan (LEP)

Local Environmental Plans are also created under the *EP&A Act 1979*. LEPs provide a localised framework for planning within individual council Local Government Areas (LGA). The area bounded by a LGA is presented as a map. This area is hence subject to the provisions presented by the LEP, unless stated otherwise in the plan and are available on the official NSW legislation website.

A LEP will cover issues pertaining to natural and cultural heritage, natural and built resources, the economy, the well being of residents and land use within the LGA. The consent authority applying to the plan will be the local council hosting the LGA. Section 36 of the *EP&A Act 1979* provides that any applicable provisions presented in a governing REP will prevail over the LEP.

9.7 Development Control Plan (DCP)

A DCP may be compiled by a local council to provide more specific, comprehensive guidelines and procedures for certain types of development. These guidelines supplement those presented in prevailing SEPP, REP or LEP instruments.

A DCP is made according to the *EP&A Act 1979* and provides additional development controls without the requirement for generation of a formal statutory plan.

9.8 Fisheries Management Act 1994 (FM Act 1994)

The *FM Act 1994* aims to conserve and enhance the fishery resources of the State for the benefit of present and future generations. Any works proposed within waters that are within the limitations of the state must adhere to the provisions of the Act. Conditions within the Act provide that permits may be required prior to the commencement of works. Enquiries and applications regarding permits may be forwarded to NSW Department of Primary Industries, Fisheries (formerly known as NSW Fisheries). All works must be conducted in accordance with the conditions provided within the permit.

9.8.1 Permit to dredge or reclaim

Any works involving dredging and reclamation within a waterway is subject to Part 7 Division 3 of the Act. Dredging consists of any work involving the excavation of water land. Reclamation is the use of any material to fill in or reclaim water land. Furthermore, reclamation also includes the deposition of any such material for the purpose of constructing anything over water land, or the draining of water for the purpose of reclamation.

Any work involving dredging and reclamation may not be carried out without a permit under s. 201. This does not apply to work authorised under the *Crown Lands Act 1989*, or to work authorised by a relevant public authority, other than a local government authority.

Water land is defined in s. 198A as land submerged by water, whether permanently or intermittently or, whether forming an artificial or natural body of water. Agricultural drainage channels most often fit this definition. Drain maintenance, such as cleaning, may be defined as dredging where sediment is excavated, and these works would require a permit.

9.8.2 Permit to obstruct fish passage

Under s. 219, a permit may be required to construct or alter a floodgate, dam, causeway, weir or any other obstruction that will or could obstruct the free passage of fish. Furthermore, s. 218 requires that fishways are to be provided in the construction or modification of weirs and dams. Fishway specifications may be attained from NSW Department of Primary Industries, Fisheries.

9.8.3 Permit to harm marine vegetation

Part 7, Division 4 provides that a permit may be required to carry out works that are to harm mangroves, seagrasses or any other declared marine vegetation existing within any *protected area*. This includes any public water land, an aquaculture lease or the foreshore of either.

9.8.4 License to harm threatened species

A license may be issued under s. 220 of the act for any action that is likely to harm a threatened species, population or ecological community, or to damage a habitat hosting a threatened species.

9.9 National Parks and Wildlife Act 1974 (NPW Act 1974)

The *NPW Act 1979* provides that the National Parks and Wildlife Service (NPWS) is responsible for all national parks, nature reserves, Aboriginal areas and other NPW estate. These areas must be managed according to the Act, which also administers the protection and care of native flora and fauna. Any activity to take place within NPW estate requires consultation with the NPWS.

9.9.1 General License to Harm Threatened Species

Section 120 of the Act provides the circumstances under which an application for a *general license* may be made authorising the harm of threatened species. Applications may be forwarded to the NSW Department of Environment and Climate Change (DECC).

9.10 Marine Parks Act 1997 (MP Act 1997)

Sections 19-20 of the *MP Act 1997* provides that a consenting authority must consult with relevant ministers and the Marine Parks Authority when assessing a DA involving proposed works that are to occur within a designated marine park.

