NORTH CENTRAL
Catchment Management Authority

Gunbower Creek
Environmental Flows Study

Flow Recommendations

July 2007

WATER TECHNOLOGY

ecological associates pty ltd

FLUVIAL SYSTEMS

Lloyd Environmental

Flow Recommendations

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1 INTRODUCTION

1.1 The Gunbower Creek Environmental Flows Project

The Gunbower floodplain and Koondrook-Perricoota floodplains together cover an area of 50 000 hectares, making them the second largest River-red gum forest in Australia. The forest and wetlands that span these floodplains hold high community value, including strong social and cultural meaning to Indigenous groups. The biodiversity value of the Gunbower floodplain has led to it being listed as a Wetland of International Importance under the Ramsar Convention. It is a wetland of national significance and a significant ecological asset with the Murray-Darling Ministerial Council (MDBMC) designating it an 'Icon Site' within The Living Murray initiative.

Gunbower Creek demarcates the south-western border of Gunbower Forest, and provides important connections between the River Murray and the wetland systems of the forest floodplain. However, the flow regime within Gunbower Creek is designed primarily to service the demands of irrigation operations. The central purpose of this investigation is to identify the key biotic (ecological and botanical) and physical (geomorphic and water quality) processes of value and to determine the flow regime through Gunbower Creek that is required to support and sustain them.

The North Central CMA requires an assessment following the FLOWS Framework (SKM et al., 2002) to determine the environmental water requirements of Gunbower Creek in order to allow for the future water management of the Creek.

1.2 Study Objectives

The overall objective of this project is to determine the environmental water requirements of Gunbower Creek, including its associated lagoons and wetlands, and to develop options to meet the environmental water needs into the future.

More specifically, this investigation will:

1. identify water dependant environmental values within each reach;
2. gauge the current health of the environmental values and the water-related and non-water related threats to these values;
3. identify the flow regimes required to maintain or enhance the environmental values;
4. identify constraints to the achievement of this environmental flow regime given the current management of the waterway for irrigation supply
5. identify interim management options to enhance the ecological objectives; and
6. make recommendations regarding the long-term changes required to maintain and enhance key environmental values along Gunbower Creek and its associated lagoons.

This Flow Recommendations Report addresses points 3 to 6. Note that points 4, 5 and 6 are usually outside the scope of a FLOWS Method investigation.

1.3 The Adopted Methodology

This project applies the FLOWS Method to determine environmental flows in rivers and streams in Victoria (SKM et al., 2002). The steps involved in the application of the method are presented in Figure 1.

The FLOWS Method assumes that the flow regime required to achieve the desired ecological condition in a river can be represented by a set of flow components. Flow components are defined in terms of the timing, duration and magnitude of flow events. Flow components are attributed to a representative set of ecological and physical characteristics and functions. For example, the flow component of "low flow in summer" might be attributed to the persistence of aquatic habitat in a stream bed.

This report, the Flow Recommendations Report, concludes Stage II of the project (Stage 1 was completed with the preparation of the Issues Paper). This report provides specific recommendations for flows that must be provided to maintain or restore the health of Gunbower Creek and the lagoons associated with it. The recommendations are based on a detailed analysis of the behaviour of the creek. A hydraulic model was used to relate river flows to the depth and width of flow at seven representative sites. This information was used to make specific links between ecological and physical processes with particular river discharges. On this basis, quantitative flow recommendations were developed.

Stage 2 of the project has involved:

- physical survey of a representative site in some reaches to support the interpretation of the extended Gunbower Creek one-dimensional hydraulic model (concurrent project);
- the simulation of various water surface profiles using the hydraulic model and development of graphs that facilitate the quantification of flow-ecology/geomorphology relationships at the project sites (specific indices or thresholds that can be evaluated using relationships between discharge and stream depth, width, velocity and shear stress);
- setting of quantitative objectives for river health;
- recommendations for a flow regime that will provide the defined environmental water requirements at each site

This report also includes a preliminary assessment of the degree to which the flow recommendations are achieved under the current management regime of the river.

Additional investigations, which are beyond the scope of this project, that are required to either refine the recommended flow regimes, or that should be undertaken as the recommended regimes are implemented, are discussed in the final section entitled Supporting Recommendations.

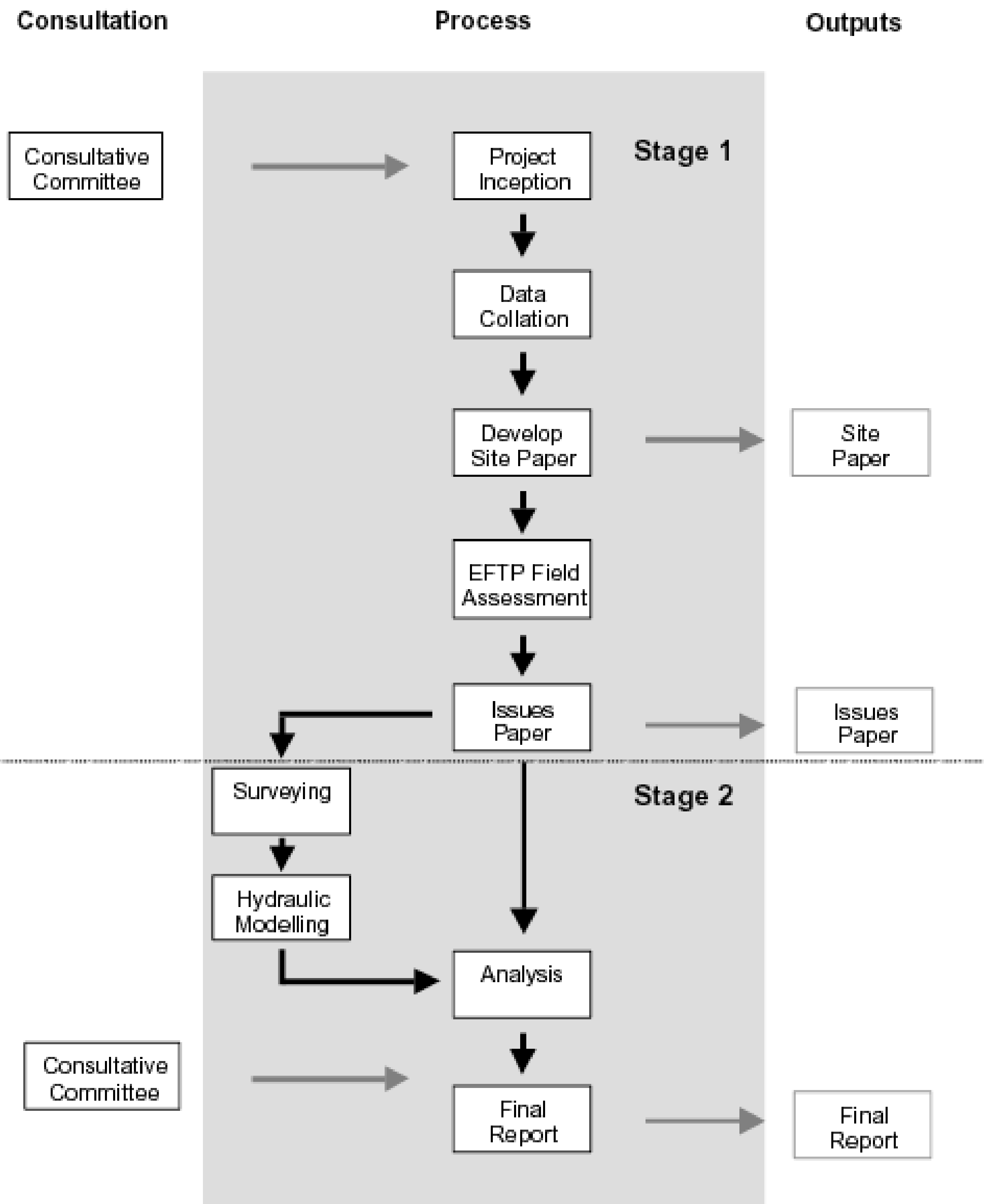

Figure 1. Flow chart illustrating the implementation of the FLOWS methodology. Note EFTP refers to the Environmental Flows Technical Panel (SKM 2002).

1.4 Vision and Objectives

The central objective of this section is to define the stream health objectives that were used to define the environmental water requirements of Gunbower Creek and its associated lagoons. These objectives are framed on the basis of overarching objectives specified by the Victorian River Health Strategy (DNRE, 2002). For the specific case of Gunbower Creek the following is proposed:

> *The vision for Gunbower Creek is to achieve a healthy functioning creek and wetland ecosystem that supports and complements the conservation values of Gunbower Forest.*

This vision is defined by the following objectives:

Ecological Objectives:

- in the Gunbower Creek and its riparian zone, the majority of plant and animal species are native and no exotic species dominates the system;
- natural ecosystem processes are maintained;
- major natural habitat features are represented and are maintained over time;
- native riparian vegetation communities exist sustainably for the majority of the Creek's length;
- native fish and other fauna can move and migrate up and down the Creek and into and out of the associated lagoons; and
- linkages between Gunbower Creek and the Gunbower floodplain and forest (and its associated wetlands) are able to maintain ecological processes;

Physical Objectives (natural processes present and within natural rates):

- channel form is in dynamic equilibrium with the flow regime; and
- sediment transport regime suitable for long term stability and provision of physical habitat features.

Note that an important limitation usually placed on environmental flow studies conducted using the FLOWS Methodology is that:

> *"…objectives should focus on flow related objectives and outcomes, and need not consider wider catchment management issues… It is anticipated that the Victorian River Health Strategy will provide the over-arching system for objectives that are not flow related." (SKM et al., 2002, p.36)*

Thus, the environmental flow recommendations presented herein were not influenced by the operational constraints on the system. Thus, the flow regime recommended is independent of these constraints. However, after establishing the recommended flow regime, the expert panel have considered how best to move toward achieving this regime into the future by making a series of 'Supporting Recommendations' (Section 4.4).

1.5 The Environmental Flows Technical Panel

The determination of the environmental flow requirements of Gunbower Creek was undertaken by the Gunbower Creek Environmental Flows Technical Panel (EFTP), which comprised:

• Dr Brett Anderson	Water Quality and Hydraulics
• Dr Marcus Cooling	Plant Ecology
• Dr Chris Gippel	Hydrology and Fluvial Geomorphology
• Lance Lloyd	Fish and Macro-invertebrate Ecology
• Dr Greg Kerr	Terrestrial Fauna and Birds
• Dr Phillip Macumber	Hydrogeology

The EFTP's investigations have been assisted by the Steering Committee and also interested members of the Gunbower Creek community, which comprised:

Representatives of the Steering Committee:

- Kathryn Stanislawski and Melanie Tranter (North Central CMA);
- Ross Stanton and Andrea Joyce (G-MW);
- Fern Hames (DSE) and John Douglas (DPI)
- Di Peace, Neville Goulding and Margot Henty (Community Representatives)

Interested members of the community:

- Norma Sheridan and Rhonda Franklin.

2 METHODOLOGY

Flow related objectives were developed in the Issues Paper on a discipline-by-discipline basis. Associations were made between each objective and the components of the flow regime on which it depends. In addition, an approach to determine the associated flow threshold, that is a means of quantifying the magnitude, duration and frequency, was indicated. Finally, the sites at which the objective is relevant are listed.

The resulting summary tables were a fundamental reference during the workshop process, as ultimately the flow regime that is recommended is designed to satisfy each of the objectives as best as possible. Indeed, each flow component that is recommended later at each site can be directly traced back to one of the objectives in the following tables. Further, each of the objectives listed in these tables are identified in the flow recommendations – demonstrating which of the flow components ensure that it is satisfied. Note that while a flow component may cause a number of objectives to be satisfied, usually there is one objective that is the key constraint.

2.1 Workshop and Final Flow Recommendations

The workshop was convened in Epsom, Victoria on 21st May, 2007. Present were the EFTP and the steering committee. At this meeting, two generic sets of flow objectives were defined: one for sites on Gunbower Creek and the other for the lagoons. During the course of the discussion, recommendations that involved modifying the current flow regime were identified, and potential threats and uncertainties associated with these changes were described. The outcome of the discussions were a list of supporting recommendations that aim to mitigate threats and uncertainties. The supporting recommendations cover:

- specific investigations that should be undertaken in order to quantify these threats;
- measures that should be taken to attenuate risk (e.g. to phase in water regime change slowly); and
- monitoring required to diagnose any issues that might arise and to help decide on the appropriate corrective actions.

As part of this process Dr Phillip Macumber made a presentation describing the hydrogeology of the Gunbower Creek region. This provided insight into the dynamics of the surface water – groundwater interactions that must be considered.

The final flow recommendation tables for each of the seven sites were completed following the workshop by specialising the two generic sets of flow objectives developed on the day. These seven flow recommendations tables are presented herein to define the environmental water requirements of Gunbower Creek and the associated lagoons.

2.2 Summary tables of flow objectives

The following sections present the summary tables of flow objectives for:

- geomorphology;
- vegetation and aquatic plants;
- waterbirds and aquatic fauna; and
- fish and macro-invertebrates.

Each flow objective listed in the summary tables is discussed in detail later in this section. In particular, the method of flow threshold determination is defined and justified in terms of the most recent and relevant research.

Table 1
Summary of flow objectives for geomorphology

ID	Geomorphic Objectives	Main Flow Components	Method of flow threshold determination	Relevant Sites
1a	Movement of sand bed material to maintain bed morphological and hydraulic diversity	High Flow Freshes	Critical shear stress (Shields equation)	Koondrook, possibly other Creek reaches[1]
1b	Scour sediments from base of pools to maintain quantity and quality of pool habitat[2]	High Flow Freshes	Critical shear stress (Shields equation)	All Creek reaches
1c	Maintain stable channel bank form	All flow components	Objective is to maintain variable flows and levels across full channel profile	Koondrook[3]
1d	Reduce rates of bank erosion	All flow components	1. Objective is to increase variability of flows and levels across full channel profile[4] 2. Max 0.12 m per day (5 mm per hour) rate of fall[5]	All except Koondrook (includes lagoons)
1e	Scour sediment accumulations from weir pools and maintain downstream sediment transport processes	Effective flows (assume Bankfull Flow or Overbank flow magnitude required)[6]	Morphologically defined bankfull or overbank and critical shear stress (Shields equation). May require coordinated Weir opening[7]	All Creek reaches

[1] Sand (and a small amount of gravel) was observed in the Koondrook reach only. The bed was not observable elsewhere, but local advice did not suggest that sand was present in other reaches.

[2] Assume silt in all reaches, except Koondrook where sediment is mostly silt and fine sand with small amounts of gravel.

[3] Koondrook reach is unique in that it has no evidence of accelerated bank erosion. This reach currently has variable flow levels.

[4] Regulated flows currently are variable over a certain (limited) range (range is narrower in the downstream direction, being minimised at weir crests). Despite this variability, levels are also stable for long periods and, from the perspective of bank erosion, this overrides the ameliorating effect of the variability. Within the constraints of the current operation of the river as an irrigation supply channel, this objective is not achievable (i.e. the range of possible water level variation is too narrow, and flow rates are determined by demand), so it is not used as a rationale. This objective can only be achieved if the Creek is not used as an irrigation carrier.

[5] This is an arbitrary rate of fall, set as being slightly lower than those rates set as rules elsewhere on the River Murray. A lower rate was considered appropriate due to the clayey bank material, which would have low rates of drainage.

[6] Effective flows are those that are most effective in sediment transport. In an unregulated river these often correspond to the morphologically defined bankfull flow (i.e. top of bank). In Gunbower Creek, bankfull conditions are artificially created by weirs, so sediment traps are in place. Overbank flows are assumed to generate higher shear stresses and velocities on the channel bed than bankfull flows.

Table 2
Summary of flow objectives for vegetation and aquatic plants.

ID	Vegetation Objectives	Main Flow Components	Method of flow threshold determination	Relevant Sites
2a	Promote colonisation of emergent macrophytes and semi-emergent macrophytes over a wide proportion of the shallow benches. Promote colonisation of mud flats by herbland species.	Exposure of benches Shallow flooding of benches Deep flooding of benches	• Shallow flooding of benches in July to December • Deep flooding of benches in August to October • Exposure of benches from January to June • Failure to provide regime in more than 2 consecutive years would degrade the plant community	All except Koondrook (includes lagoons)
2b	Maintain a flushed zone in the soil at the perimeter of the creek to maintain the health of riparian trees	High water levels	Percent of time each year creek level exceeds water table in the riparian zone. > groundwater interaction requires investigation	Nat. Channel Holmes Br. Cohuna W.P. Scout Camp
2c	Provide dry periods to control growth of Willow, Parrot Feather, Arrowhead and Yellow Water-Lily	Dry periods of more than 2 years	1. Frequency and duration of dry spells that exposes the vegetation. 2. Annual range of water level variation 3. Exposure during summer	Nat. Channel Holmes Br. Cockatoo Lag. Cohuna WP

[7] An event with coordinated weir opening to generate free flowing conditions is only required if there is major sediment build-up in the channel. Such an event would involve a relatively long period (probably in the order of weeks) of free flowing conditions to scour accumulated sediment. The degree of sediment build-up could not be assessed in this project due to the presence of water in the channel. Local advice suggests that there are sections of the channel with fine sediment accumulation, but at the present time, build-up of sediment in weir pools is not considered to be a priority issue. In the future, the channel bed should be inspected when the levels are drawn down, and the need for a channel scouring event should be reviewed.

Table 3
Summary of flow objectives for waterbirds and wetland fauna

ID	Fauna Objectives	Main Flow Components	Method of flow threshold determination	Relevant Sites
3a	Maintain gently sloping shallow banks to provide passage for nesting turtles	Variability of flow level in summer and autumn	No threshold – objective is to maintain variable flows and levels (same as 1c, 1d) to avoid steep undercut banks	All
3b	Permanent deep water refuges (in-channel)		1. Scour sediment from the base of pools (same as 1b) 2. Maintain water level in deep pools	National Ch. Holmes Br. Cohuna WP Scout Camp Koondrook
3c	Provide waterbird foraging, grazing and nesting habitat through provision of aquatic habitat in winter and spring with exposure of herblands and mud flats over summer and autumn		As per 2a	All
3d	Provide nesting habitat for colonial nesting waterbirds in spring		1. Shallow flooding of benches in July to December 2. Deep flooding of benches in August to October 3. Avoid sudden declines in level: 0.2 – 0.4 m in spring over less than 2 weeks	All

Table 4
Summary of flow objectives for fish and macro-invertebrates

ID	Aquatic Biota Objectives	Main Flow Components	Method of flow threshold determination	Relevant Sites
4a	Provide minimum depth for fish habitat	Baseflows Low flows	As per 3b.1 and 3b.2 (1.5 m above the thalweg exception)	National Ch. Holmes Br. Cohuna WP Scout Camp except Koondrook (baseflow only)
4b	Facilitate natural processes to maintain water quality	Low Flow Freshes	1. Maximum cease-to-flow duration 2. Suitable low flow freshes	National Ch. Holmes Br. Cohuna WP Scout Camp Koondrook
4c	Permanent deep water refuges in lagoons	Minimum water level	As per 3b.1	Cockatoo Lagoon
4d	Provide conditions suitable for reproduction		Inundation of macrophyte beds for a minimum duration of 3 weeks in spring.	All
4e	Provide conditions which initiate fish spawning	High Flow Fresh	While macrophytes are inundated provide a high flow fresh of minimum duration 3 days.	All
4f	Provide local fish passage	High Flows and High Flow Freshes	Minimum[8] water depth of 500 mm over inlet/outlet sills (pipes/regulators/natural) to connect lagoons to creek channel at least twice in spring and twice in summer	All
4g	Limit within-day water level fall rate	All	Maximum fall rate of 5 mm/hour	All

[8] Murray Cod not recorded in the lagoons but this requirement was designed so as to maintain a facility for them to access lagoons – hence a 500 mm depth over the sill is needed.

2.3 Geomorphic Indices

2.3.1 Bed and Bank Erosion (consolidated sediment)

Chow (1981, p. 164) noted that:

> *"The behavior of flow in an erodible channel is influenced by so many physical factors and by field conditions so complex and uncertain that precise design of such channels at the present stage of knowledge is beyond the realm of theory."*

Since that time there have been developments in the level of sophistication of river channel modeling capacity, but there have been no major advancements in relevant theory. The mobilization and transport of unconsolidated material (such as sand, gravel, cobbles etc) can be predicted reasonably well on the basis of shear stress, and there are numerous methodologies in the literature based on this approach. Prediction of the mobilization (i.e. scour) of consolidated sediments (i.e. clay-rich bed and banks) is not so amenable to a physical modelling approach, and most methods rely on empirical data from long-standing field and experimental studies. Thus, the methodology used in this study is the traditional one, as described in Chow (1981, pp. 164 - 191) and other popular channel hydraulics texts. The two methods that have been most commonly applied to this type of problem are the:

- method of maximum permissible velocity, and
- method of maximum permissible tractive force.

The tractive force (shear stress) method is preferable to the velocity method, as shear stress is more fundamentally related to particle mobilization than is velocity. The velocity method is appropriate in cases when shear stress cannot be modelled. It is important to realize that while these approaches have been applied extensively in the river engineering industry throughout the world for decades, like all empirically based approaches, they remain subject to uncertainty.

Method of maximum permissible velocity

The maximum permissible velocity (V_{max}) is the greatest mean channel velocity (V) that will not cause erosion of the channel body. A channel is stable when:

$$V < V_{max} \qquad (1)$$

Chow (1981, p. 165) noted that maximum permissible velocity is 'very uncertain and variable'. When other conditions are the same, a deeper channel will convey water at a higher mean velocity than a shallow one. This is because the scouring is related to bottom velocities, which for the same mean velocity, are higher in the shallow channel. Tables of maximum permissible velocity appear in many channel design, engineering and hydraulics publications (e.g. Chang, 1988), and they are all based on values for canals given by Fortier and Scoby (1926), and from the USSR (Anon, 1936), although some agencies have adjusted these standard values on the basis of local empirical knowledge (e.g. Stallings, 1999). The values assume a bare channel surface (i.e. no grass or other lining or vegetation).

The soils in the Gunbower Creek area are clay rich (>45%), with very low, to negligible sand content. For channels in "Stiff clay, very colloidal", which refers to "Moderately to highly plastic clay; mixtures of clay, sand, and/or gravel, with minimum clay content of 36%"

(Stallings, 1999), the maximum permissible velocity for water depth of 1 m and water transporting fine suspended solids (which applies to Gunbower Creek) is 1.5 ms^{-1} (Fortier and Scoby, 1926).

Flows with long durations often have a more significant effect on erosion than short-lived flows of higher magnitude. Fischenich and Allen (2000) and Fischenich (2001) recommended application of a factor of safety to V_{max} when flow duration exceeds a couple of hours (which is the case for Gunbower Creek during the irrigation season). A graph is provided in Fischenich (2001) for this purpose. The graph shows a value of V_{max} of 1.85 ms^{-1} for "bare soil (clay)" for very short duration flows, and for flow durations >50 hours this drops to, and appears to level out at, 0.7 ms^{-1}.

Anon (1936) gave correction factors for V_{max} for channels greater than 1 m deep (factor >1), and less than 1 m deep (factor <1). For Gunbower Creek, over the depth range 2 to 4 m, the correction factor ranges from 1.15 to 1.3.

Tabulated values of V_{max} are for straight channels, and for sinuous channels V_{max} should be reduced. Lane (1955) recommended reductions in V_{max} of 5% for slightly sinuous channels, 13% for moderately sinuous channels, and 22% for very sinuous channels. Gunbower Creek sinuosity is variable, but it would fall into the moderately sinuous class.

Allowing for these various adjustments, an appropriate value of maximum permissible velocity for Gunbower Creek is ~0.7 ms^{-1}.

Method of maximum permissible tractive force

Tractive force is the force that acts in the direction of flow on the channel bed, and is also known as bed shear force or stress. Unit bed shear stress (or unit tractive force), τ_b, is calculated by:

$$\tau_b = \gamma RS \qquad (2)$$

where

τ_b = bed shear stress (N m^{-2})

γ = the weight of water (9806 $N.ms^{-1}$)

R = hydraulic radius (m)

S = the slope of the energy grade line.

Maximum permissible shear stress (τ_{max}) is the maximum unit shear stress that will not cause serious erosion of the channel. Values of shear stress close to the maximum permissible value to prevent bed scour will obviously be sufficient to maintain the fine-grained sediment load in suspension and prevent siltation of the bed (i.e. tractive force just below the maximum permissible magnitude will maintain the channel morphology). Tables of maximum permissible shear stress appear in many channel design, engineering and hydraulics publications (e.g. Chang, 1988), and they are all based on values given by the U.S. Bureau of Reclamation (Lane, 1952; Carter, 1953).