9.11 Threatened Species Conservation Act 1995 (TSC Act 1995)

Schedules 1, 1A and 2 of the *TSC Act 1995* provide a listing of all species, populations and ecological communities classified as endangered, critically endangered or vulnerable. Furthermore, key threatening processes are also identified in Schedule 3. The Act aims to protect, preserve and promote the recovery of listed items of Schedules 1-2, which are collectively generalised as 'threatened species.'

The *TSC Act 1995* in conjunction with development assessment requirements of Parts 4 and 5 of the *EP&A Act 1979*, require that the impact of a proposed development upon any localised threatened species be assessed. A threatened species test of significance can be completed to determine the level of impact, according to s. 5A of the *EP&A Act 1979*. If a significant effect is expected, a Species Impact Statement (SIS) must be prepared in accordance with the detailed specifications presented in s. 110 of the *TSC Act 1995*. A SIS must be prepared for all development that involving any listed critical habitat.

9.11.1 License to harm threatened species

Section 91 of the *TSC Act 1995* provides that a license to harm or pick threatened species, populations or ecological communities or damage habitat may be granted. A licence application must be accompanied with the information requested in s. 92, unless the application is accompanied by a SIS. Supplement of a SIS is compulsory when an applying for a license to carry out works on land listed as a critical habitat.

9.12 Native Vegetation Act 2003 (NV Act 2003)

The activity of clearing natural vegetation may require consent from the local Catchment Management Authority as determined by the Act. It is important to note that even though consent to clear native vegetation may not be required under the *NV Act 2003*, other legislation such as the *EP&A Act 1979* may require that consent be obtained. Sections 17 and 25 of the *NV Act 2003* provide that development consent is not required if it has been approved or permitted under some other legislation.

9.13 Water Management Act 2000 (WM Act 2000)

Section 91 of the Act provides the conditions that require an approval to carry out a *controlled activity*. A controlled activity is defined by the Act as:

- The erection of a building or the carrying out of a work (within the meaning of the *EP&A Act 1979*;
- The removal of material or vegetation from land, whether by way of excavation or otherwise;
- The deposition of material on land, whether by way of landfill operations or otherwise;
- The carrying out of any other activity that affects the quantity or flow of water in a water source.

Applications should be forwarded to the NSW Department of Water and Energy (NSW DWE). Public Authorities are exempt from the need to attain a controlled activity approval under cl. 39A (1) of the *Water Management (General) Regulation 2004*.

It is important to note that this legislation has superseded the repealed *Rivers and Foreshores Improvement Act 1948*.

9.14 Sugar Industry Best Practice Guidelines and Development Assessment Exemption

The NSW sugar industry Best Practice Guidelines for ASS (Sunshine Sugar, 2005) are based on the information presented within the ASSMAC Manual. The best practice guidelines apply to existing members of the NSW Sugar Milling Co-operative Ltd. with Production Area Entitlements (PAEs). Clauses in LEPs may provide that proposed drainage works on existing cane lands with PAEs may be exempt from the development assessment processes provided that works are undertaken in accordance with an endorsed drainage management plan consistent with the best practice guidelines.