A channel is stable when:

$$\tau_b < \tau_{max} \qquad (3)$$

For channels in "Stiff clay, very colloidal", which refers to "Moderately to highly plastic clay; mixtures of clay, sand, and/or gravel, with minimum clay content of 36%" (Stallings, 1999), the maximum permissible shear stress for water depth of 1 m and water transporting fine suspended solids (which applies to Gunbower Creek) is 22 Nm^{-2} (Chow, 1981, p. 165).

Tabulated values of maximum permissible shear stress are for straight channels, and for sinuous channels the maximum permissible shear stress should be reduced. Lane (1955) recommended reductions of 10% for slightly sinuous channels, 25% for moderately sinuous channels, and 40% for very sinuous channels. Allowing for this adjustment, an appropriate value of maximum permissible shear stress for the bed of Gunbower Creek is ~16.5 Nm^{-2}.

It should be noted that unit bed shear stress is not uniformly distributed along the wetted perimeter. Computed values of shear stress based on average cross-section conditions may be adjusted to account for local variability and instantaneous values higher than mean (Fischenich, 2001). A number of procedures exist for this purpose. Most commonly applied are empirical methods based upon channel form and irregularity. According to Chow (1981, p. 170), for trapezoidal channels, the maximum shear stress on the bed is close to γRS, and on the sides it is close to $0.76\tau_b$. Fischenich (2001) recommended that for straight channels, the local maximum shear stress can be assumed to be 1.5 τ_b. Thus, on Gunbower Creek the maximum permissible shear stress assuming at the point of local maximum shear is 16.5 / 1.5 = 11 Nm^{-2}.

2.3.2 Entrainment of bed material (unconsolidated sediment)

Sediment-entrainment theories predict the mobilisation of unconsolidated sediments (silts, sands, gravels, cobbles etc). It is normally assumed that particles will be flushed out when the threshold of motion for some percentage of the particles is reached. One method of predicting when particles will become entrained in the flow is based on the Hjulstrom curves, which relate particle size to mean velocity required for erosion, deposition and transportation (Gordon et al., 2004, p.192). The critical velocity (in m/s) for initiation of sediment movement (for particles >1 mm diameter) is $V_c = 0.155 \sqrt{d}$, where d is the average particle diameter in millimetres. The Hjulstrom curve also predicts the limits for erosion of fine sands down to clay size sediment, and these values can be read from the curve (Gordon et al., 2004, p.192). The velocity near the bed is predicted by $V_b = 0.7\ V$, where V is the mean channel velocity (Gordon et al., 2004, p. 193). The bed material will become unstable when $V_b > V_c$. Estimates of the mean channel velocity required to initiate movement of sediment across the range found in Gunbower Creek were made based on these relationships.

Table 5
Mean channel velocities required to initiate sediment transport, for range of bed material particle sizes found in Gunbower Creek.

Size class (Wentworth)	Diameter range (mm)	Mean channel velocity to initiate sediment movement (m/s)	
		Lower size range	Upper size range
Very fine silt	0.0078 – 0.0039	1.0	1.4
Fine silt	0.0156 – 0.0078	0.7	1.0
Medium silt	0.0312 – 0.0156	0.5	0.7
Coarse silt	0.0625 – 0.0312	0.3	0.5
Very fine sand	0.125 – 0.0625	0.3	0.3
Fine sand	0.25 – 0.125	0.2	0.3
Medium sand	0.5 – 0.25	0.2	0.2
Coarse sand	1 – 0.5	0.2	0.2
Very coarse sand	2 – 1	0.3	0.2
Very fine gravel	4 – 2	0.4	0.3
Fine gravel	8 – 4	0.6	0.4

The Shields equation (see Gordon et al., 2004) is commonly used to predict sediment mobilization (e.g. Reiser et al., 1985; Pitlick, 1994). Gordon et al. (2004, p.194) explained that a useful "rule of thumb" is that the critical shear (designated by τ_c) (measured in N/m^2) is approximately equivalent to the diameter of the particle (measured in millimetres) (i.e. τ_c = 0.97 d, where d is median particle diameter). One difficulty is selecting an appropriate coefficient, as the method was developed for uniform sands, not mixed gravels. The above rule of thumb relationship applies to round particles, with flat-shaped particles requiring half the tractive force to initiate movement (Newbury and Gaboury, 1993, p. 68). Smaller particles can hide in the wake of large particles. The theory of 'equal mobility', based on empirical observations, states that nearly all grain sizes begin moving at nearly the same discharge (Gordon et al., 2004, p.190). This theory predicts that, rather than the entire bed becoming mobile at a particular threshold discharge, the bed selectively and progressively unravels from different locations as discharge increases. The amount of shielding, packing or imbrication, or armouring must be taken into account as well as the particle size to be mobilized (Gordon et al., 2004, p.190-1). Wilkinson and Rutherfurd (2001) found that the Shields function "rule of thumb" considerably underestimated the shear required to mobilise fine sediment (silts) based on field testing of a flushing flow for the cobble bed Upper Yarra River. This could have been related to imbrication of the sediments (whereby particles are stacked nose down into the current), which may be a position of maximum resistance to movement (Gordon et al., 2004, p.191). They recommended a shear stress of 15 N/m² to mobilise surficial fine sediment. To flush fine material from sand beds, LYDEFTP (2004) adopted an arbitrary value of 8 N/m² for the Little Yarra River.

The Shields equation only applies to bed material of sand size and coarser. Gunbower Creek appears to have dominantly a fine grained bed (silts), although sands and gravels were observed in the Koondrook reach. Flushing of fines from gravel substrate is not identified as an issue of concern in Gunbower Creek. For the coarser bed material found in Gunbower Creek (observed in Koondrook reach, but possibly occurs elsewhere), the Shields equation predicts that the sands will be mobilised at <2 N/m² and the gravels mobilised at <8 N/m² (Table 6).

Table 6
Critical shear stress required to initiate sediment transport, for coarse range of bed material particle sizes found in Gunbower Creek.

Size class (Wentworth)	Shields critical shear stress for mobilisation (N/m²)
Very fine – medium sand	0.06 – 0.5
Medium – very coarse sand	0.5 – 2
Very fine – fine gravel	2 – 8

It is well established that in-channel and riparian vegetation has a mediating influence on channel morphology, principally via the impact of plants on sediment dynamics (Ikeda and Izumi, 1990; Marston et al., 1995; Rutherfurd et al., 1999; Trimble, 1997; Zimmerman et al., 1967). In general, the behaviour of vegetation is to colonise and exploit the fertility of the riparian zone and surfaces within the stream channel, behaviour that favours encroachment and channel narrowing (Hupp and Osterkamp, 1996; Tabacchi et al., 1998). However, the hydrologic regime holds encroachment in check, with periods of inundation and the destructive power of floods acting to inhibit growth or to clear the channel by force (Nakamura et al., 2000). This dynamic balance can be adversely affected by regulated flow regimes (e.g. Nilsson and Svedmark, 2002), although in Gunbower Creek the long periods of bankfull inundation at present prevent macrophyte encroachment into the channel.

Fluvial scour depends on the erosion resistance offered by the substrates forming the wetted perimeter, with vegetation increasing erosion resistance substantially. A field study by Prosser and Slade (1994) of grasslands in southeastern Australia examined gully erosion. They reported that widespread gully erosion could be explained solely by degradation of valley floor vegetation. Using a high-discharge flume, Blackham (2004) identified two key mechanisms by which herbaceous vegetation reduces scour. Firstly the sward (plant stems above the ground surface) act as roughness elements, reducing the velocity and hence the erosive potential of overland flows. Secondly shear stress is partitioned between soil particles and the root system, with the dense root mats of grass species absorbing the bulk of the shear (Blackham, 2004). Blackham's (2004) flume data confirmed the work of other investigators in showing that a critical shear stress in the range 100 – 200 N/m^2 is required to strip grass swards from stream beds. Blackham (2004) went on to demonstrate hydraulic conditions (shear stress and duration) in small to medium sized streams are rarely sufficient to scour well-grassed surfaces.

Emergent macrophytes are a second ubiquitous vegetation agent in stream channels. Intra-annual resistance variations of around one order of magnitude are attributed to seasonal stem density changes by Shih and Rahi (1982). Similarly, Mierau and Trible's (1988, in Kadlec and Knight, 1996) measurements in Boney Marsh show a four-fold increase in the annual average Manning's n, which is primarily attributed to the increases in stem density associated with the maturation of the marsh over the ten year study period. Cases of extreme resistance occur where the channel is choked, with Guscio et al. (1965) reporting reductions in the design channel capacity of up to 97%. Chemical and mechanical control methods are often deployed to prevent infestations, however natural hydrodynamic controls can obviate the need for such interventions (Duan et al., 2002). Groeneveld and French (1995) found that colonisation by macrophytes could be prevented if flow events of sufficient water velocity and depth were delivered. They show that sufficient bending stress induced by hydrodynamic drag on the macrophyte stem caused stem rupture (lodging); failure involving permanent deformation and loss of plant function. They quantified the depth-velocity envelope required to induce rupture, providing a means to estimate the flow required to provide hydrodynamic protection against encroachment.

Natural flow regimes are composed of numerous facets, or components, occurring as a complex time series, not discrete, predictable and independent events. Scaled-down flow regimes, or regimes with certain components culled from the regime, should not be expected to produce the same morphology as a natural flow regime (Gordon et al., 2004). Environmental (regulated) flows will nearly always be simpler and less variable than natural flow regimes, so the resulting geomorphology will probably be less diverse (Gippel, 2002). It is likely that in many cases environmental flow assessments will be complicated by the existence of geomorphic disturbances additional to those caused by flow alteration. The problem of flow regulation or modification should be viewed as one of a group of potential causes of physical channel disturbance (Gordon et al., 2004).

The basic data needs for a quantitative geomorphic analysis in an environmental flows analysis are: particle size data for the river sediments of interest, usually riffle sediments (which can be surveyed in the field); critical shear stress values for mobilisation of these sediments (derived from established formula in the published literature); critical shear stress values for removing any plants on the bed surface that prevent mobilisation of bed sediments (derived from empirical values in the published literature); and, shear stress distributions for the river at various flow levels (an output of HEC-RAS hydraulic modelling). The quantitative method based on shear stress needs to be applied with a level of caution. The reliance on critical shear stress values as the trigger for a sediment movement event is theoretically defensible, and can be used to specify a series of flow events that will create the sediment mobilisation events that are thought to be ecologically important. However, natural flow regimes are composed of a multitude of events with varying shear stress conditions. There is currently a lack of knowledge regarding the importance of frequency and duration of various shear stress conditions, both from the perspective of 'completing' the geomorphic process of sediment movement, and from the perspective of facilitating the desirable ecological processes.

2.3.3 Rate of rise and fall to limit bank erosion

Regulated channels are subject to risk of slumping during drawdown events. Drawdown refers to controlled lowering of the water level, and there is a long-held conventional belief that rapid drawdown adversely affects river bank stability (Arnett, 1994). It is well recognised that in the River Murray System, rapid drawdown of water levels downstream of weirs can cause river channel erosion (MDBC, 2003a). In the lower locked section of the River Murray, a number of reaches are showing evidence of severe bank erosion due to block failure in areas downstream of weirs. According to Thoms et al (2000), this is probably due to rapid rates of river fall following weir reinstatement. Drawdown rates also have biological implications with respect to stranding of biota, and movement of fish.

In an investigation of the impacts of drawdown in southeastern Australia, Green (1999) found that natural drawdown rates could be "rapid" and thus potentially result in slumping. He suggested that in regulated rivers where the objective was to minimise the risk of slumping, the maximum rate of drawdown be defined, not in terms relative to natural rates, but in terms of the rate at which bank material drains. Unfortunately, there has been no systematic investigation of the natural rate of drainage of bank material in channels of the River Murray System. However, it can be assumed that the rate would tend to be faster in banks comprising coarser material, such as sand and gravel, and slower in clay-rich bank material. As a general rule, coarser bank material would be expected in the upper parts of the River Murray System, with finer material expected to dominate in the low energy lowland reaches (i.e. most of the River Murray System). Coarser bank material can still occur in the low energy areas, probably representing material deposited at an earlier time when the climate and hydrological regimes were wetter.

In operating the River Murray System there are some well-established constraints regarding rates of drawdown (MDBC, 2003b) (Table 7). These maximum rates are based on a mixture of tradition and practical experience, and are not based on thorough geotechnical or geomorphological studies.

With respect to the locks and weirs on the Lower River Murray, McCarthy et al. (2001, p.6) wrote:

> "*Adopting a rate of water level change requires that the rate be ecologically meaningful and ideally based on pre-regulation data for the particular site under investigation. Data of this type is typically difficult to obtain. A rate of water level fall of 3-5 cm per day, and a water level rise of 10 cm per day, was adopted by Blanch et al. (1996) to simulate pre-regulation conditions in the lower Murray River. A rate of water level rise and fall of 2 cm per day was cited by Jensen and Nicholls (1997) for the lower Murray River. It would appear prudent to err on the conservative side for whatever rate is adopted given that many weir pools have been maintained at a high level for a considerable period. Adopting a cautious approach, particularly for rate of drawdown, may be necessary to prevent undesirable effects such as bank slumping.*"

Table 7
Operational constraints on rate of variation in water level at various locations on the River Murray System. Source is MDBC (2003b).

Location	Condition	Maximum rate of change
Mitta Mitta River	Gauge level (m)	
	0 - 1.25	0.15 m/hr fall
	1.25 - 1.75	0.10 m/hr fall
	>1.75	0.05 m/hr fall
Murray at Heywoods		0.20 m/day fall†
Murray at Doctors Point		0.15 m/day fall (the "six inch rule")
Murray at Yarrawonga Weir		0.30 m/day fall
Murray at Torrumbarry Weir		0.20 – 0.30 m/day fall
		0.30 m/day rise (upstream)

† If the actual drawdown exceeds 0.15 m/day and water level is still falling, then on the following day the maximum permissible drawdown is 0.3 m minus the amount of drawdown on the previous day

Bernard McCarthy (MDFRC, pers comm., 29th June 2007) recently indicated that Jensen and Nicholls (1997) did not make any reference to risks of bank slumping with respect to their recommended maximum drawdown rate of 0.02 m per day. Although Blanch et al. (1996) suggested a rate of fall of 0.03 – 0.05 m per day was appropriate for weirs in the lower Murray, in a later paper Blanch et al. (1999) noted that "*…daily fluctuations of up to 20 cm occur below each weir, and are progressively damped with distance downstream*". In a proposal for a trial drawdown of Euston Weir, it was suggested by McCarthy et al. (2004, p. 52) that the maximum rate of drawdown be 0.07 m/day, as this "*approximates the natural rate of flood recession at Euston (data not presented)*". Recent discussion with Bernard McCarthy (MDFRC, pers comm., 29th June 2007) confirmed that the mean rates of fall in the River Murray at Boundary Bend are in the vicinity of 0.1 m per day. Also relevant to this discussion is the monitoring of three drawdown events in Mildura Weir pool in 2001, 2002, and 2003 (McCarthy et al., 2003). In those events the drawdown rate was relatively high, in the order of 0.40 m per day. Despite concerns about the possible impacts on bank stability, the first author was "*…quite surprised at the lack of bank slumping, given the caution expressed by others…*" (Bernard McCarthy, MDFRC, pers comm., 29th June 2007). Thus, it would appear that the recommended rates of fall suggested by Jensen and Nicholls (1997) and Blanch et al. (1996) of between 0.02 m and 0.05 m per day are conservative, and not based the real risk of bank slumping.

A recommended conservative limit on maximum rate of fall to limit bank slumping in Gunbower Creek is 5 mm/hour, which equates to 0.12 m/day. This rate is lower than those imposed elsewhere in the River Murray system (Table 7). At Gunbower Creek, the bank material is known to be clay-rich, so its rate of draining is likely to be on the low end of the scale.

It is worth noting that downstream of Koondrook Spillway, at the gauge, the rate of rise and fall in water level when the gates are being opened and closed nearly always exceed the above recommended maximum rate of change (see Issues Paper). In this case the high rates of water level fluctuation do not appear to cause bank erosion. This situation is quite different to those investigated downstream of River Murray weirs (referred to in the discussion above) in that the rapid rates of water level fluctuation in the Koondrook reach:

- operate over a relatively narrow range of water level;
- tend to occur as a rapid sequence of rises and falls rather than a rapid sustained fall following a long period of high water level; and
- occurs low in the channel cross-section in association with relatively low flow rates.

Also, while the rates of rise and fall are high immediately downstream of the Spillway, these rates would be attenuated with distance downstream as the cross-section widens towards the River Murray.

The problem of bank slumping due to drawdown is normally associated with sustained rapid lowering of water levels following a long period of high water levels. This situation does not apply downstream of Koondrook Weir, so no recommendations are made regarding rate of rise and fall in the Koondrook reach *with respect to geomorphological processes* (Note: the maximum rate of fall requirement for biota still applies).

2.4 Vegetation and Aquatic Plant Indices

2.4.1 Aquatic Vegetation Structure, Extent and Diversity

The structure and composition of wetland plant communities are influenced by flooding depth and the time of flooding. The wetland vegetation of the Gunbower Forest area is adapted to a seasonal cycle where water levels are generally highest in early spring and gradually fall over spring and summer. This pattern provides a diverse range of flooding depths and exposure times and consequently provides habitat for a diverse suite of plant species.

Emergent macrophytes will extend to maximum spring depths more than 1 m if the water level falls later through the year. Deep water species tend to form tall dense stands and include *Phragmites australis, Typha domingensis, Juncus ingens* and *Eleocharis sphacelata.* These plants will be less dense in areas flooded to a spring maximum of 0.5 m, where other *Juncus* speices, *Carex tereticaulis* and *Paspalidium jubiflorum* will also grow. The exposure of wetland margin will provide habitat for herbland species such as *Eleocharis acuta, Alternanthera denticulata, Rumex* sp. and *Juncus bufonius.*

Low water levels in spring and summer promotes growth in these species by reducing the metabolic cost of growing above the water column at a time when soil moisture is abundant, days are long and temperatures are high.

The lateral extent of these plant communities is influenced by the scale of the seasonal drawdown and the steepness of the bank. Stable water levels and steep banks provide suitable conditions for emergent wetland plants in only a very narrow zone which has limited diversity and less habitat value for fauna. Plants located above or below this zone will soon be eliminated as their storage tissues or propagules are exhausted. It is important that unfavourable conditions should not be provided more than two years in a row if the diversity and condition of vegetation is to be maintained.

Stable water levels promote *Typha* sp. and *Phragmites australis*. These species grow most efficiently during summer when many other plants are relatively dormant. Exposing wetland banks during summer will reduce the growth of *Typha* and *Phragmites* and promote a diverse plant community.

2.4.2 The Role of Gunbower Creek levels in maintaining riparian tree health

Historically, water levels in Gunbower Creek have normally been held above the level of the water table aquifer. The creek has recharged the water table aquifer and provided an abundant source of low-salinity soil water to riparian trees. Trees growing immediately adjacent to the creek (up to 30 m away) are generally in better health than trees growing further away.

Tree health will decline if groundwater conditions adjacent to the creek deteriorate. This would involve an increase in soil salinity or decrease in soil moisture to a point at which trees become stressed. This may occur if the creek is operated at lower levels. There is insufficient monitoring data to fully describe the nature and extent of groundwater interactions. It is possible that the creek could be operated at lower levels with no negative impact on riparian trees but this is yet to be established.

2.4.3 Role of dry periods in controlling aquatic pest plants in Gunbower Creek.

Stable water levels upstream of Cohuna Weir have promoted the growth of four aggressive pest plants, Willow (*Salix babylonica*), Parrot Feather (*Myriophyllum aquaticum*), Arrowhead (*Sagittaria graminea*), and Yellow Water-Lily (*Nymphaea mexicana*).

The provision of a seasonally variable water regime is likely to reduce the growth of these species but, now that they are established, is unlikely to eliminate them. Local, native species may gain a competitive advantage and assist in their control. It is likely that herbicides will be more effective if the plants are stressed, such as while the lakes are dry. A dry period of two years could be used in the off-stream lagoons upstream of Cohuna to impose stressful conditions and assist in control.

2.5 Terrestrial Fauna and Bird Indices

2.5.1 Barriers to Turtle Movement

Turtles spend most of their life in water but seek out sandy soils in the adjacent terrestrial landscape to lay their eggs. Obstacles between the aquatic habitat and nesting sites can prevent turtles from laying their eggs at suitable sites. Effective barriers are steep and continuous (Goodwin and Hopkins, 2005) and can be formed by dense, continuous stands of vegetation or steep banks, such as the undercut banks along Gunbower Creek. If these barriers cannot be negotiated, eggs may be layed at less appropriate sites where eggs and hatchlings are more vulnerable to predation, particularly by foxes (Goodwin and Hopkins, 2005) and where the eggs are subject to less than ideal temperature regimes, with implications for survival and gender ratios in the young (Georges et al., 2004).

Steep, sometimes undercut, banks have been created by stable water levels in Gunbower Creek. A water regime that reduces undercutting would benefit the movement of turtles. This objective is described by the geomorphic objectives to 1c 'maintain stable channel bank form' and 1d 'reduce rates of rates of bank erosion'.

2.5.2 The Role of Permanent Deep Water Refuges

Deep-water is essential habitat component of a range of invertebrate and vertebrate species. The algae, epiphytes, macro-invertebrates, zooplankton, and fish found through the water column and in the vegetation beds together constitute a complex food web supporting a variety of birds and turtles.

Large, deep bodies of water have thermal inertia, which reduces the temperature fluctuations that may stress aquatic fauna in shallow water.

Permanent deep water habitat maintains local populations of these species and provides a refuge when conditions elsewhere are unsuitable. This is particularly important in a landscape where nearby alternative refuges have been affected by regulation, salinity, land clearing and other impacts of development.

Deep water is used by a range of feeding guilds, and particularly diving waterbirds (Broome and Jarman, 1983). Deep diving ducks such as the Hardhead (*Aythya australis*) and Blue-billed Duck (*Oxyura australis*) feed on emergent and submergent plants, and insects and fish. Fish-eating (piscivorous birds) may catch fish on the surface (e.g. the White-bellied Sea-Eagle, *Haliaeetus leucogaster*, or Terns), may dive to catch fish and a range of invertebrates such as yabbies (e.g. Darter *Anhinga melanogaster*, Grebes and Cormorants). Grazing waterfowl such as the Black Swan (*Cygnus atratus*) will upend and use their long neck to browse on plant material in deep water. Great Crested Grebes build floating nests of water plants attached to emergent plants in deep water. Deep water distant from the shoreline also provides security for many waterbirds that feed along the shoreline.

Permanent deep water also provide habitat for two freshwater Tortoise species (Chessman, 1988; Goodwin and Hopkins, 2005). The Short-necked Tortoise (*Emydura macquarii*) is an omnivorous scavenger and grazer that feed mainly during the day. Their diet includes filamentous algae, aquatic vegetation, crustaceans, molluscs, fish, tadpoles, and carrion (Chessman, 1986). Their preferred general habitat is permanent, relatively calm, deep, and clear water (Chessman, 1988; Goodwin and Hopkins, 2005). The Broad-shelled Tortoise (*Chelodina expansa*) is wholly carnivorous, specialised for feeding on highly motile prey (Chessman, 1983). It is an ambush predator that hides in mud or dense vegetation to strike at passing fish, yabbies and other aquatic animals and insects.

2.5.3 Foraging, Grazing and Nesting Habitat for Riverine Fauna

The most important factor affecting survival of wetland birds is habitat loss (Kingsford, 1998). As a result of historic water management practices, wetlands are not as extensive, flood for a shorter period, and have altered patterns and timing of inundation than they did in the past. A range of fauna and in particular waterbirds is affected by these changes to wetland habitat. Broadly there are two areas that determine requirements of waterbirds and their distribution on Australian wetlands: feeding and breeding requirements.

Food availability plays a key role in attracting and maintaining a diversity of species in large numbers within a wetland. The distribution and abundance of prey in a particular wetland usually determines the composition of the waterbird community. Along the edge of the creek and around the fringe of the lagoons is a zone of vegetation that is potentially inundated and exposed with the rise and fall of water in the creek. The cycle of growth and decay, resulting from regular inundation and exposure of vegetation along these margins, is the basis of a complex food web that provides food to the vertebrates that forage in, on, and around the water (Baxter et al., 2005). The emergence of adult insects from the water contributes significantly to riparian consumers such as insectivorous birds, bats, lizards and spiders (Baxter et al., 2005). This pattern of inundation and exposure needs to occur over seasonal and annual time frames as ongoing rapid and/or erratic changes in water levels within a wetland result in low numbers of aquatic invertebrates, the food of many waterbirds (Briggs et al., 1997). Natural or artificial waterbodies that offer an array of water depths and vegetation associations, have rich communities of invertebrates and carry higher numbers of species and individuals of waterbirds (Broome and Jarman, 1983). World-wide the greatest diversity and abundance of waterbirds is found in water depths of between 10 and 20 cm (Isola et al., 2000; Taft et al., 2002). As a consequence it is important to maximise the area inundated at this depth in order to maximise species diversity and numbers. Large woody debris in and on the edge of the creek and associated wetlands, adds structural complexity to habitats. The presence of woody debris increases energy retention in a stream supporting increased invertebrate abundance (Pusey and Arthington, 2003). It consequently constitutes an important component of the habitat for all levels of the food chain.

It is useful to think of waterbird community on a wetland as a set of feeding guilds: e.g. piscivores, herbivores, predominantly invertebrate feeders, and omnivores. Wetlands often support many species of waterbird at one time through adaptation of bill and leg shape, which ensure that a wide variety of different food types are available among the species. The water depth used by different waterbird species at foraging sites is strongly linked with neck and leg length (Baker, 1979). While larger birds will use deeper water in which to forage, they prefer shallow water when food is available as it is more profitable, using less energy to forage (Lovvorn, 1994).

There are two broad strategies for waterbird breeding: colonial breeding and isolated nesting. All waterbird species usually require secluded areas for breeding, often among emergent vegetation like reeds or lignum. These areas need to be concealed from predators, which are usually birds or reptiles. Feral cats, foxes and pigs feed on nesting waterbirds as well. For most species flooding for a sufficient time to raise young is an important factor in successful breeding. In altricial birds (those that feed their young at the nest) such as pelicans, storks, herons, egrets, ibises and spoonbills, breeding has been shown to depend on the area of trees that was flooded for at least four months (Briggs et al., 1997). Many water birds require nesting hollows or will only build nests in living trees (Briggs et al., 1997; Young, 2001). Waterhens, crakes and rails build their nests under the cover of dense emergent plants. Grebes form nests at water level in dense stands of reeds and rushes by collecting together a mass of submerged and floating water plants.

The extent of control of water level in wetlands affects the type of species that will use the wetland to breed (Briggs et al., 1997). In heavily controlled wetlands the water levels fluctuate frequently or alternatively remain constant for long periods. Precocial waterbirds (those that do not feed their young), such as ducks, are known not to breed on wetlands with such highly controlled water regimes.

Platypus (*Ornithorhynchus anatinus*) are known to be present in the upper section of Gunbower Creek and at Safes Lagoon. Melody Serena of the Australian Platypus Conservancy (platypus.apc@westnet.com.au) provided an extract from the Platypus Care database (as at May 27, 2007). She wrote that the:

> *"…database includes reasonably recent reports of platypus seen in Gunbower Creek from its extreme upper reaches downstream to the vicinity of Taylor Lagoon, plus sightings in Longmore, Gum, Cockatoo and Taylor Lagoons. Given that much of Gunbower Creek is fairly degraded from the viewpoint of a platypus, it seems reasonable to conclude that the lagoons are probably providing important habitat for the species in this area, with population pressure causing neighbouring parts of the creek also to be inhabited. However, this is only a hypothesis – I don't have any hard evidence to back it up."*

Grant and Temple-Smith (1998) in an extensive review were able to define the 'ideal' platypus habitat. This habitat is a river or stream with sections of relatively steep earth banks, in which the platypus make burrows, consolidated by the roots of native plant species whose foliage overhangs the bank. They make several entrances to their burrows at various levels in the river bank to enable them to enter or exit their burrows concealed at all water levels (Grant, 1995; Young 2001). Close proximity of burrow entrances to the water is an important habitat variable, as a platypus moves relatively slowly on land and are susceptible to predation when not in the water (Serena, 1994). Platypus maintain and use multiple burrows (2-6), and there is no evidence that the number of burrows used is affected by changing water levels or breeding condition (Gust and Handasyde, 1995). Within the 'ideal' platypus waterway there is a diversity of microhabitats, including aquatic vegetation and logs, with a series of distinct pools in which little sand accumulates.

Constant high water levels and regulated flow conditions are considered to be detrimental to platypus habitat and food resources (Serena, 1995), so recommendations that create fluctuating water levels are likely to be beneficial to platypus. Their main diet is macro-invertebrates (Burrell, 1974; Grant and Temple-Smith, 1998) and therefore flow recommendations, which support aquatic macro-invertebrates, increasing diversity and abundance, are likely to be beneficial to platypus (Grant and Temple-Smith, 1998). They breed each year in spring irrespective of water levels or flows (Grant, 1995; Young, 2001).

2.5.4 Timing of flooding and waterbird breeding

Breeding in waterbirds is stimulated in most species by flooding of a wetland, but other stimuli such as season and rainfall, are thought to be important (Young, 2001). Timing of flooding is important for some species, with the best time for breeding being in spring and early summer in southern Australia when food levels are higher (Young, 2001). For waterbirds to breed successfully they must build up their fat reserves prior to breeding, with higher levels of food required to achieve this. The best breeding responses to flooding by waterbirds occurs in spring following inundation of previously dry wetlands (Maher, 1991). The breeding success of altricial birds depends on the area of trees that was flooded for at least four months (Briggs et al., 1997).

Ongoing rapid and/or erratic changes in water levels within a wetland also result in low numbers of aquatic invertebrates, the food of many waterbirds (Briggs et al., 1997)

2.5.5 Nesting Requirements of Colonial Nesting Waterbirds

A few waterbird species nest in large colonies (e.g. Black Swan, Ibis, Grebes, Cormorants, Egrets and Herons). Colonially nesting waterbirds, such as egrets and ibis, only breed successfully when their nests are surrounded by water (Young, 2001). Waterbirds such as cormorants, herons and egrets build stick nests in trees next to lakes or wetlands, with the branches used often overhanging open water (Young, 2001). Species such as Straw-necked Ibis will build their nests in flooded lignum (*Muehlenbeckia florulenta*) vegetation. Some species such as ibises and spoonbills sometimes create platform nests by trampling down rushes, reeds or cumbungi. Nearly all colonially nesting waterbirds are vulnerable to changing water levels, which is presumably a measure of food availability (Kingsford, 1998; Young, 2001). For example Ibis will abandon nests if water levels drop dramatically (Kingsford, 1998).

2.6 Fish and Macro-invertebrate Indices

2.6.1 Provide summer refuge for fish and macro-invertebrates

Low flows are required to keep pools full of water and to regulate stream temperatures over summer period. A continuous low flow is required in summer in order to provide summer refuge for fish (and their prey). This continuous flow in low flow channel will keep pools full of water and regulate stream temperature (Sabo et al., 1999), provide habitat for fish (Bond and Lake, 2003a and b, Pusey, et al. 2000), and support the food chain (Pusey and Arthington, 2003; King, 2004b). Deep holes within anabranches provide refuges for fish and invertebrates in drought years and hot summers, as well as providing resting points for migrating fish such as Murray Cod, Silver Perch and Golden Perch (Reynolds, 1983, Mallen-Cooper and Harris, 1993; Mallen-Cooper, 1999; Mallen-Cooper and Stuart, 2003). Large fish (such as Murray Cod) require large and deep pools for shelter (Cadwallader, 1979; Koehn, 1996; Treadwell and Hardwick, 2003). Therefore, some pools in the reach should be at least 1.5 m deep over summer (Jones and Stuart, 2007). Without such flows pools can become too warm for some fish and oxygen levels drop to levels that stress or kill native fish (Bond and Lake, 2003b). Exotic fish, such as Eastern Gambusia, which have the ability to survive in near anoxic conditions and low oxygen conditions can lead to these fish dominating (Lloyd, 1987). Pools provide habitat for macro-invertebrates which require permanent water (Boulton and Lloyd, 1991). During the summer period low flows provide greater areas of low- or no-velocity habitats which result in greater densities of micro-invertebrates due to increased residence time of water (King, 2004b).

2.6.2 Facilitate natural processes to maintain water quality

Small floods (or low flow freshes) are required to flush nutrients from pools. Pools may become isolated or poorly mixed as the summer proceeds and water quality and habitat conditions may decline. A low flow fresh is required 2 to 3 times in late spring and summer. These flows need to be sufficient to mix pools and provide flow downstream (Ferari et al., 1989; Reynolds, 2000, Bond and Downes, 2003; King, 2004b). Low flow freshes through summer are also necessary to support macro-invertebrates living in dry bed sections between pools by replenishing interstitial spaces with moisture during cease-to-flow periods (Jenkins and Boulton, 2003; King, 2004b).

2.6.3 Provide permanent deep water refuge in lagoons

A minimum water level is required in the lagoons over summer in order to provide summer refuge for fish (and their prey). This minimum water level is required to maintain pools of a suitable depth to avoid excessive water temperatures (Sabo *et al.* 1999), provide a viable habitat for fish (Bond and Lake 2003, Pusey *et al*. 2000), and support the food chain (Pusey and Arthington, 2003; King, 2004b). Moderate sized fish (such as Freshwater catfish and Silver Perch) require moderate sized and deep pools for shelter. Therefore, some pools in the lagoon should be at least 750 mm deep over summer (Cadwallader, 1979; Koehn, 1996, Treadwell and Hardwick, 2003). Without such a minimum level the lagoons can become too warm for these fish and oxygen levels will drop to a degree that stresses or kills native fish (Bond and Lake, 2003). Exotic fish, such as Eastern Gambusia, which have the ability to survive in near anoxic conditions and low oxygen conditions, can lead to these fish dominating (Lloyd, 1987).

2.6.4 Provide conditions suitable for reproduction

Flows in spring (and early summer) are required to create extensive habitat across the stream to enable energy and food resources to be swept into the stream channel which enable fish to build condition to allow spawning (Pusey and Arthington, 2003; King, 2004a; King, 2004b). Inundation of new habitat will create habitat and stimulate invertebrate production and growth. After breeding, this habitat provides conditions for eggs and larvae to hatch and grow. Ideally, long duration flows (which last 14 to 21 days) which cover in-stream vegetated bars are required to support a range of fish species (Table 8 and Table 9). Given that many of the small bodied fish live only one or two years, then these flows are required annually.

Spring and summer freshes increase the depth of water over benches and aquatic vegetation beds increasing: connectivity; allowing drift; recolonisation of habitats; new habitat to be created; and, allowing macro-invertebrate populations to grow rapidly (Poff and Ward, 1991; Hillman and Quinn, 2002; Jenkins and Boulton, 2003; King, 2004b). Invertebrates are known to lay eggs in floodplain and wetland sediments, which hatch following inundation leading to a rapid increase in population (Boulton and Lloyd, 1992). These build very large biomasses of micro- and macro-invertebrates that provide adult fish with adequate food to build condition for spawning. A subsequent fresh is then required to provide a second round of micro- and macro-invertebrate growth of a suitable size to feed developing fish fry (Boulton and Lloyd, 1992).

2.6.5 Provide conditions which initiate fish spawning

High flow freshes in spring are required to initiate spawning in several of the native fish. The requirement is to inundate in-stream benches with a high flow fresh which covers benches by at least 500 mm in a short peaked flow (at least 3 days duration). Species that do not require flooding can exploit the productivity boost resulting from such freshes (Lake, 1967; Humphries, 1995; O'Connor and Koehn, 1998; Humphries and Lake, 2000; Treadwell and Hardwick, 2003; King et al., 2003; King, 2004a).

2.6.6 Provide local fish passage

High flows and high flow freshes enable lagoons to be connected to Gunbower Creek by water over lagoon entrances which will allow fish to move between the lagoons and creek to find food or mates or escape predation. Flows of greater than 300 mm depth over the sill of the lagoon entrance, at least twice per-season, for 3 days or longer will allow the maximum number of fish species to move (more frequent connections are likely to be exploited by native fish). This is particularly important in spring when many fish move to find mates and seek maximum food resources for reproduction, but is also important in summer when fish may need to seek shelter in the creek (Koehn and O'Connor, 1990; Bond and Lake, 2003b; Treadwell and Hardwick, 2003).

2.6.7 Provide flows to rework edge and bench sediments infrequently, to create habitat variability

The physical process of disturbing sediment and vegetation to create habitat variability is required very occasionally when bankfull flow events occur; this encourages a diverse and active riparian zone. A diverse and active riparian zone is important to fish and macro-invertebrates in terms of providing energy to riverine food webs, nutrient transport, storage and release, bank stability and thermal buffering (Bond and Downes, 2003; Fisher et al., 1997; Stanley et al., 1982). Occasional disturbance of the vegetation will allow release of organic matter and woody debris, renewal of vegetation stands to prevent dominance by single species, new growth, and will promote diversity by allowing space for new species to colonise (Junk et al., 1989; Pusey and Arthington, 2003).

2.6.8 Facilitate natural processes to maintain water quality

Small floods (or low flow freshes) are required to flush nutrients from pools. Pools may become isolated or poorly mixed as the summer proceeds and water quality and habitat conditions may decline. A low flow fresh is required 2 to 3 times in late spring and summer. These flows need to be sufficient to mix pools and provide flow downstream to provide aeration and mixing (Ferari et al., 1989; Reynolds, 2000, Bond and Downes, 2003; King, 2004b).

2.6.9 Provide conditions suitable for growth and reproduction of macro-invertebrates

High flow freshes are required to entrain organic matter from riparian zone into stream channel to be used as energy and food during the growth season for most macro-invertebrates of late winter and spring. Water flowing deeply across in-stream bars at a velocity sufficient to lift and move leaf litter would be approximately 300 mm over the high bars in the channel. This also creates more habitat to allow invertebrates to colonise and breed newly inundated surfaces thereby ensuring high levels of production and food resources for fish and other predators (Boulton and Lloyd, 1992; Hillman and Quinn, 2002; Jenkins and Boulton, 2003).

Table 8.
Ecological requirements of key fish species actually or likely to inhabit the Gunbower Creek system. These are based on current knowledge but these can only be considered as approximate until further research is conducted on these species [derived from www.fishbase.org; Allen et al. (2002); Koehn and O'Connor (1990); Lloyd (1987); Merrick and Schmida (1984); McDowall (1980); Treadwell and Hardwick (2003)].

Fish Species Common Name	Scientific Name	Life Span	Spawning Season	Incubation Duration*	Migration	Other
Australian Smelt	*Retropinna semoni*	1-2 years	Sept - Nov	9-10 days	Active movers between habitats and along anabranches	Aquatic vegetation required as a substrate for laying eggs
River Blackfish	*Gadopsis marmoratus*	4–7 years	Nov - Jan	7 - 10 days (plus 21 days "tethered" larvae)	Local	Hard substrate required – hollow logs as a substrate for laying eggs
Southern Pigmy Perch	*Nannoperca australis*	2-5yrs	Sept – Nov	2-4 days	Local	Aquatic plants for spawning and habitat Vegetation or rocks as instream habitat required
Freshwater Hardyhead	*Craterocephalus stercusmuscarum fulvus*	~3 years	Oct – Feb	4 - 7 days	Local	
Murray Hardyhead	*Craterocephalus fluviatilis*	1.25 years	Sept – Jan	? (4-7 days)	Local	Aquatic vegetation important habitat for food and refuge. Inundation of edges of lakes or wetlands is important to stimulate and provide food resources for successful reproduction and recruitment.
Crimson Spotted Rainbowfish	*Melanotaenia fluviatilis*	4-5 years	Oct-Dec	6-7 days plus 2 days attached to vegetation	Local	Aquatic plants for spawning

Table 8. (cont.)

Ecological requirements of key fish species actually or likely to inhabit the Gunbower Creek system. These are based on current knowledge but these can only be considered as approximate until further research is conducted on these species [derived from www.fishbase.org; Allen et al. (2002); Koehn and O'Connor (1990); Lloyd (1987); Merrick and Schmida (1984); McDowall (1980); Treadwell and Hardwick (2003)].

Fish Species Common Name	Scientific Name	Life Span	Spawning Season	Incubation Duration*	Migration	Other
Flat-headed and Dwarf Flat-headed Gudgeon	*Philypnodon grandiceps* and *Philypnodon sp.*	4-7 years	Oct - Feb	4-6 days	Local	Hard surfaces required as a substrate for laying eggs
Freshwater Catfish	*Tandanus tandanus*	8 years	Oct - Jan	7-8 days	Local	Suitable substrate for nest building (sand or gravel) and aquatic plants for larval recruitment
Murray Cod	*Maccullochella peelii peelii*	> 50 years	Sept – Dec	6-13 days	Local, River/Floodplain and moderate distance	Logs or hard river bank required as a substrate for laying eggs. Higher recruitment recorded flowing spring and early summer flooding.
Trout Cod	*Maccullochella macquariensis*					
Western Carp Gudeon	*Hypseleotris klunzingeri*	2-3 years	Sept – Feb	2 days	Local	Hard surfaces required as a substrate for laying eggs. Aquatic vegetation is required for habitat
Golden Perch	*Macquaria ambigua*	>20 years	Sept – Feb	1–1.5 days	Local, River/Floodplain and long distance	Rising water levels generally initiates spawning though not always required.
Silver Perch	*Bidyanus bidyanus*	>20 years	Nov – Jan	1-1.5 days	Local, River/Floodplain and long distance	Rising water levels initiates spawning
Bony Bream	*Nematalosa erebi*	>5 years	Oct – Dec	Short? <2 days	Local	

*Time that eggs take to develop into larvae (eggs require inundation at least for this period)

Table 9
Fish Species of conservation significance in Gunbower Creek and Forest (McDowall 1980, Douglas *et. al.* 1998, Richardson *et. al.* 2005, PIRVic 2007)

Fish Species		Conservation Status	
Common Name	**Scientific Name**	**FFG Act**	**EPBC Act**
Murray Jollytail*	*Galaxias rostratus*	Data Deficient	
Fly-Specked Hardyhead	*Craterocephalus stercusmuscarum fulvus*	Listed	
Murray Hardyhead*	*Craterocephalus fluviatilis*	Endangered	Vulnerable
Crimson Spotted Rainbowfish	*Melanotaenia fluviatilis*	Listed	
Chanda Perch*	*Ambassis agassizii*	Extinct	
Freshwater Catfish	*Tandanus tandanus*	Vulnerable	
Murray Cod	*Maccullochella peelii peelii*	Vulnerable	Vulnerable
Trout Cod*	*Maccullochella macquariensis*	Critically Endangered	Endangered
Golden Perch	*Macquaria ambigua*	Vulnerable	
Silver Perch	*Bidyanus bidyanus*	Critically Endangered	

- Not recorded in recent surveys

3 SUMMARY OF HYDRAULIC ANALYSIS

3.1 Hydraulic Modelling

3.1.1 Overview

A numerical hydraulic model was developed for Gunbower Creek spanning its entire length. The model included the River Murray from Echuca to Barham, with Gunbower Creek modelled as an anabranch. A range of flow scenarios with and without weirs were modelled to provide an indication of the likely range of water surface profiles achievable. Given the lack of survey for the reach downstream of Koondrook Weir a simple preliminary model was developed to assess the implications of River Murray tailwater and Koondrook Weir flows on the water surface profile of this reach. For this project, models were constructed using MIKE 11 software, which is designed to perform one-dimensional steady and unsteady state calculations for river reaches. Three major elements are required to define a river reach within MIKE 11: reach geometry (cross-section survey); upstream and downstream boundaries/flow conditions; and the specification of hydraulic roughness. The following sections describe the methods used to quantify each of these elements.

3.1.2 Reach geometry

Figure 2 shows the location of existing cross-sections in relation to the seven environmental flow sites. A total of 26 surveyed cross-sections were available along Gunbower Creek from a survey conducted in 2005.

Figure 2. Location of sites investigated with respect to the existing cross-section survey available for Gunbower Creek

A limited number of additional cross-sections were surveyed in April 2006 for this investigation. These included eleven cross-sections covering five of the sites as listed in Table 10. The survey was designed to infill existing information gaps, not so much for the purpose of constructing hydraulic models, but for identifying key ecological features of the sites.

Table 10
Auxiliary Survey Locations (June 2007)

Site	Name	Coordinates	Number of cross-sections
2	Cockatoo Lagoon	E 262363 N 6022791	1
3	Gunbower Creek at Holmes Bridge	E 260110 N 6026479	3
5	Gunbower Creek at Scout Camp	E 245416 N 6041279	3
6	Safes Lagoon	E 245324 N 6041340	2
7	Gunbower Creek downstream of Koondrook Weir	E 241230 N 6050908	2

Surveys at Cockatoo and Safes Lagoons provided a first approximation of the bathymetric form of these wetlands; in particular the depth of the deeper sections and the extent of the shallow surfaces. At Cockatoo Lagoon elevations of the inlet (known as Jumbo's Cut) were taken from engineering drawings to be 82.20 mAHD[9] and the relative invert of the outlet culvert (at the Cocky Bank) was measured at the time of the field inspection to be approximately 600 mm lower[10]. The inlet sill level at Safes Lagoon was unknown, so a survey of this level was requested[11].

[9] Engineering drawings and survey data from which Jumbo's Cut (inlet) and the Cocky Bank (outlet) were constructed were provided by Price Merrett & Associates via the North Central CMA (PMA file number F1999B, Surveyed in 1995).

[10] Water depth at Jumbo's Cut was 600mm above the invert of the culvert (1200mm diameter concrete pipe) while water depth at the Cocky Bank culvert (relative to the invert) was 1200mm (measured at 1530 hrs on 27 April 2007). Neglecting water surface slope between the inlet and the outlet (which will be very small given the short distance and low flow on the day) the invert at the Cocky Bank culvert was taken to be approximately 600mm lower than at Jumbo's Cut culvert.

[11] The outlet sill at Safes Lagoon was known to be higher than the inlet. The principal connection to Gunbower Creek is therefore via the inlet and hence only the inlet sill was surveyed for this project.

The purpose of the surveys conducted at the Holmes Bridge and Scout Camp sites was to provide more detailed information on the bathymetry at these locations. The survey was required to augment field observations given that at the time of the field inspection water levels and turbidity were high, making it impossible to distinguish features lower in the channel. Of particular interest were:

1. the extent and elevation of regions at the margins of the channel where macrophytes were growing;
2. whether there were benches or bars lower in the channel (i.e. heterogeneity of the bed); and
3. whether there was any evidence of pools (i.e. longitudinal variability of the thalweg).

The motivation for surveying downstream of Koondrook Weir was to quantify changes in channel morphology down the reach and to provide additional cross-sections to construct a hydraulic model of this reach (the 2006 survey provided only one cross-section in this reach).

In addition to the topographic survey, Di Peace completed a spot-survey of depths around Safes Lagoon and sites in the vicinity of Safes Lagoon along Gunbower Creek from a boat using sounding equipment (a commercial fish finder). The survey was completed on the 28th May 2007 with the objective being to find and measure the depth of the deepest locations around the lagoon and along the creek. Di provided map showing the measurements taken (Figure 3). The measurements suggest that around most of the length of Safes Lagoon the deepest part of the cross-section is around 2 m deep, with the deepest hole being 2.2 m. The measurements show significant shallowing toward the outlet of the lagoon, confirming the use of the inlet as the critical sill controlling water flow into and out of this lagoon. The measurements along Gunbower Creek include more than 14 spot depths at points along approximately 6 river kilometres. The measured depths range from 1.8 – 5.8 m with a median of 4 m. The considerable variability in depth suggests that pools are present along the creek. Furthermore, the presence of shallower sections between the deeper holes[12] suggests that the pools are likely to be a significant feature if the reach was drained. Finally, the presence of such deep pools this far down Gunbower Creek suggests that they are not filling with sediment. This may be due in part to either a low sediment supply combined with a current operating regime sufficient to flush most unconsolidated substrates from these deep holes.

3.1.3 Model Boundaries

The model consisted of one upstream flow boundary at Echuca Wharf and numerous downstream boundaries including Taylors Creek diversion (immediately upstream of Gunbower Weir), No. 3 Channel (immediately upstream of Cohuna Weir), No. 4 & 5 Channel (immediately upstream of Koondrook Weir), the River Murray at Barham and various high-flow River Murray effluents modelled with stage-discharge relationships.