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12. MANUFACTURER DIRECTORY

Company	Address	Contact	For supply
Armon Engineering	Contact: Greg Breckell 37-39 Nance Road KEMPSEY NSW 2440	Phone: (02) 6562 8020 Fax: (02) 6562 8677	Pre-fabricated stainless steel weir
AWMA Water Control Solutions	Contact: Anthony Burrell 17 Roviras Road PO Box 433 COHUNA VIC 3568	Phone1: 1800 664 852 Phone2: 03 5456 3331 Fax: 03 5456 4330 info@awma.au.com www.awma.com/gates	Sluice gates, penstocks, sidewinder and lay-flat gates, along with automatic actuation systems
Blackwoods (Newcastle)	Contact: Greg	Phone: 02 4962 2300 www.blackwoods.com.au	Hand brake winch systems and rigging equipment
Custom Fibreglass Mouldings	Contact: Bruce Lamotte 32 Jasmine Close CUNDLETOWN NSW 2430	Mobile: 0428 501 142 Fax: 02 6553 8738	Fibreglass ballast gate, and other vacuum sealed fibreglass design
Fluid Control	Unit 3, 160 Fison Avenue West EAGLE FARM QLD 4009	Phone: 07 3268 6866 Fax: 07 3268 5466 sales@fluidcontrol.com.au www.fluidcontrol.com.au	For supply and installation of: Rubber check valves (provided by Red Valve – Tideflex valves)
Goondiwindi Precast	Contact: John Jacob PO Box 1148 GOONDIWINDI QLD 4390	Phone: 07 4671 0673 Fax: 07 4671 0674 Mobile: 0438 831 914 jjacob@bigpond.com www.goondiwindiprecast.com.au	Concrete headwalls, drop-board weirs and concrete box culverts
Gulf Rubber	12-13 Green Street REVESBY NSW 2212	Phone: 02 9772 4877 Fax: 02 9771 2060 www.gulfrubber.com/products/one-wayvalves	Elastomer check valves
Humes	Cnr Woodstock Avenue & Glendenning Road ROOTY HILL NSW 2766	Phone: 1300 361 601 Fax: 02 9625 5200 www.humes.com.au/ProdsServices/PipelineSys/PS_FloodGates.shtml Www.humes.com.au/ProdsServices/PrecastConcrete/PC_BoxCulverts.shtml	Top-hinged fibreglass moulded flap gates, concrete and associated products
Matlou Pty Ltd ATF the John Frost F/T	Contact: John Frost RMB 813 Frost Road ANNA BAY NSW 2316	Phone: (02) 4982 1883 Mobile: 0428 434 197 Email: matlou@nelsonbay.com	For supply and installation of: Aluminium flap gates, automatic tide gates, culverts and structural works
PileQuip Australia	PO Box 976 WINDSOR NSW 2756	Phone: 02 9838 3144 Fax: 02 9838 3150 info@pilequip.com.au http://www.pilequip.com.au/equipment/sheet_piles	Sheet pilings
Rhinoflex Valves	Contact: Stuart Julien 2 Luderman Road NORANDA WA 6062	Phone: 08 9275 8584 Fax: 08 9275 0258 Mobile: 0405 505 073 Www.rhinoflexvalves.com/rubbercheckvalve	Rubber duckbill check valves

Company	Address	Contact	For supply
Rocla	Rocla Head Office Tower A, Level 5, 821 Pacific Highway CHATSWOOD NSW 2067	Phone1: 13 1004 Phone2: (02) 9928 3500 Fax: (02) 9928 3580 solutions@rocla.com.au www.rocla.com.au	Top-hinged fibreglass tidal flap gates, concrete and associated products
Vonmac	Contact: Danielle Triandafyllidis (Marketing & Logistics) 20 English Ave CLOVELLY PARK SA 5042	Phone: 08 8276 2982 Mobile: 0402 627 246 dan@vonmac.com.au www.vonmac.com.au/plastipile.htm	For design, supply and installation of: Plastipile solid plastic sheet pilings. onmac will also conduct geotechnical surveys as requested
Water Research Laboratory – University of New South Wales	Contact: William Glamore King Street MANLY VALE NSW 2093	Phone: 02 9949 4488 Fax: 02 9949 4188 Mobile: 0404 822 080 jbyrnes@watergates.com.au www.wrl.unsw.edu.au	For hydrological assessment and modelling. Can design and construct suitable structures based on hydrological assessment, including smartgate technologies
Watergates sp	Contact: John Byrnes 27 Pine Street MANLY NSW 2095	Phone: 02 9972 0975 Fax: 07 3816 2662 Mobile: 0401 064 065 jbyrnes@watergates.com.au www.watergates.com.au	Heavy duty flap gates, penstocks, lay-flat gates and automated actuation systems

This is an abridged list and additional contacts can be found in the local phone directory.