[12] e.g. near the intersection of Ti Tree Plain Track and Koondrook Track the average water depth of 1.8 - 2.5 m is just downstream of the 5.8 m hole

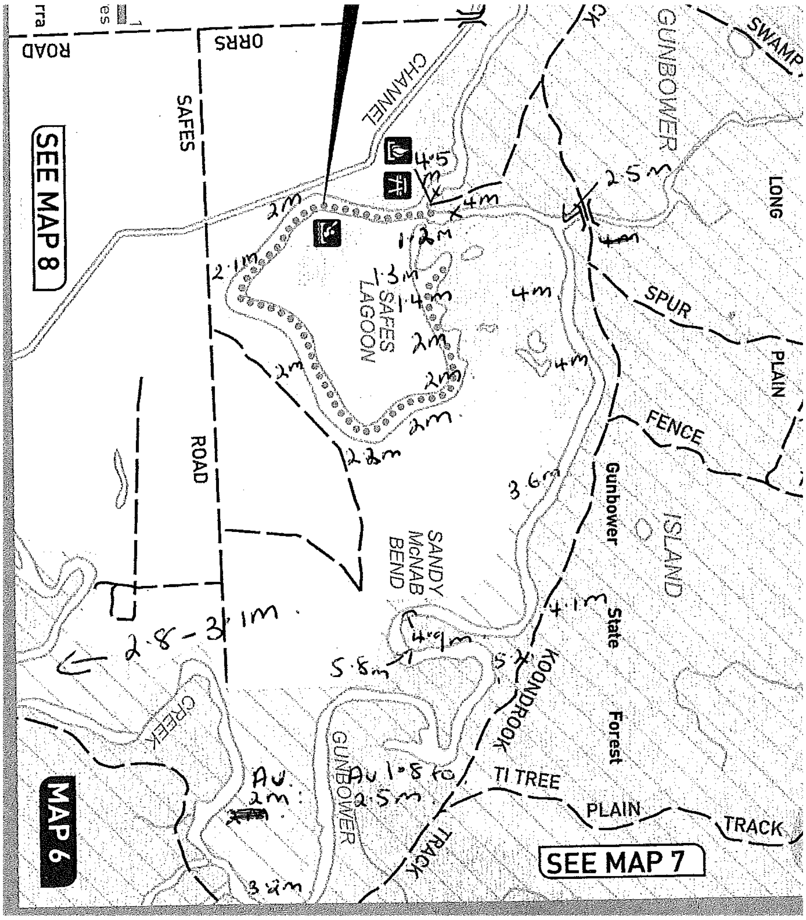

Figure 3. Spot survey of deep points within Safes Lagoon and along Gunbower Creek

The model also consisted of various control structures, controlling the flow splits and the weir pool levels to accurately represent actual conditions. The following controls were set for each of the control structures in the model:

- Gunbower Weir Pool – water elevation of 84.6 mAHD,
- Cohuna Weir Pool – water elevation of 81.43 mAHD,
- Koondrook Weir Pool – water elevation of 78.0 mAHD,
- Torrumbarry Weir – water elevation of 86.05 mAHD,
- National Channel Headworks – constant discharge for each scenario

3.1.4 Hydraulic Roughness

Hydraulic resistance (also called 'stream roughness') is a measure of the friction generated between flowing water and the channel boundary. Higher values of resistance are associated with rough-textured boundaries, with highly sinuous channels, and with turbulent flows down rapids and through vegetation. Flows through high resistance channels move more slowly and at a higher stage than through lower resistance channels at the same discharge. The magnitude of resistance determines the discharge at which different channel features are inundated, for example the bankfull flow at which flooding commences, and the speed at which flows are conveyed and accumulate down the network.

A detailed calibration process is currently being undertaken for the extended hydraulic model of Gunbower Creek. At the time of the environmental flow study, the one-dimensional model of the creek had been constructed but there was only time for limited verification of its accuracy. As a first approximation, flow resistance was estimated based on the pre-existing, calibrated model for the lower section of Gunbower Creek (downstream of Cohuna). On this basis a Manning's **n** value of 0.05 was adopted for all within-channel flows. The importance of roughness is limited to sections of the creek that are a long distance from the next weir downstream, and then only for higher discharges (as the water level in the remainder of the reach is controlled by the weir backwater).

The value of **n** = 0.05 is reasonably high in the context of lowland rivers. However, it is reasonable given that flowing sections of the creek are controlled by stream constrictions (e.g. in the vicinity of Holmes Bridge) where significant large wood is known to be present in the channel (Ross Stanton pers. comm.). The validity of the selected roughness value was confirmed by examination of the water surface profiles at bankfull discharge (shown in the next section). These results demonstrate that the model predicts bankfull discharges that are consistent with the discharges described by the operators of the creek for irrigation water delivery (Goulburn-Murray Water as per Ross Stanton).

3.2 Model Results

The hydraulic model was run for two principal scenarios: first, to simulate the hydraulic properties of the creek in the present operating configuration (i.e. with weirs in place) and second, to understand how the creek might have operated prior to regulation.

3.2.1 Hydraulic characteristics under current operating conditions – irrigation season

Under current irrigation supply conditions the water surface profile of Gunbower Creek is principally controlled by the following elements: upstream inflow at the National Channel Headworks; the operation of the weir pools (Gunbower, Cohuna and Koondrook); and the outflow through the three irrigation effluents (Taylors Creek, No. 3 Channel, and No. 4 and No. 5 Channel).

Simulations were run for discharges at approximately 100%, 75%, 50% and 25% of the full capacity supply. Nominally the full capacity discharges are 4000 ML/d, 1500 ML/d and 900 ML/d upstream of Gunbower, Cohuna and Koondrook weirs respectively. Water surface profiles from the simulations are shown in **Error! Reference source not found.**. The key point to note from these water surface profiles is the degree of depth variability that occurs as a function of the discharge supplied. The only other means to vary elevation at a given site along the creek is by drawing down weir pool levels. However, such a move can compromise the ability to deliver flow to irrigation effluents and downstream reaches without resorting to the use of pumps.

Note that the maximum discharge reported in **Error! Reference source not found.** (red lines) is about 5-10% lower than the full capacity discharge. Instead, this is the bankfull discharge for the reach as indicated by the model and the left and right bank elevations interpreted from the survey data. These bankfull discharge values are consistent with advice received from the creek operator who noted that minor flooding occurs at some locations when the full supply discharge is delivered down any given reach (Ross Stanton pers. comm.). Thus, the results support the adoption of a Manning's **n** value of 0.05 as discussed earlier.

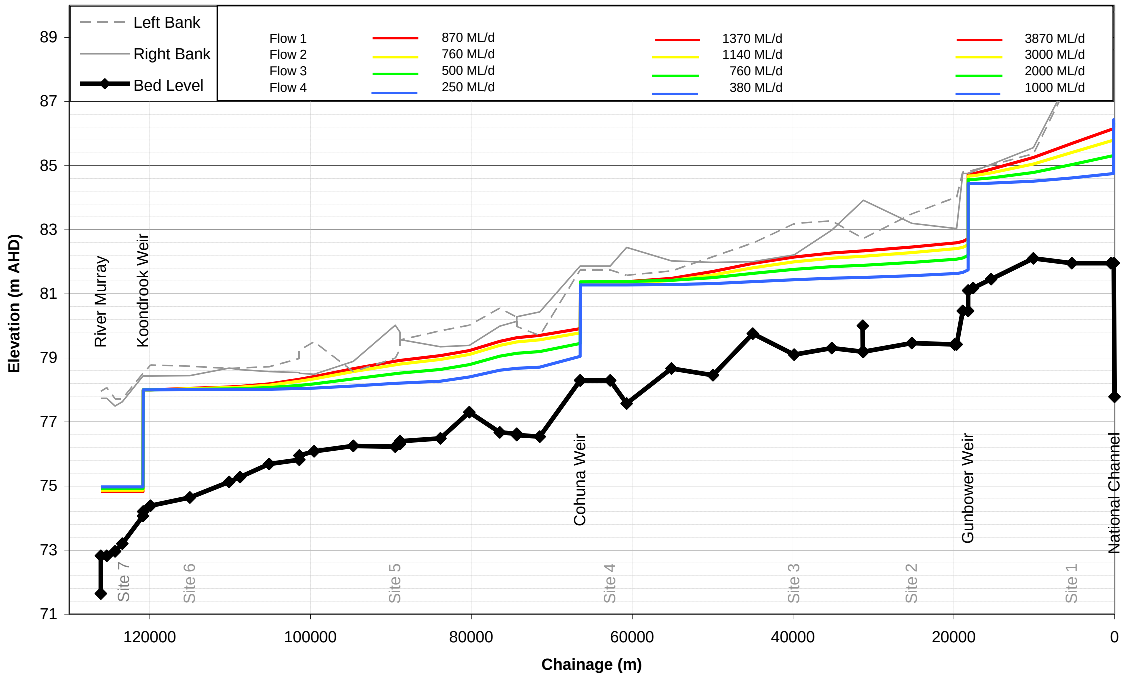

Figure 4. Gunbower Creek water surface profiles for irrigation season under current operating conditions.

3.2.2 Hydraulic characteristics under current operating conditions –winter season

The traditional operational practice was to lower water levels in Gunbower Creek in winter. For the last 5 years (presumably winter 2001 – 2006) water levels during winter have been "held up" mainly for the purposes of loss management (i.e. minimisation of net loss from the system, and less water required for start-up) (Ross Stanton, Goulburn-Murray Water, pers. comm., July 3, 2007). Operationally this means that Koondrook and Cohuna weirs have been held at between 10 and 30 cm below full supply level. The impact of this is that some portions of the creek (downstream of Gunbower and Cohuna weirs in particular) are have been almost empty in winter. Also, water from Gunbower Weir can be drained into Kow Swamp (and therefore not lost to the Gunbower Creek system), leaving this weir pool at approximately 50% of full supply depth. In the future, the arrangements will be varied somewhat from year to year to expose silt banks to frost for weed control.

The water surface profile for the current winter operational regime can be seen to vary about a range that sees the depth vary from a maximum of about 3 m just upstream of Koondrook and Cohuna weirs (1 m upstream of Gunbower Weir) to depths as shallow as 0.4 m upstream of Koondrook Weir, 0.8 m upstream of Cohuna Weir ad 0.5 m upstream of Gunbower Weir (Figure 5) (there may be shallower sections not indicated by the available survey data). The limited cross-section data suggest that these levels expose the overcut benches for the upstream half (approximately) of the lengths of the creek between Koondrook Weir to Cohuna Weir and Cohuna Weir to Gunbower Creek (Figure 5). The benches are well exposed upstream of Gunbower Weir (Figure 5).

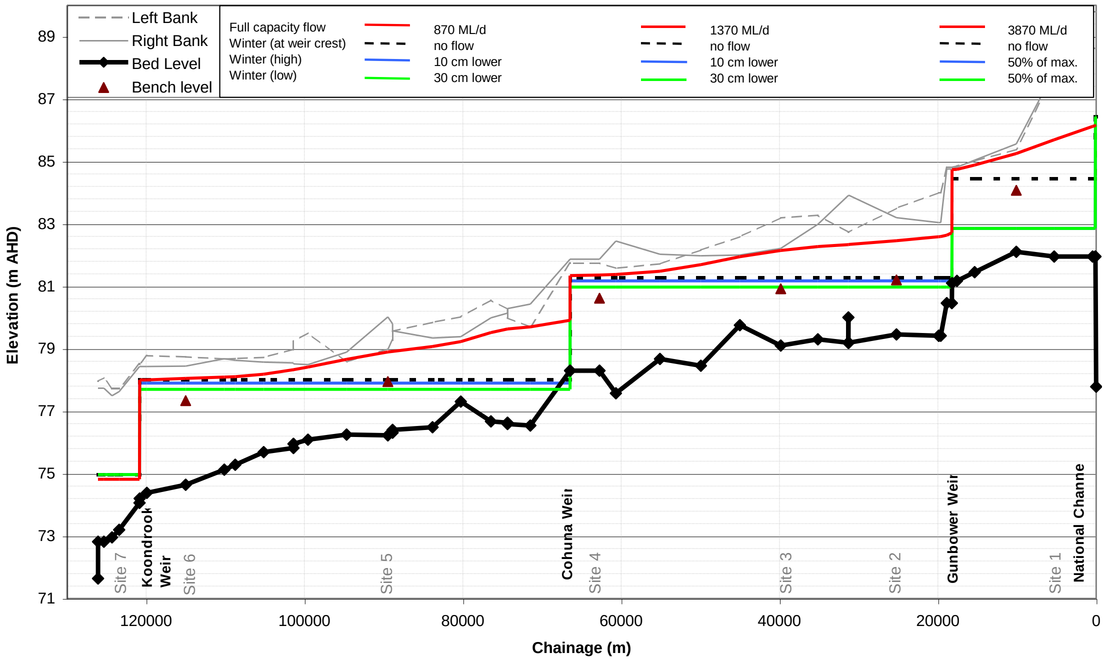

Figure 5. Gunbower Creek water surface profiles for winter season under current operating conditions. Full capacity irrigation season flow profile shown for comparison.

3.2.3 Approximate hydraulic behaviour prior to regulation

In order to provide a perspective on how Gunbower Creek might have operated prior to the introduction of regulation all the weirs and the irrigation effluent channels were removed[13]. A series of simulations were run at discharges ranging up to bankfull flows at the upstream end of the creek. The resulting water surface profiles are shown in Figure 6 and are distinctly different from the regulated profiles of **Error! Reference source not found.**. In these cases the profiles are controlled by inflows via the National Channel from the River Murray, the tailwater in the River Murray at Barham and the geometry of Gunbower Creek.

A key point to note from the simulation results presented in Figure 6 is how bankfull discharge decreases along Gunbower Creek (i.e. from right to left). In the upper part of the creek (near site 1) the bankfull capacity exceeds 4,000 ML/d. The minimum bankfull capacity for the reach between chainage 20,000 and 60,000 (Gunbower to Cohuna Weirs) lies very close to Site 3 (Holmes Bridge). The bankfull discharge at this location lies somewhere between the yellow and green lines, in other words very close to 1,500 ML/d. Downstream of Cohuna to Koondrook (chainage 60,000 to 120,000), there are a range of locations where the bankfull capacity dips under 1,000 ML/d. The point to note is that each of these capacities is very similar to the present-day operating capacity of these reaches. This fact is worth bearing

[13] Note that this scenario only approximates pre-regulation conditions. In a true pre-regulation simulation the National Channel would be removed and replaced by the more tortuous paths through the channels that now comprise Splatt and Turner Lagoons. Constructing such a case is beyond the scope of this investigation.

in mind as it suggests that at maximum irrigation supply, the hydraulic constraints are not the weirs but the geometry and roughness of the creek itself.

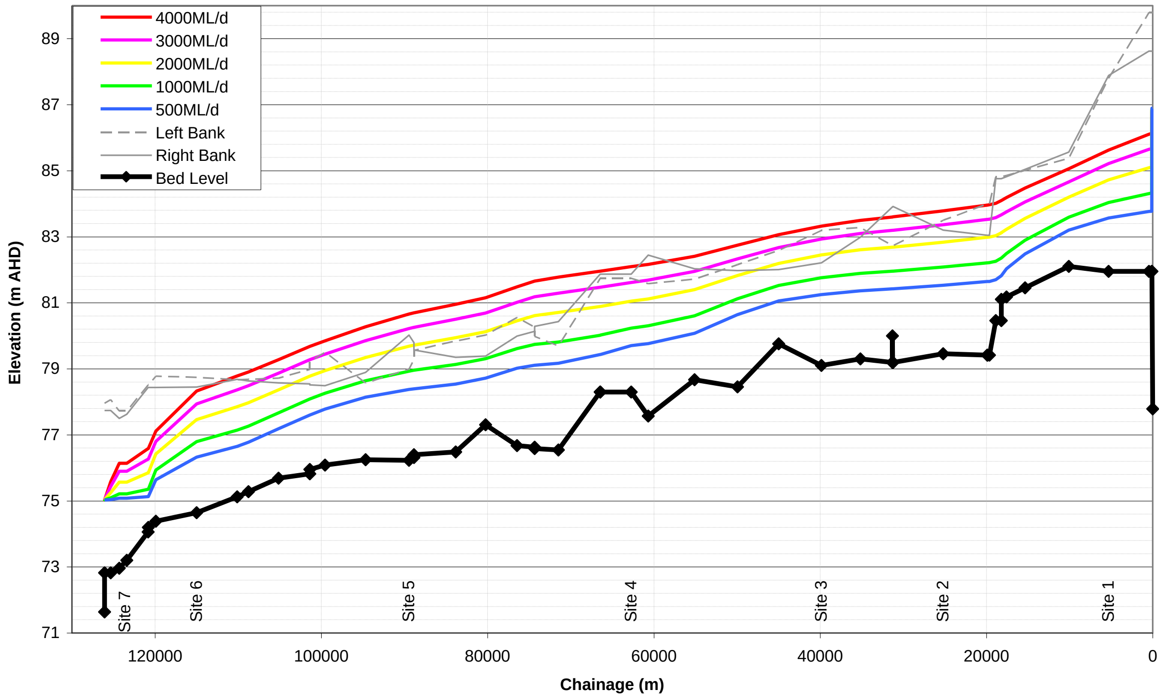

Figure 6. Gunbower Creek water surface profiles with weirs removed.

3.3 Standard Hydraulic Results at Each Site

A series of standard output plots were produced for each of the seven sites. The purpose of the plots was to provide sufficient information to understand how flow levels vary at each site and also to enable the flow-ecology or flow-geomorphology relationships to be evaluated. In many cases the hydraulic results must be interpreted using the hydrologic data presented in the earlier Issues Paper (Anderson et al., 2007).

The standard set of hydraulic results includes the following:

- First, plots to indicate how water surface elevation varies with discharge for the two simulation configurations (with weirs and without). For the two lagoon sites the water level variation within the lagoon was assumed to be identical to the variation at a nearby cross-section in the creek.
- Second, for each of the sites along Gunbower Creek (i.e. sites 1, 3, 4, 5, and 7), geomorphic thresholds for sediment entrainment/erosion were plotted (shear stress and velocity criteria).
- Third, for each lagoon a simple evaporation model was run to indicate to a first approximation how much the water level might be expected to decrease over a season if the lagoons were cut off from the creek.

3.3.1 Water level variation at specific locations

The primary reason for preparing the simulations was to be able to relate discharge in each reach to flow depths at each of the seven sites. Flow depth varies with discharge by virtue of water surface slope, with the magnitude of variation increasing with distance upstream of each weir. The maximum variation due to water surface slope is in the order of 1 m which occurs just downstream of each weir.

In addition to water surface slope variations, changes in weir pool depths are also possible. The most significant variation in weir pool depth occurs at Koondrook Weir where the tolerance in the control system results in variations between 78.05 and 78.25 mAHD (North Central CMA, 2007, p.70). This operating tolerance must be added to the variation due to water surface slope shown in the simulations. For the purpose of this project the objective was to show the maximum range of water surface elevations at each site, hence at the lowest discharge the weir was assumed to be at the lowest level, and for the highest discharge the weir pool height was assumed to be at its highest level.

Lower water levels may be experienced at each site as a result of the weir pool level being drawn down (as used to happen during the winter period). Higher water levels will only be experienced during times of flood.

Two standard plots were produced for each site to highlight the water level variations with respect to the morphologic features evident at each site. First, a plot of the measured cross-section[14] showing the elevation of the water surface at various irrigation discharges (i.e. current creek configuration with weirs in place). Second, a plot of the measured cross-section showing water surface elevations for the case where the weirs were removed. Samples of these plots are shown in Figure 7 and Figure 8 for site 5: 'Tree Tops' Scout Camp.

3.3.2 Threshold assessment for sediment entrainment and erosion

The wetted perimeter is covered by sediments, large wood and, in some places, by vegetation. The movement or removal of these covers can be related to various hydraulic thresholds, as described earlier in Section 2.3. These thresholds are expressed in terms of shear stress and mean flow velocity. A range of hydraulic thresholds was computed at each site to assist with the interpretation of the hydraulic data.

For coarse bed sediment mobilisation, shear stress thresholds were computed by applying Shields Critical Shear Stress Method (Gordon et al., 2004, p.194) and velocity thresholds were computed using the Hjulstrom curve (Gordon et al., 2004, p.192). These thresholds were calculated for three particle size ranges (Table 11). For fine bed sediment entrainment, velocity thresholds were computed for two size classes using the Hjulstrom curve (Gordon et al., 2004, p.192) (Table 11). For erosion of consolidated bank sediment (i.e. sediment bound by clay) maximum permissible velocity and shear stress thresholds were computed for the reaches (Table 11). It should be noted that the maximum permissible velocity value of $V_{max} \approx 0.7$ m/s for Gunbower Creek from National Channel to Koondrook does not mean that no erosion will occur at velocities below this threshold. The regulated flows have very long

[14] Cross-sections were either existing cross-sections measured in 2006, or those measured in 2007 explicitly for this project.

duration, while the method of maximum permissible velocity is based on an assumption of natural hydrographs that rise and fall over a matter of days at most. Long-duration regulated flows are known to result in bank erosion regardless of the velocity; the process is one of slow fretting of the bank as the clays become dispersed under saturation.

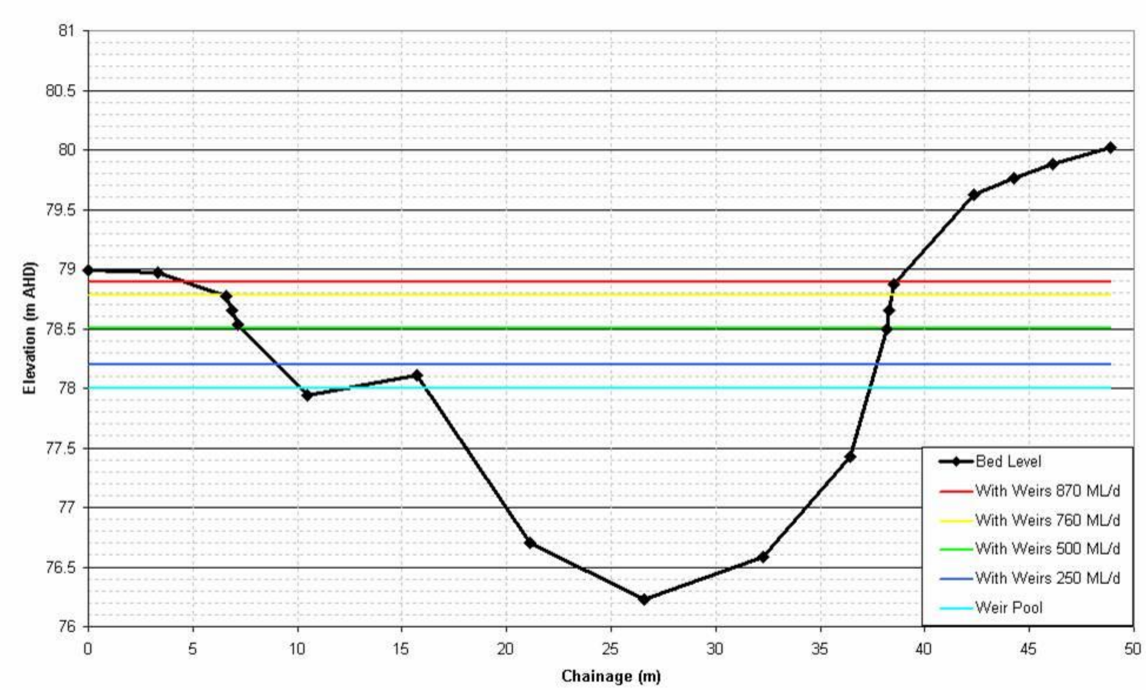

Figure 7. Gunbower Creek @ Scout Camp (Site 5) showing flow depth variation with discharge under the current configuration (with weirs).

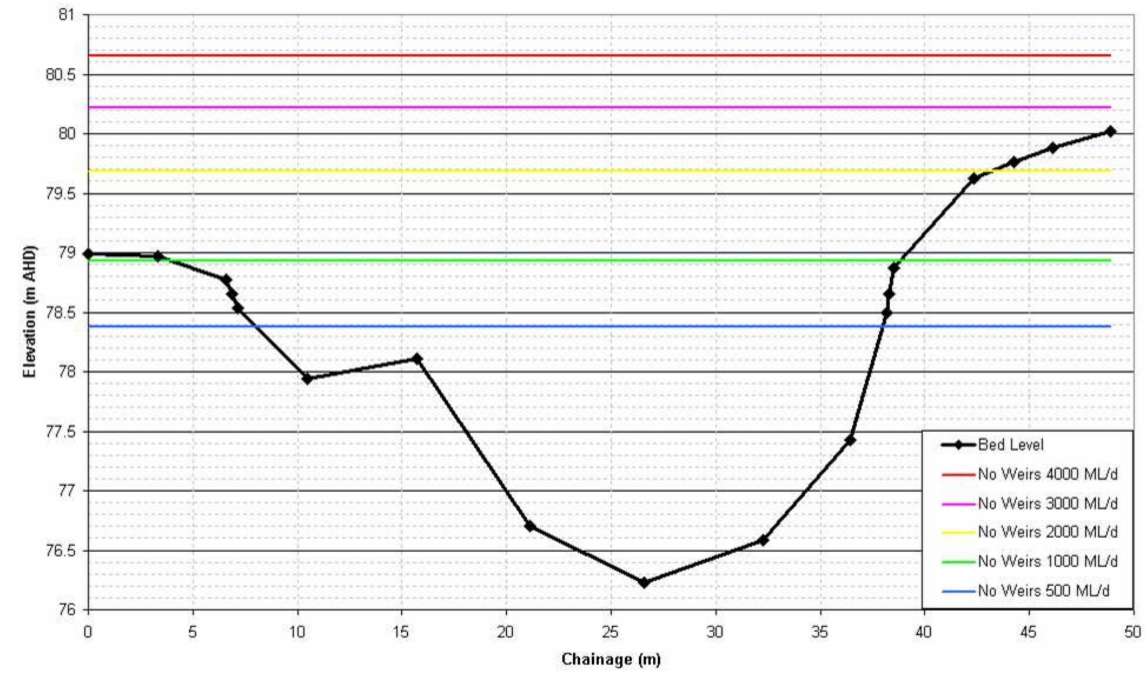

Figure 8. Gunbower Creek @ Scout Camp (Site 5) showing flow depth variation with discharge under the configuration without weirs or irrigation effluents.

Table 11
Details of the thresholds computed to predict sediment entrainment expressed in terms of either a maximum permissible shear stress (N/m²) or a threshold velocity (m/s)

Coarse bed sediment entrainment - Site 7 (Koondrook) – possibly applies to other Creek reaches

Substrate	Conditions	Relationship	Threshold
Very fine - medium sand (*d* = 0.06 – 0.5 mm)	spherical shape; normal, settled bed	$\tau_{max} = 0.97\,d$ $V_{max} = (0.155\sqrt{d})/0.7$	$\tau_{max} = 0.06 – 0.5$ N/m² $V_{max} = 0.3 – 0.2$ m/s
Medium – very coarse sand (*d* = 0.5 – 2 mm)	spherical shape; normal, settled bed	$\tau_{max} = 0.97\,d$ $V_{max} = (0.155\sqrt{d})/0.7$	$\tau_{max} = 0.5 – 2$ N/m² $V_{max} = 0.3 – 0.2$ m/s
Very fine – fine gravel (*d* = 2 – 8 mm)	spherical shape; normal, settled bed	$\tau_{max} = 0.97\,d$ $V_{max} = (0.155\sqrt{d})/0.7$	$\tau_{max} = 2 – 8$ N/m² $V_{max} = 0.3 – 0.6$ m/s

Fine bed sediment entrainment - Sites: 1, 3, 4, 5, 7

Substrate	Conditions	Relationship	Threshold
Very fine silt (*d* = 0.008 mm)	Not bound by clay	V_{max} = Hjulstrom $V_c/0.7$	$V_{max} = 1.4$ m/s
Medium silt (d = 0.016mm)	Not bound by clay	V_{max} = Hjulstrom $V_c/0.7$	$V_{max} = 0.7$ m/s
Coarse silt (*d* = 063 mm)	Not bound by clay	V_{max} = Hjulstrom $V_c/0.7$	$V_{max} = 0.3$ m/s

Bank erosion (consolidated sediment bound by clay) – applies to natural hydrographs of a few days duration, not to long duration regulated flows

Locations	Conditions		Threshold
1. Downstream of National Channel 3. Holmes Bridge 4. Cohuna Weir Pool 5. Tree Tops Scout Camp	duration depth sinuosity	long =< 0.7 m/s >2m (+15%) moderate (-13%)	$V_{max} \approx 0.7$ m/s
7. Koondrook Weir to River Murray	duration depth sinuosity	short =< 1.5 m/s <1m (-15%) moderate (-13%)	$V_{max} \approx 1.0$ m/s
1. Downstream of National Channel 3. Holmes Bridge 4. Cohuna Weir Pool 5. Tree Tops Scout Camp 7. Koondrook Weir to River Murray	substrate sinuosity local max. shear	clay (>36%), may have some sand (22 N/m²) moderate (-25%) $= 1.5 \times \tau_{avg}$	$\tau_{max} = 11$ N/m²

The critical geomorphic thresholds (Table 11) can be simplified to a smaller number of thresholds. It can be seen that mobilization of the gravels, sands and medium-coarse silts is achieved by velocities ≥0.7 m/s or ≥8 N/m². For events with natural hydrographs, the banks will be stable under these conditions. Mobilisation of very fine silts requires velocities up to 1.4 m/s. For events with natural hydrographs, the banks may be unstable under these conditions.

Two charts were produced for the five sites along Gunbower Creek showing the variation of (1) shear stress and (2) velocity with discharge. Also plotted on these charts were the relevant thresholds from Table 11. Sample shear stress and velocity threshold charts (for Site 3, Holmes Bridge) are shown in Figure 9 and Figure 10 respectively.

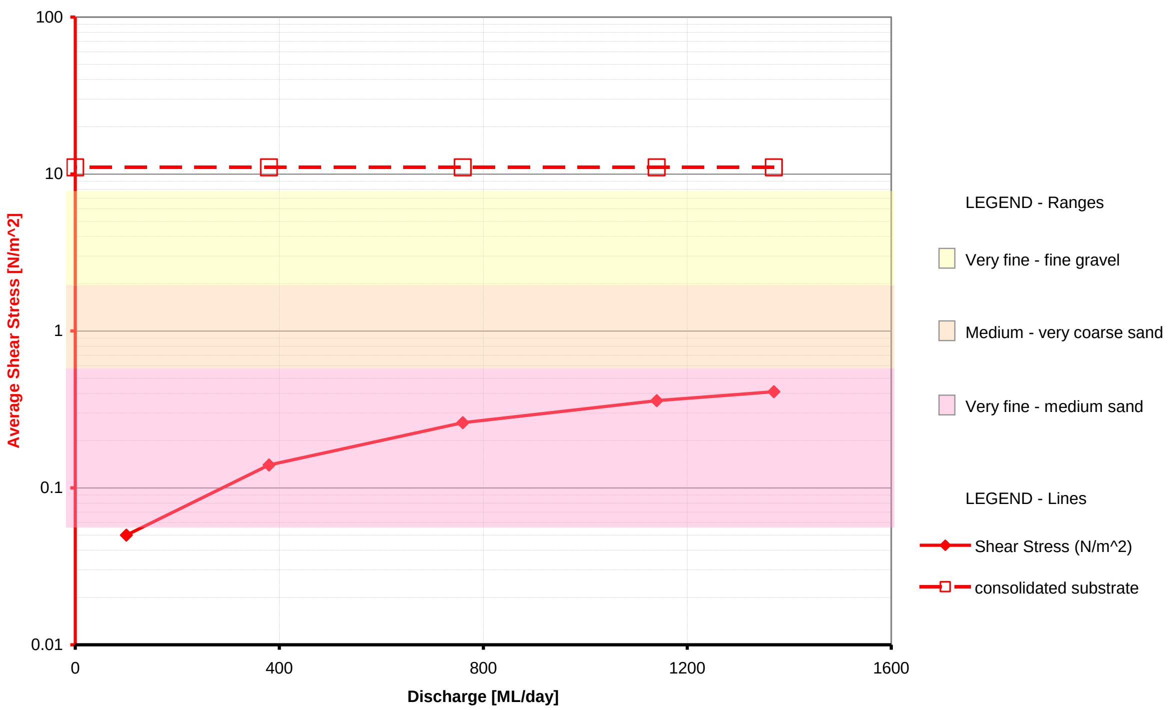

Figure 9. Gunbower Creek @ Holmes Bridge (Site 3) showing the variation of shear stress (solid red line) with increasing discharge (simulation with weirs). A range of thresholds are shown either as a coloured range of values or as single-valued dashed lines. Note that shear stress is shown on a logarithmic scale.

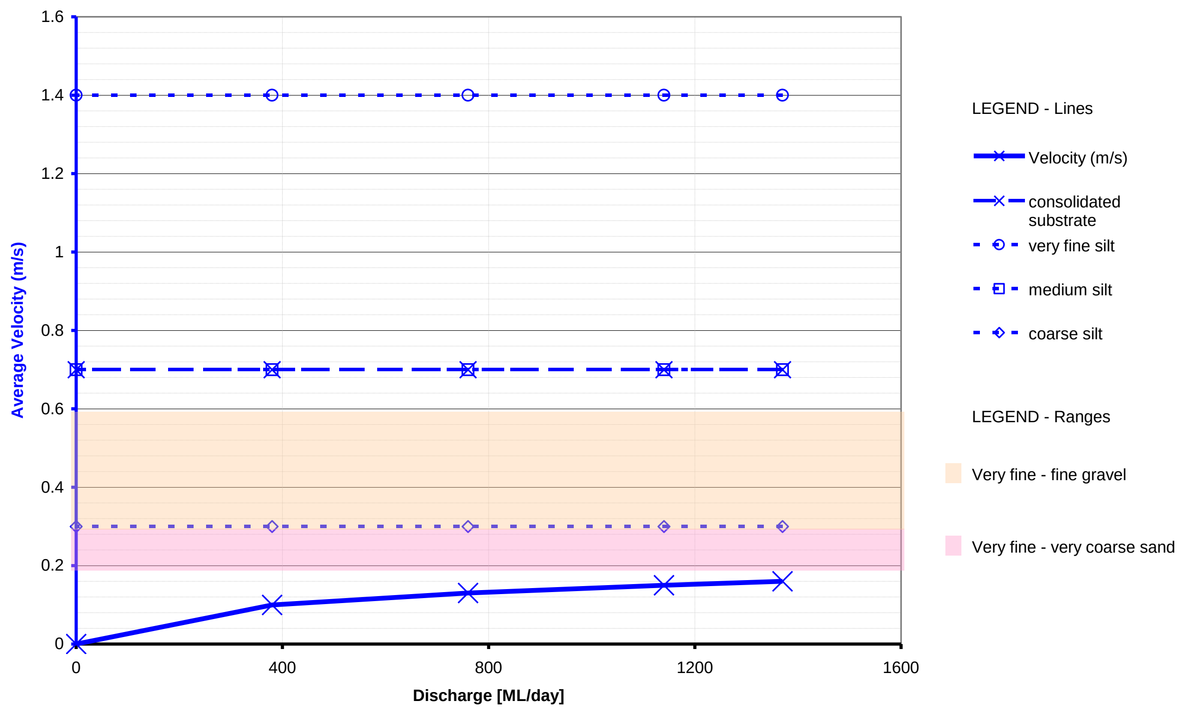

Figure 10. Gunbower Creek @ Holmes Bridge (Site 3) showing the variation of velocity (solid blue line) with increasing discharge (simulation with weirs). A range of thresholds are shown either as a coloured range of values or as single-valued dashed lines.

3.3.3 Simple evaporation rate investigation of Cockatoo and Safes Lagoons

The water regime of the lagoons fed by water from Gunbower Creek is held at a higher level than would be the case under an unregulated hydrologic regime. One of the key recommendations contemplated during this project was to disconnect these wetlands from the creek and allow them to dry out over summer and autumn. Consequently, there was a need to establish the rate of evaporative loss from the lagoons and hence how fast and how far the water level might recede in a season (following disconnection).

There was insufficient scope to construct and calibrate a hydrological water balance model for the lagoons. Indeed, even a simple water balance model would require reasonably detailed bathymetry which was not available (and could not be measured) to this project. Furthermore, there was little information available to quantify either the interaction between shallow groundwater systems and the lagoons, or leakage flows from Gunbower Creek via subsurface flow to recharge a disconnected lagoons.

To make a first approximation of the rate at which the lagoons would dry out a simplified approach was taken. The bed of the lagoons were assumed to be impermeable, meaning that no water would be lost or gained from groundwater or from the creek. The only source of loss would be via evaporation from the free surface and the evapotranspiration of vegetation within the lagoon.

The estimated evapotranspiration was based on gridded mean monthly pan evaporation from the Bureau of Meteorology Climatic Atlas of Australia - Evapotranspiration CD-ROM, for the cell (25 km grid) closest to Torrumbarry. The evaporation data that were used in producing the grids are from the Bureau of Meteorology's class A pan evaporimeters.

The Pan evaporation data were factored using monthly pan to wetland coefficients. These were taken from the empirical work of Hoy and Stephens (1979) from Lake Wyangan, a wetland in western NSW. Evaporation from open water, as is the common form of wetlands, can be estimated from Pan evaporation data by applying a factor that accounts for the differences between the small, shallow pans and large open water bodies. The literature on this topic often cites a single factor of 0.7, but Hoy and Stephens (1979) measured monthly factors on Lake Wyangan. The average of the empirically determined monthly pan factors for this wetland was 0.82. Further factoring can be undertaken to account for the presence of vegetation in wetlands, but the factors are species dependent, seasonally dependent, and not well known. Some plants evapotranspire more than open water and some less. Given the mix of vegetation in wetlands, the overall effect of vegetation on evapotranspiration rates is usually not much different to open water. Thus, the evapotranspiration estimates are specific to the Gunbower Creek location, and are specific to wetlands.

In addition, a rough depth versus volume relationship was computed using the single surveyed cross-section for each lagoon. This cross-section was interpolated around the length of the lagoon using the 12D terrain modeling software (http://www.12d.com/). Logical assumptions were made regarding the geometry near the inlet and outlets of each lagoon. This approach generated an approximate bathymetry from which the depth versus volume relationship could be computed. This relationship was then used to estimate the volume of water lost as the depth of the lagoon declined.

For each lagoon, two evaporation scenarios were considered: one with the lagoon starting at maximum water depth; and the second with the lagoon starting at a lower depth (simulating the case where the lagoon was drawn down prior to disconnection). Disconnection in both cases occurred at the start of January and the loss of depth and volume was computed monthly until August. A sample chart showing the results for Cockatoo Lagoon is given in Figure 11.

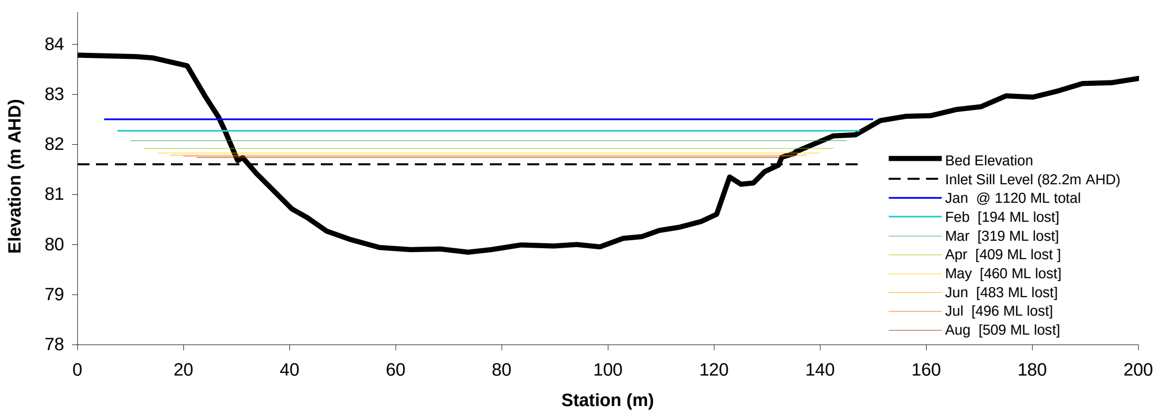

Figure 11. Cockatoo Lagoon (Site 2) showing a first estimate of water level decrease in Cockatoo Lagoon due to evaporation. This scenario starts with the lagoon full in January and decreasing until August. The approximate volume of water lost to evaporation is also reported in the legend.

4 FLOW RECOMMENDATIONS

4.1 Principles Used to Develop and Assess Achievement of Flow Recommendations

Flow recommendations were developed for Gunbower Creek and the lagoons connected to it on the basis of the flow indices defined in Section 2. These indices were interpreted for each location using the hydraulic analysis summarised in Section 3 and the hydrologic investigation reported in the Issues Paper (Anderson et al., 2007). The specifications for the flow objectives in terms of magnitude or elevation apply only at the specific modelled sites. It is important to realise that these are representative sites, and that had sites in other parts of reaches been modelled, they would likely have returned different values of stage height in particular, and possibly discharge.

Flow recommendations are reported in two parts. First, recommendations are made for each of the five reaches along the Gunbower Creek (sites: 1, 3, 4, 5 and 7). Second, recommendations for the two lagoons (Cockatoo Lagoon: site 2; Safes Lagoon: site 6) are reported. A brief conclusion is then provided that explains what these recommendations mean in the context of the current flow regime.

Achievement of the flow objectives is assessed against the current flow regime. Here, the current regime is as described in the hydrology section of the Issues Paper, and elaborated in terms of water levels in Section 3 of this report. The current winter regime involves maintaining relatively high water levels through winter, as depicted in Figure 5. Under this regime the water levels are lowered somewhat in winter, but from the perspective of exposing the benches and gently sloping surfaces in the channels and lagoons, only the upper half of the reaches (i.e. distant from weirs) are routinely affected. Achievement of flow objectives, or otherwise, can be strictly assessed only at the modelled sites. We assume that achievement, or otherwise, at a site means that there is a high likelihood that this also applies for the entire reach of which that site is representative.

In an unregulated stream the achievement of freshes, bankfull and overbank flows is assessed in a straightforward way against the specified frequency, peak magnitude and minimum duration. In a regulated stream like Gunbower Creek it is the case that the fresh and high flow components may be achieved in terms of magnitude (or stage height) and frequency, but in terms of duration the regulated hydrograph bears little resemblance to a natural hydrograph - it could be that the duration is "over-achieved", which might have either positive or negative ecological implications. For Gunbower Creek there are no negative implications for the vegetation, as the long duration of the high flows will have either a neutral or perhaps positive consequence for the plants of interest. As part of environmental flow studies for Gunbower Forest in the 1990s (Lloyd et al., 1991) sampling in Gunbower Creek indicated that several small fish species were breeding and recruiting in September after the channel was filled in August (Lloyd, unpublished data). Even though the channel is no longer completely emptied over winter, the rise in flows in August would probably still stimulate this breeding. Certainly the February to May part of the regulated water regime is much more stable than under a natural regime, but by February most fish will have completed the breeding and recruitment stages of their life cycles (Table 8). From the geomorphic perspective variable flows are preferable to stable flows in promoting bank stability, but the variability in stage achievable over the narrow range of regulated flows is too small to have any impact on bank stability. Bank stability would be enhanced only if the stage was regularly varied across its entire range in the irrigation season (not compatible with Gunbower Creek being used as an irrigation carrier). Thus, it is concluded that, given the practical constraints of system operation, "over-achievement" of the duration dimension of the flow objectives during the irrigation season is not a significant ecological/geomorphological issue.

4.2 Flow Recommendations for Sites on Gunbower Ck

The flow recommendations for Gunbower Creek centre on the provision of a seasonal cycle of wetting and drying on the benches at the perimeter of the channel. This will promote a community of emergent and semi-emergent macrophytes. The main channel will be permanently inundated to provide a refuge for fish and other aquatic fauna.

From the geomorphological perspective, the flow recommendations are based on minimising bank erosion, and maintaining sediment transport, which includes scouring deposited material from pools.

4.2.1 Flow Recommendations for Site 1: Gunbower Creek below National Channel

Gunbower Creek below the National Channel featured extensively modified habitat. Woodland vegetation had largely been cleared from the surrounding floodplain and stock had access to much of the channel. However the same physical habitats characteristic of the rest of the creek were present: a central deep channel, overcut benches bordered by a small vertical erosional face. The flow recommendations for this reach (Table 12) reflect the local cross-sectional profile of the creek but address the same ecological objectives described above.

Table 12
Flow objectives for Site 1: Gunbower Creek below National Channel

Component	Flow			Rationale	Current Achievement[15]
	Magnitude	Frequency	Duration		
Feb - May max.	<84.1 mAHD	2 out of 4 years	Feb - May	2a, 3c, 4d: Expose benches[16]; can only survive 2 years of not being met sequentially	Not achieved
Fish Spawning Fresh	≥84.7 mAHD (≥1,680 ML/d)	once in spring 2 in 3 years	3 days	4e, 2a: Flooding of benches	Achieved

[15] Achievement is relative to current regulated flow regime, which involves maintaining high water levels through winter.

[16] Providing conditions for macrophyte colonisation of banks may provide a level of protection against overcut erosion (thus geomorphic objective 1d is indirectly addressed).

Component	Flow: Magnitude	Flow: Frequency	Flow: Duration	Rationale	Current Achievement[15]
Refuge[17] in Dec - June	83.5 mAHD	2 out of 3 years worst year 83.0 mAHD	always greater than 83.0 mAHD	3b.2, 4a	Mostly achieved[18]
Low Flow Fresh Dec - Mar	84.0 mAHD	2 spring, 2 summer	2 days each	4f connectivity to lagoons[19] 4b maintain low nutrient and moderate DO[20]	Achieved
Bankfull flow (any time)	85.25 mAHD (3,870 ML/d)	Annual	~7days[21]	1a: Sands and fine gravels (if present) mobilised 1b: Coarse silt scoured[22]	Achieved
Maximum rate of fall				4g: Max. 120 mm per day - fish reasons 1d.2: Max. 120 mm per day to minimise risk of bank slumping	Achieved 94% of time that stage falls

[17] Aquatic refuge habitat - assuming no pools, as insufficient data available. Fish require 1.5 m (turtles require less ~0.5 m) (Cadwallader 1978; Treadwell and Hardwick, 2003). A depth of 1 m may be tolerated in very dry years. Deep pools are known to exist in Gunbower Creek but they have not been well documented. The refuge level is therefore conservative. It could be relaxed if pools are found to provide the required depth at lower levels.

[18] Water level lowered to just below 83 mAHD from mid-May – June part of period (Figure 5). This does not significantly compromise achievement of the objective, but lowering to 83.5 mAHD would be preferable.

[19] There are no data on sills, but the thalweg of the lagoons is similar to that of the natural channel downstream of the National Channel, so it is likely that this objective is met at this elevation.

[20] Water quality monitoring should be conducted in association with any flow regime changes enacted. To quantify the magnitude, frequency and duration of low flow freshes required to flush a developing blue-green algal bloom for example, more detailed investigations are necessary (see Section 5.4).

[21] Duration is arbitrary based on likely minimum natural duration and time required to scour and transport sediments.

[22] Medium and fine silts not scoured at this level. Once mobilised, all size classes will be transported, so incoming suspended sediment will remain in suspension.

4.2.2 Flow Recommendations for Site 3: Holmes Bridge

The width of the benches at Holmes Bridge varies. In some areas they are absent and at other locations they are well-developed. Pest plants, which are promoted by stable water levels, are present in this reach. The recommended flow regime (Table 13) includes a seasonally fluctuating water level that is likely to reduce their vigour and may promote competing native species. The reach includes pools, which have not been fully identified and described. Thus, the minimum 'refuge' water level is intended to maintain pool depth, limit temperature rise through summer, and to ensure a degree of connectivity between them.

Table 13
Flow objectives for Site 3: Holmes Bridge

Component	Flow			Rationale	Current Achievement[23]
	Magnitude	Frequency	Duration		
Aug - Oct peak	≥81.8 mAHD (≥830 ML/d)	2 out of 4 years	Aug - Oct	2a, 3c, 3d.2 Can only survive 2 years of not being met sequentially	Achieved
Aug - Oct min.	81.3 mAHD	2 out of 4 years	Aug - Oct	2a, 3c, 3d.1	Achieved
Aug - Oct rate	max drop of 0.2 m over 2 weeks	in years where macrophytes flooded	Aug - Oct	3d.3 Fauna reasons	Rate can exceed this
Feb - May max.	<80.9 mAHD	2 out of 4 years	Feb - May	2a, 2c, 3c, 4d: Expose benches[24]; can only survive 2 years of not being met sequentially	Not achieved
Fish Spawning Fresh	≥82 mAHD	once in spring 2 in 3 years	3 days	4e	Achieved

[23] Achievement is relative to current regulated flow regime, which involves maintaining high water levels through winter.

[24] Providing conditions for macrophyte colonisation of banks may provide a level of protection against overcut erosion (thus geomorphic objective 1d is indirectly addressed).

Component	Flow			Rationale	Current Achievement[23]
	Magnitude	Frequency	Duration		
Refuge [25] in Dec - June	79.0 mAHD	2 out of 3 years worst year 78.5 mAHD	always greater than	3b.2, 4a	Achieved
Low Flow Fresh Dec - Mar	82.1 mAHD	2 spring, 2 summer	2 days each	4f connectivity to lagoons[26] 4b maintain low nutrient and moderate DO[27]	Achieved
Bankfull flow (any time)	82.26 mAHD (1,600 ML/d)	Annual	~7days[28]	1a: Medium sands may be locally mobilised 1b: Silts may be locally scoured[29]	Achieved
Overbank flow (any time)	≥82.26 mAHD	Annual	~7days[30]	1e: Sands locally mobilised[31]	Not achieved
Maximum rate of fall				4g: Max. 120 mm per day - fish reasons 1d.2: Max. 120 mm per day to minimise risk of bank slumping	Achieved 96% of time that stage falls

[25] Aquatic refuge habitat - assuming no pools, as insufficient data available. Fish require 1.5 m (turtles require less ~0.5 m) (Cadwallader 1978; Treadwell and Hardwick, 2003). A depth of 1 m may be tolerated in very dry years. Deep pools are known to exist in Gunbower Creek but they have not been sufficiently documented. The refuge level is therefore conservative. It could be relaxed if pools are found to provide the required depth at lower levels.

[26] Sill between Gunbower Creek and Cockatoo is at 81.6 m (see Reach Geometry in Hydraulic Analysis)

[27] Water quality monitoring should be conducted in association with any flow regime changes enacted. To quantify the magnitude, frequency and duration of low flow freshes required to flush a developing blue-green algal blooms for example, more detailed investigations are necessary (see Section 5.4).

[28] Duration is arbitrary based on likely minimum natural duration and time required to scour and transport sediments.

[29] General scour of silts does not occur at this water level.

[30] Duration is arbitrary based on likely minimum natural duration and time required to scour and transport sediments.

[31] Silt mobilisation not guaranteed – this is a depositional environment. Once mobilised, all size classes will be transported, so incoming suspended sediment will remain in suspension.

4.2.3 Flow Recommendations for Site 4: Cohuna Weir Pool

Gunbower Creek gradually broadens as it approaches Cohuna Weir to provide an extensive wetland habitat. The creek is managed for aesthetic purposes immediately upstream of the weir, but near the caravan park has a complex channel form of flooded benches and low islands.

The flow recommendations for this reach (Table 14) reflect the relatively narrow range of water levels that occur close to the weir crest. The specified freshes, minimum levels and seasonal cycle are designed to achieve the ecological objectives at this location.

Note: A transition must be managed between the flow regime recommended for the weir pool and that recommended for the flowing sections upstream of the weir pool (i.e. Site 3: Holmes Bridge). An effort has been made to ensure that the two sets of recommendations are compatible. However, it is acknowledged that compromises are likely to be required when it comes to implementing these recommendations to design a flow regime for the entire system.

Table 14
Flow objectives for Site 4: Cohuna Weir Pool

Component	Flow			Rationale	Current Achievement
	Magnitude	Frequency	Duration		
Aug - Oct peak	≥81.3 mAHD (any flow)	2 out of 4 years	Aug - Oct	2a, 3c, 3d.2 Can only survive 2 years of not being met sequentially. 4f connectivity to lagoons[32]	Achieved
Aug - Oct min.	81.1 mAHD	2 out of 4 years	Aug - Oct	2a, 3c, 3d.1	Achieved

[32] Taylor's Lagoon is currently connected by an open cut and small pipe throughout the irrigation season. There is no data on this sill and it is uncertain whether this level is sufficient to achieve this objective.

Component	Flow: Magnitude	Flow: Frequency	Flow: Duration	Rationale	Current Achievement
Aug - Oct rate	max. drop of 0.2 m over 2 weeks	in years where macrophytes flooded	Aug - Oct	3d.3 Fauna reasons	Rate can exceed this
Feb - May max.	<80.6 mAHD (0.7 m below weir crest)	2 out of 4 years	Feb - May	2a, 2c, 3c, 4d: Expose benches[33]; can only survive 2 years of not being met sequentially	Not achieved
Fish Spawning Fresh	≥81.5 mAHD	once in spring 2 in 3 years	3 days	4e	Achieved
Refuge[34] in Dec - June	79.7 mAHD	2 out of 4 years worst year 79.2 mAHD	always greater than	3b.2, 4a, 4c	Achieved
Low Flow Fresh Dec - Mar	80.9 mAHD	2 spring, 2 summer	2 days each	4b maintain low nutrient and moderate DO[35]	Achieved
Bankfull flow (any time)	81.6 mAHD (1,600 ML/d)	Annual	~7days[36]	1a: Medium sands may be locally mobilised 1b: Silts may be locally scoured[37]	Achieved

[33] Providing conditions for macrophyte colonisation of banks may provide a level of protection against overcut erosion (thus geomorphic objective 1d is indirectly addressed).

[34] Aquatic refuge habitat - assuming no pools as insufficient data available. Fish require 1.5 m (turtles require less ~0.5 m) (Cadwallader 1978; Treadwell and Hardwick, 2003). A depth of 1 m may be tolerated in very dry years. Deep pools are known to exist in Gunbower Creek but they have not been sufficiently documented. The refuge level is therefore conservative. It could be relaxed if pools are found to provide the required depth at lower levels.

[35] Aim is to replace and mix a sufficient volume of the weir pool to avoid water quality issues. This is a first estimate. Water quality monitoring should be conducted in association with any flow regime changes enacted. To quantify the magnitude, frequency and duration of low flow freshes required to flush a developing blue-green algal blooms for example, more detailed investigations are necessary (see Section 5.4) .

[36] Duration is arbitrary based on likely minimum natural duration and time required to scour and transport sediments.

Component	Flow: Magnitude	Flow: Frequency	Flow: Duration	Rationale	Current Achievement
Overbank flow (any time)	>81.6 mAHD (>1,600 ML/d)	Annual	~7days[38]	1e: Sands may be locally mobilised[39]	Not achieved
Maximum rate of fall				4g: Max. 120 mm per day - fish reasons 1d.2: Max. 120 mm per day to minimise risk of bank slumping	Achieved 97% of time that stage falls

[37] General scour of silts does not occur at this water level.

[38] Duration is arbitrary based on likely minimum natural duration and time required to scour and transport sediments.

[39] Silt and sand mobilisation not guaranteed – this is a depositional environment. Once mobilised, all size classes will be transported, so incoming suspended sediment will remain in suspension.

4.2.4 Flow Recommendations for Site 5: 'Tree Tops' Scout Camp

At Tree Tops Scout Camp Gunbower Creek passes through the Red Gum Forest and Black Box Woodlands of the lower part of Gunbower Island. In some areas remnant vegetation is present on both sides of the creek. There are important linkages to other habitats via the woodlands and wetlands including Safes Lagoon, Reedy Lagoon, Black Lagoon and Little Gunbower Creek.

The flow recommendations for this reach (Table 15) are modified here to match the local cross-sectional profile of the creek. Deep pools are known to be present but have not been fully described: minimum 'refuge' flows will maintain them and the channel connecting them. Low flow freshes are designed to provide surface water linkages between the creek and adjacent wetland habitats.

Table 15
Flow objectives for Site 5: 'Tree Tops' Scout Camp

Component	Flow			Rationale	Current Achievement[40]
	Magnitude	Frequency	Duration		
Aug - Oct peak	≥78.5 mAHD (≥500 ML/d)	2 out of 4 years	Aug - Oct	2a, 3c, 3d.2 Can only survive 2 years of not being met sequentially.	Achieved
Aug - Oct min.	78.3 mAHD	2 out of 4 years	Aug - Oct	2a, 3c, 3d.1	Achieved
Aug - Oct rate	max drop of 0.2 m over 2 weeks	in years where macrophytes flooded	Aug - Oct	3d.3 Fauna reasons	Rate can exceed this
Feb - May max.	<77.9 mAHD	2 out of 4 years	Feb - May	2a, 2c, 3c, 4d: Expose benches[41]; can only survive 2 years of not being met sequentially	Not achieved

[40] Achievement is relative to current regulated flow regime, which involves maintaining high water levels through winter.

[41] Providing conditions for macrophyte colonisation of banks may provide a level of protection against overcut erosion (thus geomorphic objective 1d is indirectly addressed).

Component	Flow: Magnitude	Flow: Frequency	Flow: Duration	Rationale	Current Achievement[40]
Fish Spawning Fresh	≥78.7 mAHD	once in spring 2 in 3 years	3 days	4e	Achieved
Refuge[42] in Dec - March	77.7 mAHD	2 out of 3 years worst year 76.95 mAHD	always greater than	3b.2, 4a, 4f connectivity to lagoons[43]	Achieved
Refuge April - Nov	76.95 mAHD	2 out of 3 years worst year 76.7 mAHD	always greater than	3b.2, 4a (cooler temps therefore lower thermal mass required)	Achieved
Low Flow Fresh Dec - Mar	78.2 mAHD (250 ML/day)	2 spring, 2 summer	2 days each	4b maintain low nutrient and moderate DO[44]	Achieved
Bankfull flow (any time)	78.83 mAHD (800 ML/d)	Annual	~7days[45]	1a: Medium sands may be locally mobilised 1b: Silts may be locally scoured[46]	Achieved
Overbank flow (any time)	≥78.83 mAHD	Annual	~7days[47]	1e: Sands locally mobilised[48]	Not achieved

[42] Summer aquatic refuge habitat - assuming no pools, as insufficient data available. Fish require 1.5 m (turtles require less ~0.5 m) (Cadwallader 1978; Treadwell and Hardwick, 2003).

[43] The sill to Safes Lagoon is 76.2 mAHD. Data are not available for other lagoons in this reach, which may have higher sills.

[44] Water quality monitoring should be conducted in association with any flow regime changes enacted. To quantify the magnitude, frequency and duration of low flow freshes required to flush a developing blue-green algal blooms for example, more detailed investigations are necessary (see Section 5.4).

[45] Duration is arbitrary based on likely minimum natural duration and time required to scour and transport sediments.

[46] General scour of silts does not occur at this water level.

[47] Duration is arbitrary based on likely minimum natural duration and time required to scour and transport sediments.

[48] Silt mobilisation not guaranteed – this is a depositional environment. Once mobilised, all size classes will be transported, so incoming suspended sediment will remain in suspension.

Component	Flow			Rationale	Current Achievement[40]
	Magnitude	Frequency	Duration		
Maximum rate of fall				4g: Max. 120 mm per day - fish reasons 1d.2: Max. 120 mm per day to minimise risk of bank slumping	Achieved 96% of time that stage falls

4.2.5 Flow Recommendations for Site 7: Koondrook Weir to River Murray

It is recommended to manage the channel below Koondrook Weir as a backwater environment subject to occasional flushes and floods from Gunbower Creek. The extent and depth of inundation is controlled by water levels in the River Murray (as discussed in detail in section 4.3.6 of the Issues Paper). In fact the hydrology of the backwater substantially controls the health and productivity of this reach and this is reflected by the recommendations in Table 16. Recommendations cannot be made to control River Murray levels, so the primary flow recommendation is that an open connection be maintained at the junction between Gunbower Creek and the Murray.

Flow recommendations for Gunbower Creek below the Koondrook Weir centre mainly on geomorphic and aquatic fauna objectives. Vegetation is a less significant component of this reach, which has an intact parabolic-shaped channel with little perennial vegetation. Annual and ephemeral plants colonise the banks opportunistically as water levels gradually recede after peaks in flow and are a minor component of the ecosystem.

Low flow freshes are recommended to maintain water quality in the backwater and to turn over some of the coarser sediment (promoting macroinvertebrate populations). A larger bankfull flow is also necessary to maintain channel form and morphologic variability. Refuge habitat for fish has not been provided as it is assumed that they are able to migrate to the River Murray should refuge be required.

This reach is currently subject to very rapid rates of rise and fall in water levels close to the Spillway. These are detrimental to aquatic fauna and are likely to inhibit the use of the upper 1 km of the reach by fish (when backwater levels are sufficient to allow passage). The health of this upper section would be markedly improved if these high rates of change could be attenuated.

Table 16
Flow objectives for Site 7: Koondrook Weir to River Murray

Component	Flow: Magnitude	Flow: Frequency	Flow: Duration	Rationale	Current Achievement
Backwater from River Murray	n/a	permanent	n/a	4a, 4d, 4e, 4f	Achieved
Low Flow Fresh Dec - June	100 ML/d	2 summer, 2 autumn	2 days each	1c[49], 4b maintain low nutrient and moderate DO[50]	Achieved
Bankfull flow[51] (any time)	>600 ML/d	Annual	~7days[52]	1a, 1e: Sands may be mobilised[53] 1b: Silts may be locally scoured[54] 1c	Achieved
Maximum intra-day rate of fall				4g: Max. 5 mm/hour and 120 mm per day - fish reasons	Currently not met in upper 1 km of reach

[49] 100 ML/d provides suitable shear stress to entrain coarse sand. Sediment transport may be compromised if backwater conditions coincide with the flush. It is important to achieve free-flowing conditions for the greatest distance downstream.

[50] There are at present no known water quality problems downstream of Koondrook Weir. This suggests that the current combination of a relatively constant leakage flow plus flow pulses from Koondrook Weir is sufficient to maintain water quality in the backwater. Water quality monitoring should be conducted in association with any flow regime changes enacted. To quantify the magnitude, frequency and duration of the low flow fresh required to flush a blue-green algal blooms for example, more detailed investigations are necessary (see Section 5.4). However, the present summer regime provides a good starting point.

[51] This discharge is generally sub-bankfull from a strictly morphological perspective - the channel is mildly incised here as it cuts down to the River Murray.

[52] Duration is arbitrary based on likely minimum natural duration and time required to scour and transport sediments.

[53] Sand transport will slowed or halted if a strong Murray backwater is present.

[54] General scour of silts does not occur at this water level.

4.3 Flow Recommendations for Lagoons Connected to Gunbower Ck

Gunbower Creek features a number of wetlands that have a surface water connection at current normal operating levels. The wetlands therefore share the water level regime of Gunbower Creek but do not transmit the flow of the main watercourse. The wetlands feature a similar geomorphology of a central deep channel and shallow sloping surfaces, however, the wetlands inspected were much larger in scale compared to the creek, as they are relict channels from a former geological period with a wetter climate.

Regulators could be used to allow the water levels in the wetlands to be managed independently of the main channel. This would allow partial implementation of the flow recommendations in some or all of the wetlands without disruption to the current operations in the creek. It would also be possible to manage the wetland water regimes in a complementary cycle; in any season flooded and dried habitats could be provided in different wetlands. This would allow full implementation of the flow recommendations while reducing the risks of any impacts associated with sustained flooding or drying on wetland biota at any single site.

The overall objective of the flow recommendations is to provide a seasonal cycle of wetting and drying in the wetlands while maintaining the deep parts of the channel as a permanent refuge for aquatic fauna (particularly fish, turtles and waterbirds). The cycle replicates the seasonality of pre-regulation flows in the River Murray. The deepest water level, entirely inundating the benches, is required in August to October. This will provide the flooded vegetation required for waterbird breeding, fish breeding and macroinvertebrate production. Additional peaks, above this level, are specified in spring to promote fish spawning. The water level would gradually fall over spring and summer to expose the benches and to promote a diversity of plant species across the elevation gradient. Muddy areas will gradually be exposed through spring and summer, providing foraging habitat for wading birds. A rapid rate of fall in the water level can cause waterbirds to abandon nests, and a maximum drawdown rate is specified. Complete exposure of the benches is required in late summer and autumn in 2 out of 4 years to achieve the intended plant community – persistent flooding over this period can promote excessive growth of the summer-growing species Typha sp. and *Phragmites domingensis*. A minimum water level is specified to provide a permanent habitat and drought refuge in the wetlands. During periods when water levels are low, the surface water connection between wetlands and the main channel may be broken. Low flow freshes are required in the creek to overtop the sill between wetlands and the creek and to allow fish and other fauna to disperse. These events will also refresh the lagoons and reduce the risks of low dissolved oxygen and eutrophication.

Complete drying of the wetlands is advised to assist the eradication of pest plants, which are dependent on stable water levels, particularly upstream of Cohuna Weir. This should only be undertaken when other wetlands are managed to provide alternative, flooded habitat.

Under the recommended flow regime the fretting of the bank, which arises due to stable water levels, should no longer occur. Eliminating conditions that create the steep bank provides an opportunity to batter down the vertical step at the perimeter of the lagoons to create ramps that will not be rapidly eroded. Gently sloping ramps will facilitate the movement of turtles from wetlands to nesting sites in adjacent floodplain areas (see also Supporting Recommendations: Section 5.6).

4.3.1 Flow Recommendations for Site 2: Cockatoo Lagoon

Cockatoo is a broad former river channel with gently sloping banks on the inside of the loop. The recommended flow regime has the potential to provide a very productive and highly diverse wetland ecosystem by creating very broad emergent macrophyte beds. Extensive macrophyte beds provide the shelter required by shy waterbirds (e.g. Crake and Bittern) and also support the food webs on which wading birds and fish depend. It is likely that at this site that Red Gum will colonise the upper fringe of the wetland, which may, eventually, provide the flooded trees favoured by colonial nesting waterbirds.

Complete drying of the wetland over a period of 2 to 3 years should be considered as a component of an eradication plan for Yellow Waterlily and Willow. Once controlled, the recommended flow regime (Table 17) could be implemented.

Table 17
Flow objectives for Site 2 Cockatoo Lagoon

	Flow				
Component	Magnitude	Frequency	Duration	Rationale	Current Achievement
Aug - Oct peak	≥82.2 mAHD (≥1,020 ML/d)	2 out of 4 years	Aug-Oct	2a, 3c, 3d.2 Can only survive 2 years of not being met sequentially.	Achieved
Aug - Oct min.	81.9 mAHD	2 out of 4 years	Aug - Oct	3c, 3d.1	Achieved
Aug - Oct rate	max drop of 0.2 m over 2 weeks	in years where macrophytes flooded	Aug - Oct	3d.3 Fauna reasons	Rate possibly exceeds this
Feb - May max.	<81.3 mAHD	2 out of 4 years	Feb - May	2a, 2c, 3c, 4d: Expose benches[55]; can only survive 2 years of not being met sequentially	Not achieved
Fish Spawning Fresh	≥82.5 mAHD	once in spring 2 in 3 years	3 days	4e 4f connectivity to lagoons[56]	Achieved

[55] Providing conditions for macrophyte colonisation of banks may provide a level of protection against overcut erosion (thus geomorphic objective 1d is indirectly addressed).

Component	Flow: Magnitude	Flow: Frequency	Flow: Duration	Rationale	Current Achievement
Refuge[57] Dec - Mar	81.4 mAHD	2 out of 4 years worst year 80.65 mAHD	always greater than	3b.2, 4a, 4c	Achieved
Refuge[58] April - Nov	80.65 mAHD	2 out of 4 years worst year 80.4 mAHD	always greater than	3b.2, 4a, 4c (cooler temps therefore lower thermal mass required)	Achieved
Low Flow Fresh Dec - Mar	81.7 mAHD (500 ML/day)	2 spring, 2 summer	2 days each	4b maintain low nutrient and moderate DO[59]	Achieved
Complete drying[60]	Complete drying	1* year in 5	summer	2c	Not achieved
Maximum rate of fall				4g: Max. 120 mm per day - fish reasons 1d.2: Max. 120 mm per day to minimise risk of bank slumping	Probably achieved most of the time

* to be confirmed. Compare to 1 year in 5 drying in Richardson Lagoons

[56] Sill between wetland and creek is 81.6 mAHD. This level provides 0.5 m depth over the sill.

[57] Aquatic refuge habitat. Catfish and Perch known to these lagoons. Smaller than Cod therefore lower depths required. Also 'warm water' species, therefore don't need the same thermal mass (turtles require less ~0.5 m) Initial estimate of 1.0 m (Cadwallader 1978; Treadwell and Hardwick, 2003).

[58] Provide for fish known in lagoons - initial estimate 0.75 m to be confirmed.

[59] Water quality monitoring should be conducted in association with any flow regime changes enacted. To quantify the magnitude, frequency and duration of low flow freshes required to flush a developing blue-green algal blooms for example, more detailed investigations are necessary (see Section 5.4)

[60] Promote habitat preferences of native species (e.g. Red Gum and species that grow with them) and make less hospitable to exotics (e.g. willows).

4.3.2 Flow Recommendations for Site 6: Safes Lagoon

Safes Lagoon features shallow sloping surfaces up to 30 m wide and a broad central channel. The wetland therefore has the potential to develop extensive and productive emergent macrophyte beds and herblands with complimentary permanent aquatic habitat. Red Gum forest fringes the wetland and is likely to encroach down-slope if the benches are exposed over spring. This will eventually provide flooded tree habitat favoured by colonial nesting waterbirds. It is expected that the boundary between the wetland and the surrounding forest will become less distinct and there will instead be a continuous gradient from floodplain to aquatic vegetation down the wetland banks.

A permanent, resident assemblage of fish will occupy the deep pools in the central wetland areas and will make use of the benches when flooded in spring and by freshes.

Turtles are known to nest in the sandy soils around the lagoons. The recommended seasonally fluctuating water regime (Table 18) will reduce fretting at the bank edge and will allow sloping ramps to nesting sites to be constructed.

Note that complete drying (objective 2c) is not recommended for Safes Lagoon as it does not suffer from pest plants at this time.

Table 18
Flow objectives for Site 6: Safes Lagoon

Component	Flow: Magnitude	Flow: Frequency	Flow: Duration	Rationale	Current Achievement
Aug - Oct peak	≥77.9 mAHD	2 out of 4 years	Aug - Oct	2a, 3c, 3d.2 Can only survive 2 years of not being met sequentially.	Achieved
Aug - Oct min.	77.7 mAHD	2 out of 4 years	Aug - Oct	3c, 3d.1	Achieved
Aug - Oct rate	max drop of 0.2 m over 2 weeks	in years where macrophytes flooded	Aug - Oct	3d.3 Fauna reasons	Rate possibly exceeds this

Component	Flow: Magnitude	Flow: Frequency	Flow: Duration	Rationale	Current Achievement
Feb - May max.	77.3 mAHD	2 out of 4 years	Feb - May	2a, 2c, 3c, 4d: Expose benches[61]; can only survive 2 years of not being met sequentially	Not achieved
Fish Spawning Fresh	≥78 mAHD	once in spring 2 in 3 years	3 days	4e	Achieved
Refuge[62] in Dec - March	77.4 mAHD	2 out of 4 years worst year 76.65 mAHD	always greater than	3b.2, 4a, 4c	Achieved
Refuge[63] April - Nov	76.7 mAHD	2 out of 4 years worst year 76.5 mAHD	always greater than	3b.2, 4a, 4c 4f connectivity to lagoons[64]	Achieved
Low Flow Fresh Dec - Mar	77.5 m AHD	2 spring, 2 summer	2 days each	4b maintain low nutrient and moderate DO[65]	Achieved
Maximum rate of fall				4g: Max. 120 mm per day - fish reasons 1d.2: Max. 120 mm per day to minimise risk of bank slumping	Probably achieved most of the time

[61] Providing conditions for macrophyte colonisation of banks may provide a level of protection against overcut erosion (thus geomorphic objective 1d is indirectly addressed).

[62] Aquatic refuge habitat. Catfish and Perch known to these lagoons. Smaller than Cod therefore lower depths required. Also 'warm water' species, therefore don't need the same thermal mass (turtles require less ~0.5 m) Initial estimate of 1.0 m (Cadwallader 1978; Treadwell and Hardwick, 2003).

[63] Cooler temps therefore lower thermal mass required. Provide for fish known in lagoons - initial estimate 0.75 m to be confirmed.

[64] The sill between Safes Lagoon and Gunbower Creek is 76.2 mAHD. A level of 76.7 mAHD will provide the 0.5 m depth required for fish passage.

[65] Water quality monitoring should be conducted in association with any flow regime changes enacted. To quantify the magnitude, frequency and duration of low flow freshes required to flush a developing blue-green algal blooms for example, more detailed investigations are necessary (see Section 5.4)

4.4 Conclusions

Under the current water management regime, Gunbower Creek supports important conservation values. It supports a diverse community of fish, supports turtle breeding and provides habitat for waterbird breeding, foraging and shelter. These values are not under any specific threats from the current water regime and ecologically the system can be considered to be in a steady state.

Although the creek system currently supports important conservation values, it has the potential to support much greater conservation values. These centre on the water regime of the creek margin, particularly the overcut benches which have formed since regulation. With an appropriate water regime, the creek margins could support more diverse, extensive and productive aquatic plant communities that would promote the diversity and abundance of fish, would provide a greater variety of food sources and prey for waterbirds and would also improve habitat quality for water rats, turtles and other aquatic fauna. Waterbird breeding would increase in the number and diversity of breeding birds and the regularity of breeding events. These are values associated with seasonal wetlands in the Gunbower Creek region and have been impacted significantly in the region by river regulation and diversions. They have are proposed here as the most appropriate objectives to promote ecological health in Gunbower Creek.

The creek system is managed almost exclusively for irrigation supply. In general, the difference between the current water regime and the recommended water regime is an excess of water in the summer and autumn period. The recommended flows would impact on current creek operations mainly because they would reduce the availability of water during the irrigation season. Implementation of the flow recommendation would require an assessment of the scale of the impact and an exploration of alternative water supply options.

5 SUPPORTING RECOMMENDATIONS

5.1 Current Operational Commitments and Environmental Flow Recommendations

There is little scope to alter the current operations of Gunbower Creek without reducing its effectiveness as a water supply channel. The creek is operated at or close to the maximum capacity during the irrigation season – any additional flow would result in the creek breaking its banks. There is little scope to lower water levels as this would reduce the head available to distribute the water to other delivery channels.

While the flow recommendations maintain water in most reaches throughout the year and would not, to a large extent, change the visual appearance of the creek, they would dramatically impact on the role of the creek as a water supply. The recommended levels would match the current water supply requirements for only brief parts of the irrigation season. The current arrangements match the environmental requirements where:

- high water levels are required to inundate overcut benches, shallow sloping surfaces and upper lagoon banks during spring;
- benches, shallow sloping surfaces and upper lagoon banks are required to be exposed during summer and late autumn (although currently this requirement is not met[66]); and
- providing a refuge habitat for aquatic fauna throughout the year.

The high water levels required for irrigation supply are in conflict with the recommended water regime because they exceed the recommended levels during the summer and autumn period.

The highest priority flow recommendations centre on the quality and diversity of habitat on the overcut benches and the sloping banks of the lagoons. They involve flooding shallow sloping surfaces in spring and exposing them over summer. Lowering creek levels to expose these surfaces in summer is incompatible with the supply of water during the peak irrigation season. At most sites, the recommended spring level is exceeded by low creek discharges (Table 19), which is compatible with current arrangements. However exposure of the benches and shallow sloping surfaces between February and May requires flow to cease completely and the weir pools to be drawn down (Table 19).

Alternative arrangements would be required to supply water to consumers (i.e. an alternative channel or pipeline) to meet the autumn low water level recommendation. An alternative channel or pipeline could be used or pumps could be used to lift water into distributary channels from Gunbower Creek.

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[66] After the irrigation season ends in May, inflows to the creek system cease and water levels are allowed to fall. This does not meet the flow recommendations because the benches are exposed in very late autumn instead of mid-summer.

Table 19.
Discharge of Gunbower Creek at recommended spring (bench inundated) and autumn (bench exposed) levels for surveyed sites. Note that discharges and levels required to inundate and expose benches will vary from these values throughout the Creek.

Site	Bench exposed (Feb - May max.)		Bench inundated (Aug - Oct peak)	
	Level (mAHD)	Relative level at no flow	Level (mAHD)	Discharge (ML/d)
1. Gunbower Ck Downstream of National Channel	≤84.1	0.4 m below weir pool at no flow	≥84.7	≥1,680 ML/d
2. Cockatoo Lagoon	≤81.3	at weir pool level at no flow	≥82.2	≥1,020 ML/d*
3. Holmes Bridge	≤80.9	0.4 m below weir pool at no flow	≥81.8	≥830 ML/d
4. Cohuna Weir Pool	≤80.6	0.7 m below weir pool at no flow	≥81.3	Any flow†
5. Tree Tops Scout Camp	≤77.9	0.1 m below weir pool at no flow	≥78.5	≥500 ML/d
6. Safes Lagoon	≤77.3	0.7 m below weir pool at no flow	≥77.9	Any flow‡

* Refers to the sloping lagoon surface on the inside of the bend. Assumes free connection to Creek.

† Site 4 is just upstream of the weir, where the weir maintains water level above the bench independent of discharge. This reach upstream towards Gunbower Weir will require flow to inundate the benches (not modelled).

‡ The sloping lagoon surface on the inside of the bend is inundated at normal pool level. It remains inundated at levels ≥0.1 m below normal pool level. Assumes free connection to Creek.

It would be possible to fully implement the flow recommendations in the lagoons, but not Gunbower Creek, if the lagoons were isolated from the creek using regulators. The water level in the lagoons could be raised by taking water from Gunbower Creek and then lowered by closing the connection to the creek and allowing evaporation and seepage to occur. There are three issues that will require careful management if this approach were followed.

1. Fish passage between the lagoons and the creek would be constrained to periods when the connection was open. However, openings at the appropriate time of year and for sufficient duration could ensure that adequate fish passage was provided during periods when the levels in the lagoon and the creek were similar.
2. The type of regulator is important for fish passage. Pipes provide poor passage for fish and often have velocities too high for fish to swim against. They are dark and sometimes inhabited by large predatory fish. These factors all reduce the likelihood that fish will successfully negotiate piped connections. Therefore, structures which are able to be opened, have light or are wide enough to ensure low flow velocities will enhance the chances of successful fish passage.

3. Water quality would have to be closely monitored if the lagoons were cut off for the periods of time suggested. The key issues associated with disconnection include: potential for shallow saline groundwater intrusion, salinisation or acidification, and eutrophication. Each of these issues was discussed in detail in the Issues Paper (Anderson et al., 2007), and supporting recommendations are made to address the concerns later in this section.

At present the open connections to Gunbower Creek enable some turnover of water in the lagoons. This turnover is at present also enhanced by the extraction of water for irrigation on Cockatoo Lagoon. The rate of replacement is poorly understood at present. The current operation of Gunbower Creek would not be affected.

5.2 Groundwater Relationships

During the irrigation season, Gunbower Creek is operated at a higher level than the water table aquifer. The creek will, to some extent, recharge the aquifer. Recharge contributes to the water requirements and health of trees immediately adjacent to the creek and may contribute to groundwater threats, particularly salinisation, to the floodplain beyond the flushed zone.

A number of questions need to be addressed in order to examine the effect of creek levels on groundwater levels and salinity adjacent to the creek:

- How does water in the creek contribute to a flushed zone in supporting tree health?
- How does water in the creek contribute to elevated ground water levels adjacent to the creek and in the forest?
- If water levels in the creek were lowered, how would groundwater levels respond?
- If water levels in the creek were lowered, how would creek salinity levels respond?

The last question was answered in the Issues Paper through analysis of water quality records. This analysis showed that the past practice of lowering the creek water level in winter did increase the salinity, but not by very much.

It is recommended that a study into the relationship between ground water, salinity and historical and proposed creek levels is undertaken to determine how proposed changes to flows may impact on riparian tree health.

5.3 Water Quality in Pools

Recommendations regarding pool water levels during low or cease to flow periods assume water quality in pools at all depths is appropriate to sustain fauna. If pools during low flow, or cease to flow events, have highly saline water lying in the bottom, or low dissolved oxygen (DO) levels or high temperatures then under the proposed flow regime they may not constitute appropriate refuge habitat.

It is recommended that a survey of the creek be undertaken to evaluate the possibility of saline or anoxic water lying in deep holes in the creek, particularly during summer and autumn. During low flow periods over summer vertical conductivity, DO, and temperature profiles of deep holes need to be recorded. This will indicate the likelihood/potential of gradual saline discharge to the creek, or nutrient streaming, at lower water levels.

5.4 Water Quality and Flushing Events

High levels of the floating fern *Azolla* sp. and Blue Green Algae growth can result in threats to fauna within the creek during low flow events in spring and summer when associated with high nutrient loads. Dense mats of *Azolla* sp. on the water surface can result in low light levels and anoxia in the water column (Morris et al., 2003), resulting in submerged macrophyte and fauna death. Blue green algal blooms can be toxic to fish and other aquatic fauna through the ingestion of microcystins. Microcystin concentrations found in nature can potentially affect several trophic levels in the aquatic ecosystem, in particular by inducing failure of sensitive stages (e.g. fish fry) to develop and accumulate in the food chain (Malbrouck and Kestemont, 2006).

It is recommended that the creek be monitored during these periods and low flow freshes be used to replace the volume of water in the creek and flush out accumulated Blue Green Algae and *Azolla* sp., and reoxygenate the water column. The aim is to turn over the low flow volume in the creek (i.e. to the depth of 1.5 m).

5.5 Survey Deep Holes in Creek and Lagoons

Deep holes within the creek and lagoons provide potentially important refuge habitat for fish and turtles during low flow or cease-to-flow events. It is recommended that a longitudinal survey be conducted of a number of sample reaches along Gunbower Creek to identify the presence of these deep holes and to quantify their number, depth and approximate volume. Similar surveys are recommended for each of the lagoons. The aim would be to provide similar data to that collected for Safes Lagoon by Di Peace (see Section 3.1.2). Information on the frequency and extent of deep holes would allow a suitable water depth to be recommended so as to maintain viable refuge habitat to ensure faunal survival particularly over summer during low flow or cease-to-flow events.

5.6 Turtle Ramps

Long-term relatively stable water levels change the natural interface ecosystem between land and water to one where aquatic and emerging plants grow continuously in a permanent zone. Where water levels vary seasonally, vegetation cover varies up and down the bank in a transitional zone. Under stable water conditions where a fretted vertical bank forms in conjunction with a permanent zone of emergent plants this may present an effective barrier to the movement of turtles from water to land (Goodwin and Hopkins, 2005). This has implication for the migration of turtles from the water to the nesting site, particularly at Safes Lagoon. A consequence of this restriction to movement is that the nesting habitat becomes limited to a relatively narrow zone, significantly increasing the chances of predation of eggs and hatchlings, particularly by foxes (Goodwin and Hopkins, 2005).

Recommendations to reduce the rate of fretting and provide a gentle slope to the banks are:

- introduce more variable water levels to reduce fretting associated with the constant stable water levels; and,
- provide conditions that promote riparian aquatic vegetation that stabilise banks.

However, the banks will take several years to stabilise. Until the banks stabilise, the turtles will need to negotiate existing banks. This is particularly relevant to the Broad-shelled Turtle

(*Chelodina expansa*), which lays eggs in autumn (mid-March to mid-May (Goodwin and Hopkins, 2005)). During this period the low water levels recommended would mean that females will need to scale the existing undercut bank without the aid of bank full levels that were historically maintained at this time of year.

It is recommended that the banks of the Safes Lagoon be remodelled to provide egress over sloping banks (ramps) at a number of locations, to minimise risks to Broad-shelled Turtle breeding over this period.

5.7 Sills to Wetlands

To allow fish to move between wetlands and the main channel of Gunbower Creek it is recommended that a water depth of 0.5 m is periodically provided throughout the year. Sill levels data is available for Safes Lagoon and Cockatoo Lagoon and has been used to set flow objectives. However, there are other important wetlands where the sills are not known. It is recommended that the sill levels are measured and the flow recommendations modified if necessary.

5.8 Changes to Lagoon Flushing

One of the key flow recommendations identifies the need to disconnect lagoons from Gunbower Creek during summer and autumn in order to allow the water levels to decline in a normal pattern. There are a range of risks associated with disconnection (discussed earlier), prime among them is that this eliminates any circulation of freshwater through the lagoons. In order to maintain lagoon water quality small flushing flows have been recommended. The purpose of these flows is to refresh the water in the lagoons, to break down stratification but not to top-up the lagoon levels. Further investigation is required to define the magnitude, duration and frequency of flows required to achieve these aims.

Indeed, a very useful first step would be to quantify the existing turnover rates within the lagoons and identify the mechanisms via which turnover occurs. For example, it has been asserted that Safes Lagoon enjoys higher water quality than Cockatoo Lagoon because water in it has a lower residence time due to greater fluctuation in creek levels. However, data on creek level variation does not support this explanation, so the question remains: how is high water quality being maintained at Safes Lagoon?

5.9 Extending Lagoon Recommendations to Other Locations

The lagoon flow recommendations defined by this study provide flow regimes for Cockatoo and Safes Lagoons. These recommendations were based in particular on the inundation and exposure of shallow sloping surfaces found at the margins of the lagoons. These regions have the potential to develop extensive and productive emergent macrophyte beds and herblands with complimentary permanent aquatic habitat. Therefore, a number of the flow recommendations are tied directly to the vertical levels observed in the surveyed cross-section. Two recommendations flow from this situation:

- First, recommendations for Cockatoo and Safes Lagoon are based substantially on a single surveyed cross-section. While it is thought that this cross-section represents a typical section, it would be wise to confirm this is the case by surveying additional sections prior to changing the water regime.

- Second, in order to specify suitable flow regimes for other lagoons in the system (e.g. Splatt, Turner, Phyland, Longmore and Gum) cross-sectional surveys of these lagoons are required. This data would be necessary information to address lagoon flushing as well (Section 5.8).

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7 APPENDIX 1: COMPLETE HYDRAULIC RESULTS

This appendix reports the hydraulic results compiled for each of the seven sites. As described in the main body of the report, the standard set of hydraulic results includes the following:

- First, plots to indicate how water surface elevation varies with discharge for the two simulation configurations (with weirs and without). For the two lagoon sites the water level variation within the lagoon was assumed to be identical to the variation at a nearby cross-section in the creek.
- Second, for each of the four 'flowing' stream sites (i.e. sites 1, 3, 5, and 7; excluding Cohuna weir pool), geomorphic thresholds for sediment entrainment were plotted (shear stress and velocity criteria).
- Third, for each lagoon a simple evaporation model was run to indicate to a first approximation how much the water level might be expected to decrease over a season if the lagoons were cut off from the creek.

In addition, to provide context, an aerial picture indicating the location of the site is shown at the beginning of each hydraulic data set.

7.1 Site 1: Gunbower Creek downstream of National Channel

Figure 12. Location map for Site 1: Gunbower Creek downstream of National Channel. The site at which field observations were made is shown by the white circle, the location of measured cross-sections is indicated in red.

There was no cross-section in the immediate vicinity of the location that was examined during the field inspection. Two measured cross-sections were available (as indicated in Figure 12). The upstream cross-section is for the National Channel itself (an artificial section) while the downstream cross-section was in a natural section of Gunbower Creek. The latter was most similar to the location at which we made observations and hence the following plots show only the downstream cross-section.

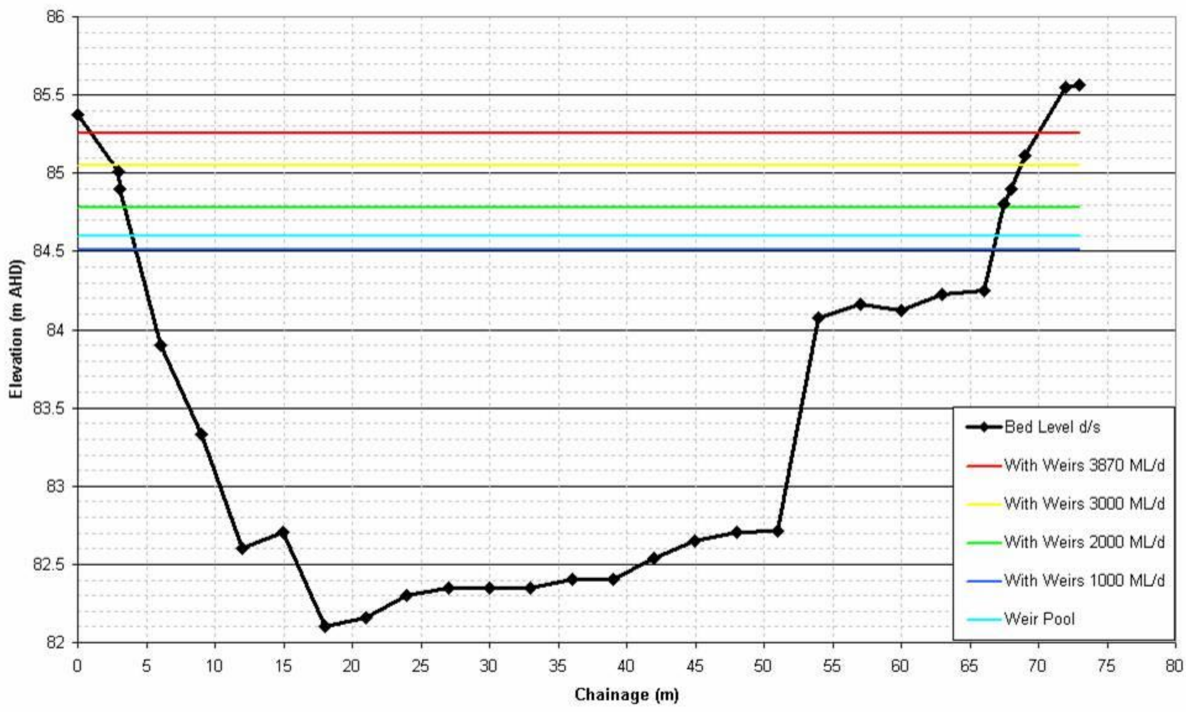

Figure 13. Gunbower Creek downstream of National Channel (Site 1) showing flow depth variation with discharge under the current configuration (with weirs).

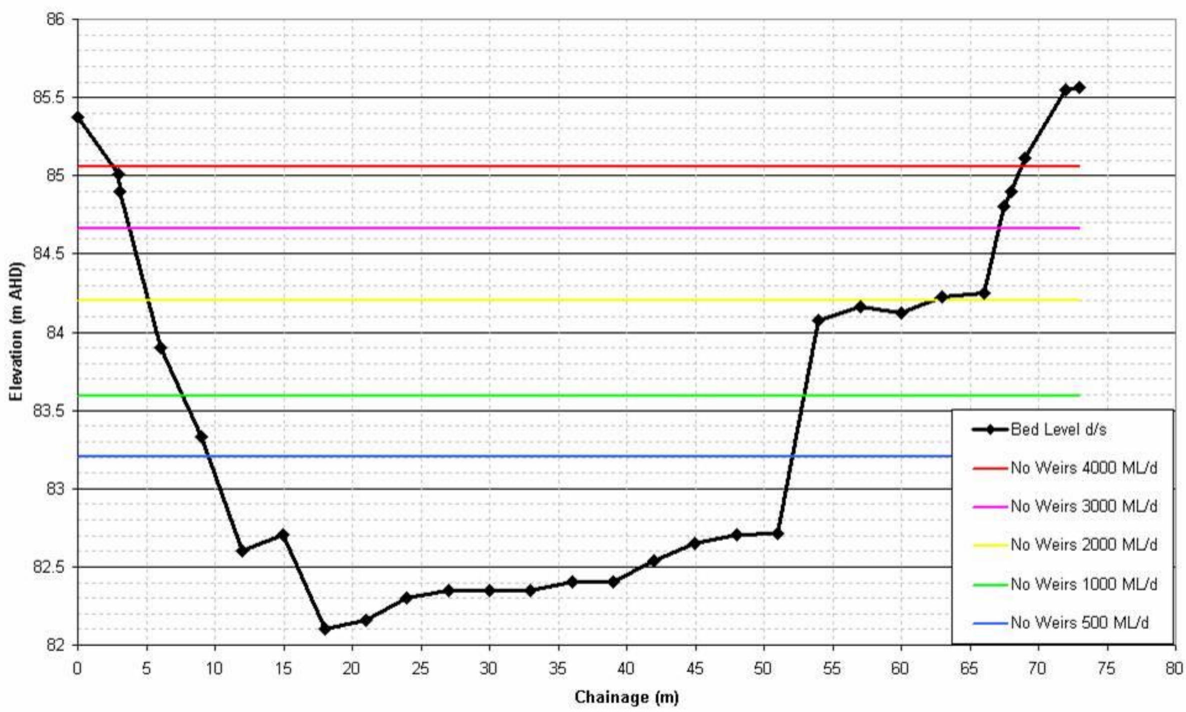

Figure 14. Gunbower Creek downstream of National Channel (Site 1) showing flow depth variation with discharge under the configuration without weirs or irrigation effluents.

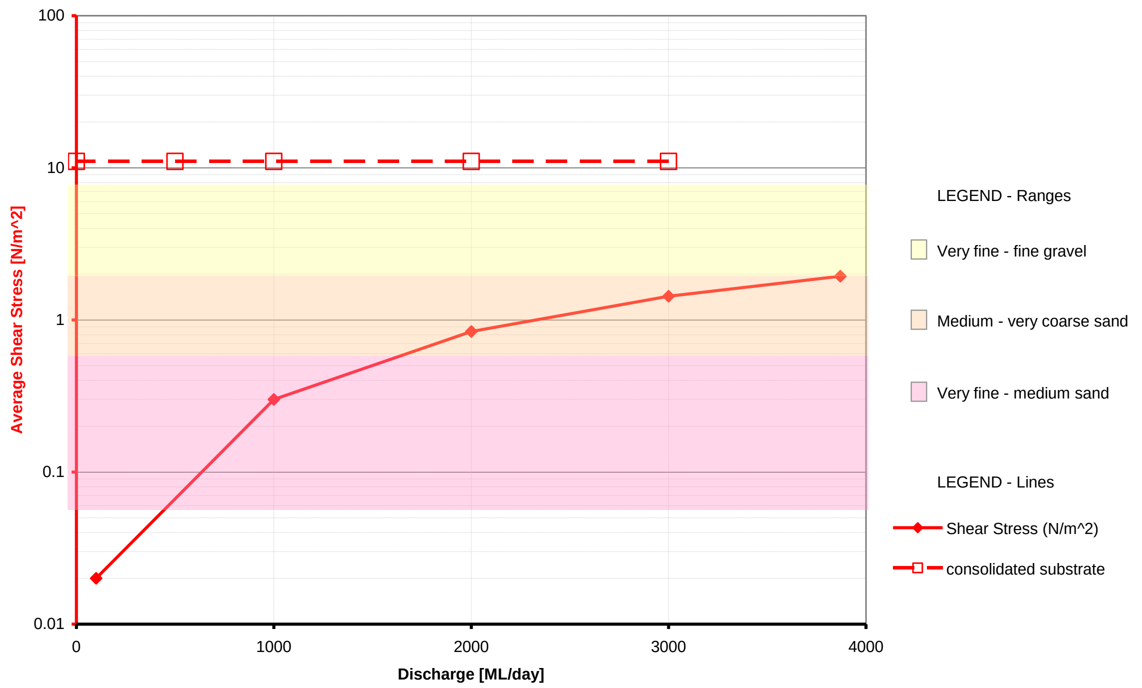

Figure 15. Gunbower Creek downstream of National Channel (Site 1) showing the variation of shear stress (solid red line) with increasing discharge (simulation with weirs). A range of thresholds are shown either as a coloured range of values or as single-valued dashed lines. Note that shear stress is shown on a logarithmic scale.

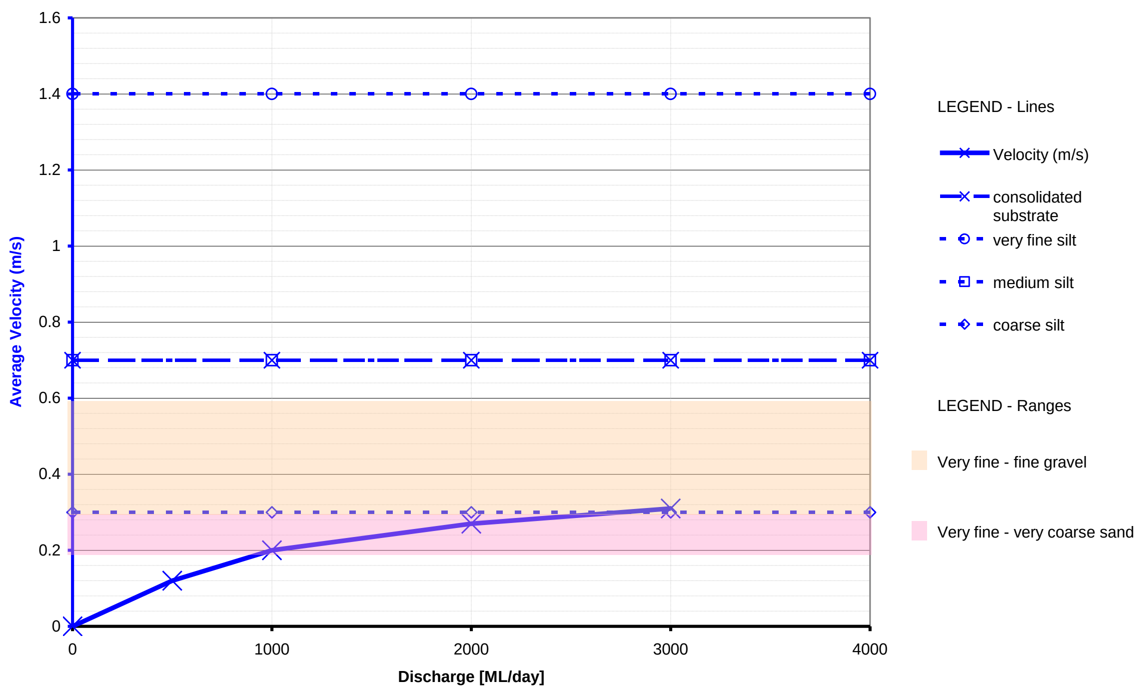

Figure 16. Gunbower Creek downstream of National Channel (Site 1) showing the variation of velocity (solid blue line) with increasing discharge (simulation with weirs). A range of thresholds are shown either as a coloured range of values or as single-valued dashed lines.

7.2 Site 2: Cockatoo Lagoon

Figure 17. Location map for Site 2: Cockatoo Lagoon. Field observations were made at the locations indicated by the yellow circles (the lagoon cross-section was measured within the yellow circle at the top of this figure). The white circle indicates the location of the measured cross-section at which water surface elevation results were taken and referred into the lagoon itself.

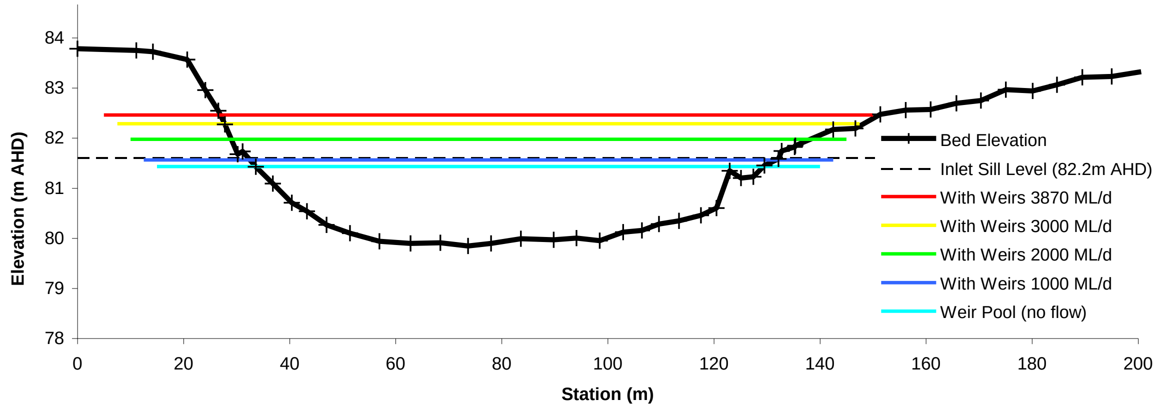

Figure 18. Cockatoo Lagoon (Site 2) showing depth variation with discharge in Gunbower Creek under the current configuration (with weirs).

Note that Figure 18 indicates that at very low discharge in Gunbower Creek (discharge <1,000 ML/d) Cockatoo Lagoon should become disconnected (assuming the sill level is correct).

7.2.1 Evaporative Loss Results

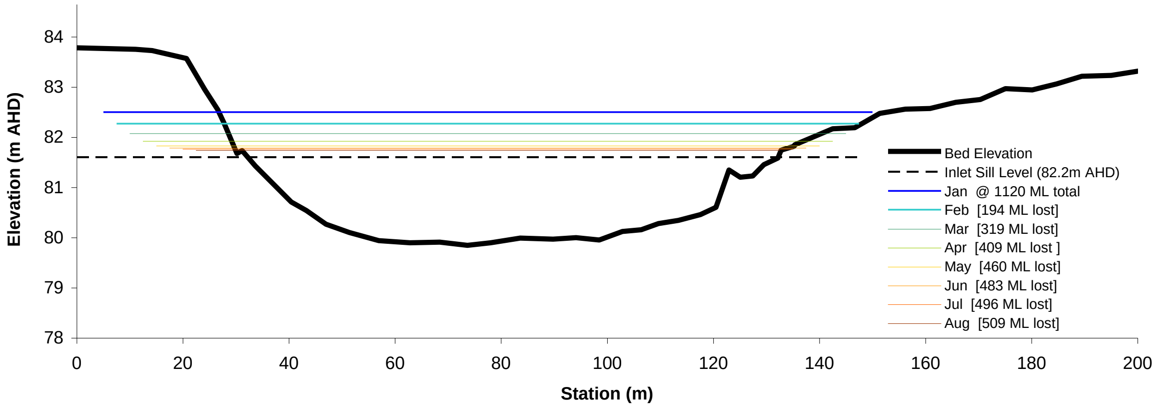

Figure 19. Cockatoo Lagoon (Site 2) showing a first estimate of water level decrease in Cockatoo Lagoon due to evaporation. This scenario starts with the lagoon full in January and decreasing until August. The approximate volume of water lost to evaporation is also reported in the legend.

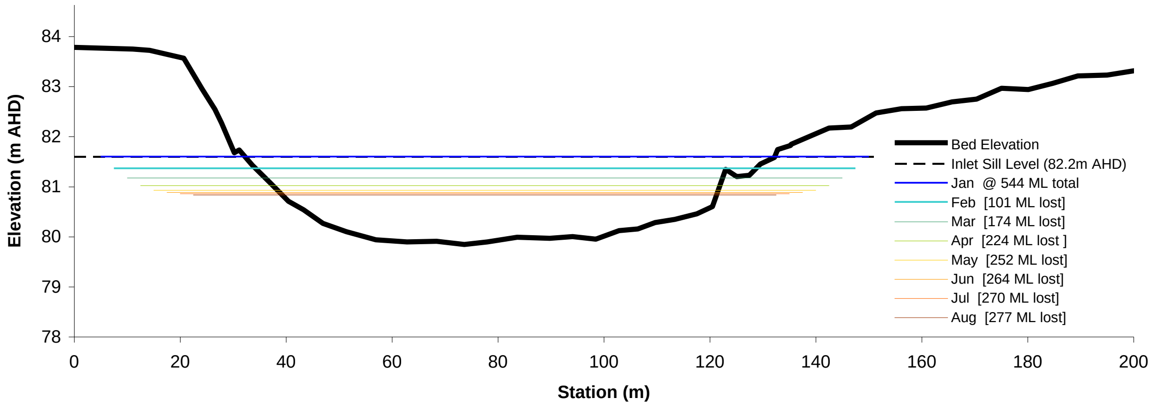

Figure 20. Cockatoo Lagoon (Site 2) showing a first estimate of water level decrease in Cockatoo Lagoon due to evaporation. This scenario starts with the lagoon emptied to the sill level at the start of January and decreasing until August. The approximate volume of water lost to evaporation is also reported in the legend.

7.3 Site 3: Holmes Bridge

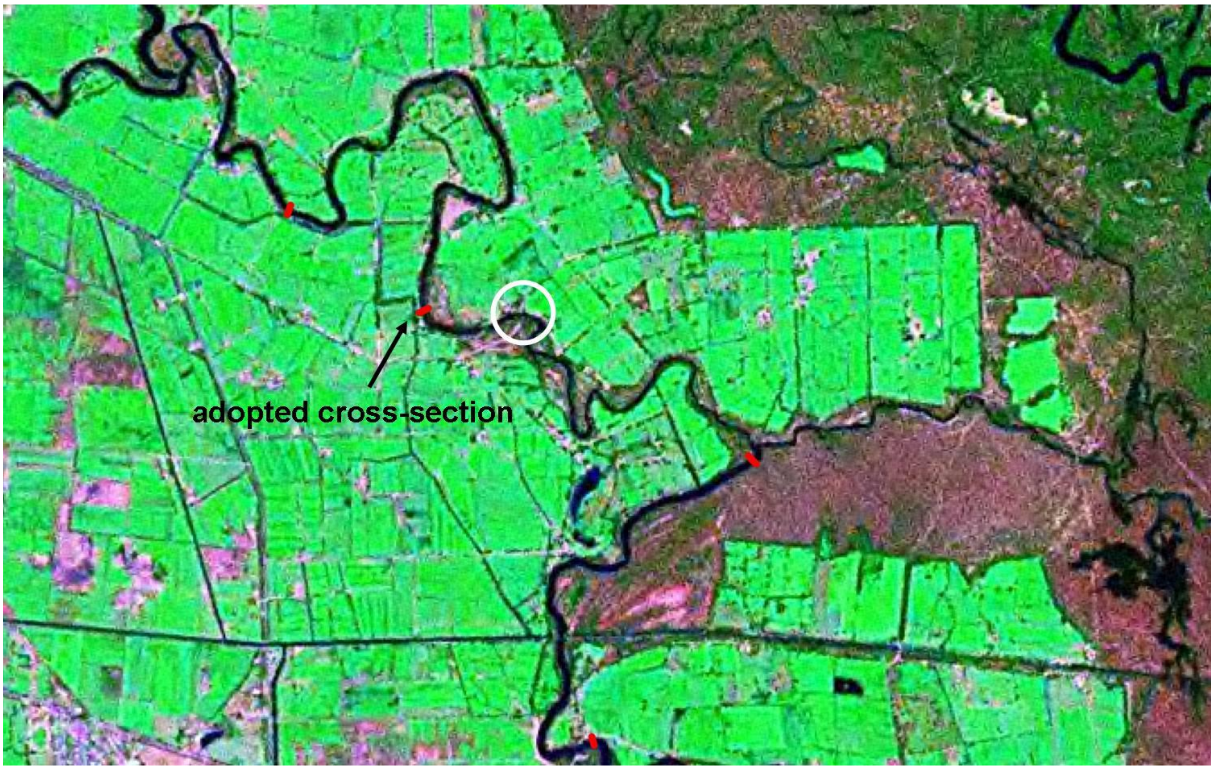

Figure 21. Location map for Site 3: Gunbower Creek @ Holmes Bridge. The site at which field observations were made and additional cross-sections were surveyed is shown by the white circle. The black arrow shows the location of adopted cross-section from which simulation results were taken.

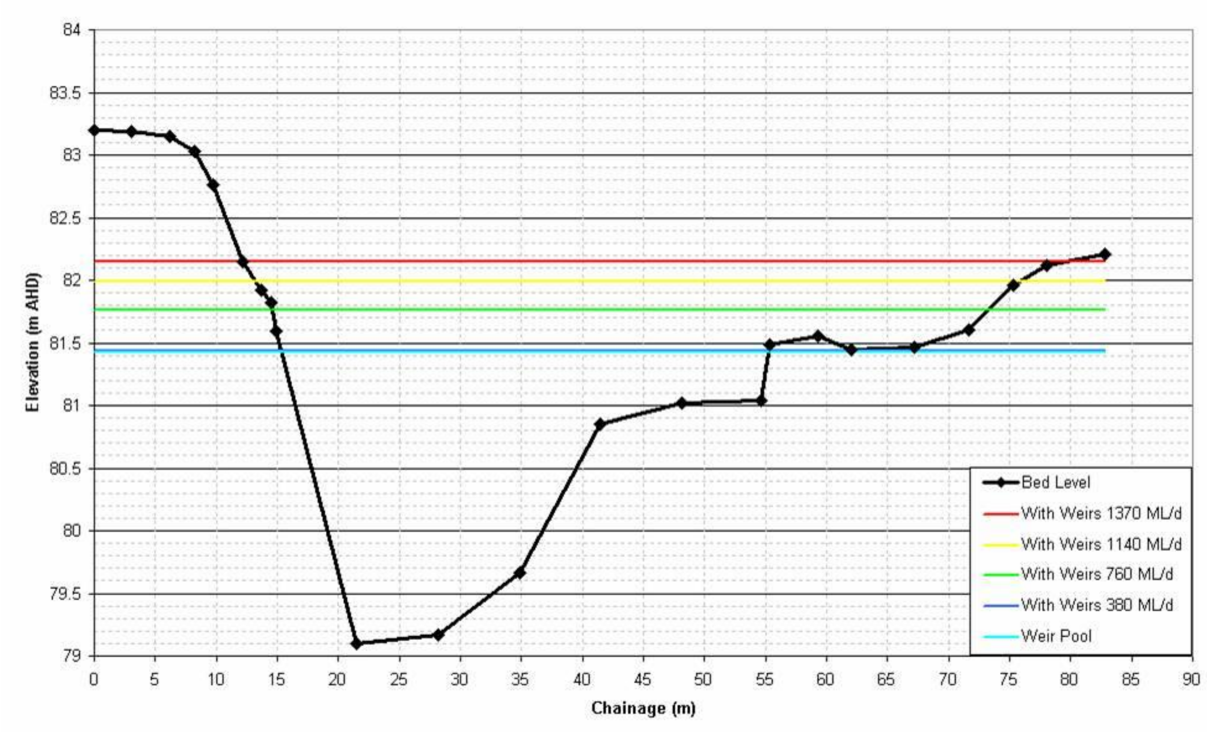

Figure 22. Gunbower Creek @ Holmes Bridge (Site 3) showing flow depth variation with discharge under the current configuration (with weirs).

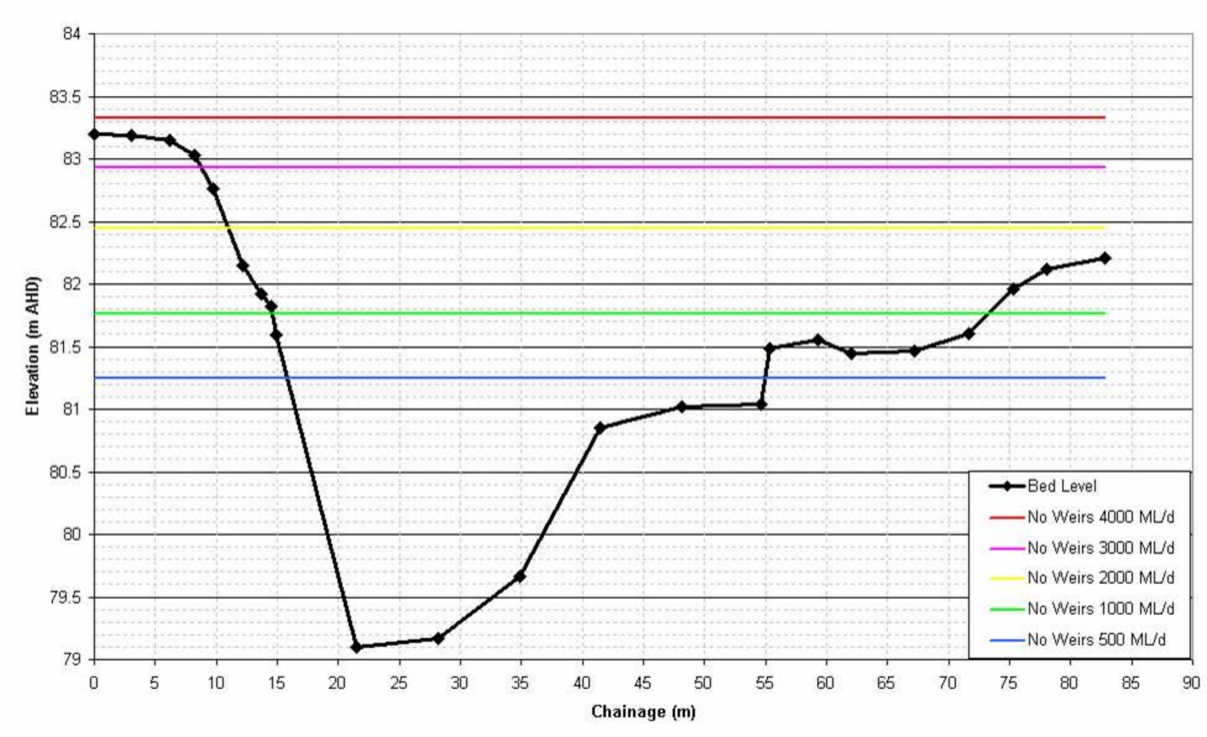

Figure 23. Gunbower Creek @ Holmes Bridge (Site 3) showing flow depth variation with discharge under the configuration without weirs or irrigation effluents.

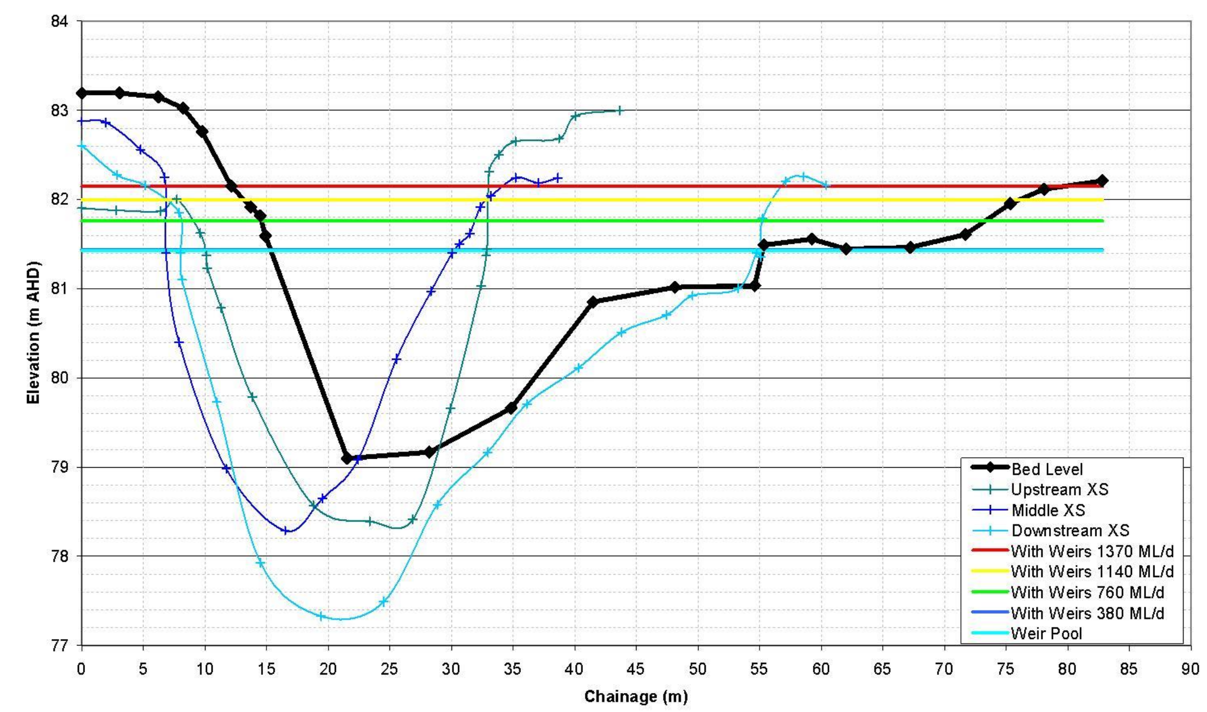

Figure 24. Gunbower Creek @ Holmes Bridge (Site 3) showing flow depth variation with discharge under the current configuration (with weirs). This plot shows the three additional cross-sections surveyed at the inspection site.

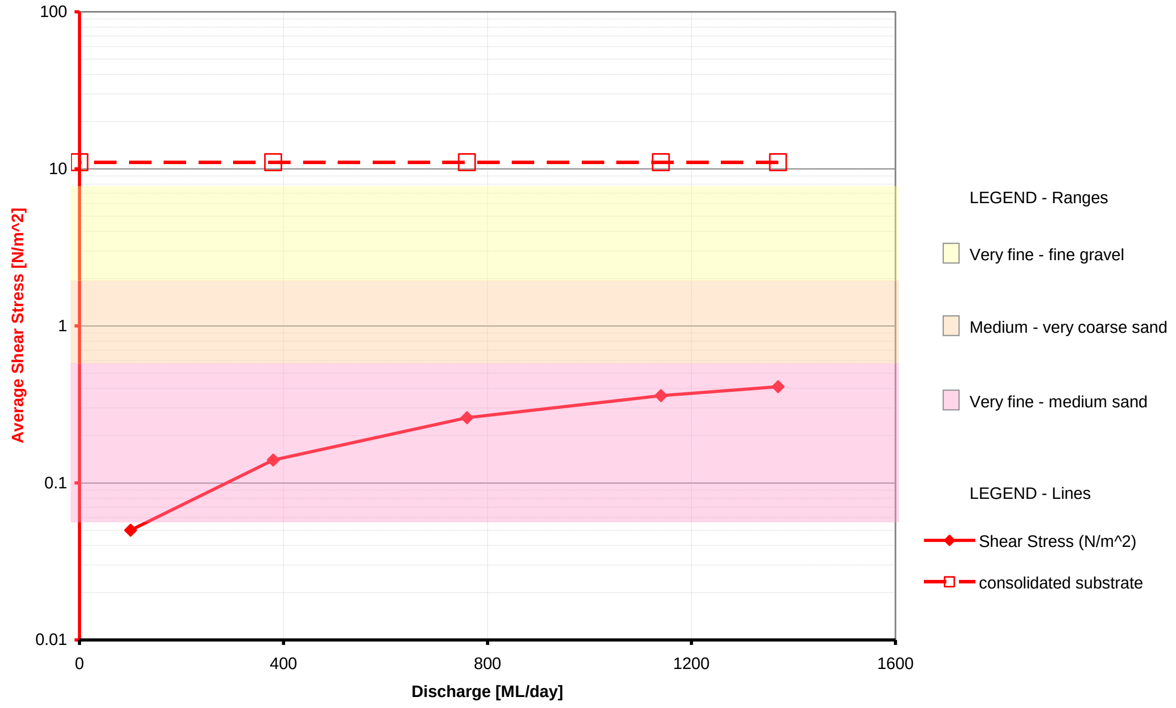

Figure 25. Gunbower Creek @ Holmes Bridge (Site 3) showing the variation of shear stress (solid red line) with increasing discharge (simulation with weirs). A range of thresholds are shown either as a coloured range of values or as single-valued dashed lines. Note that shear stress is shown on a logarithmic scale.

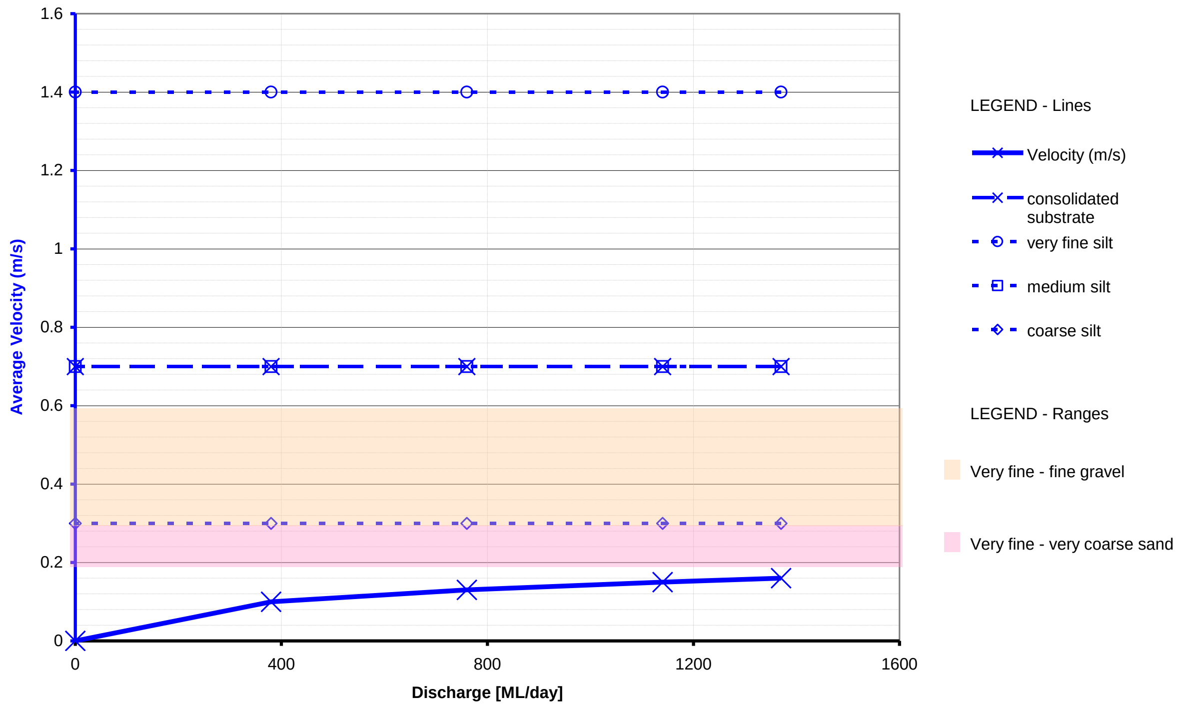

Figure 26. Gunbower Creek @ Holmes Bridge (Site 3) showing the variation of velocity (solid blue line) with increasing discharge (simulation with weirs). A range of thresholds are shown either as a coloured range of values or as single-valued dashed lines.

7.4 Site 4: Cohuna Weir Pool

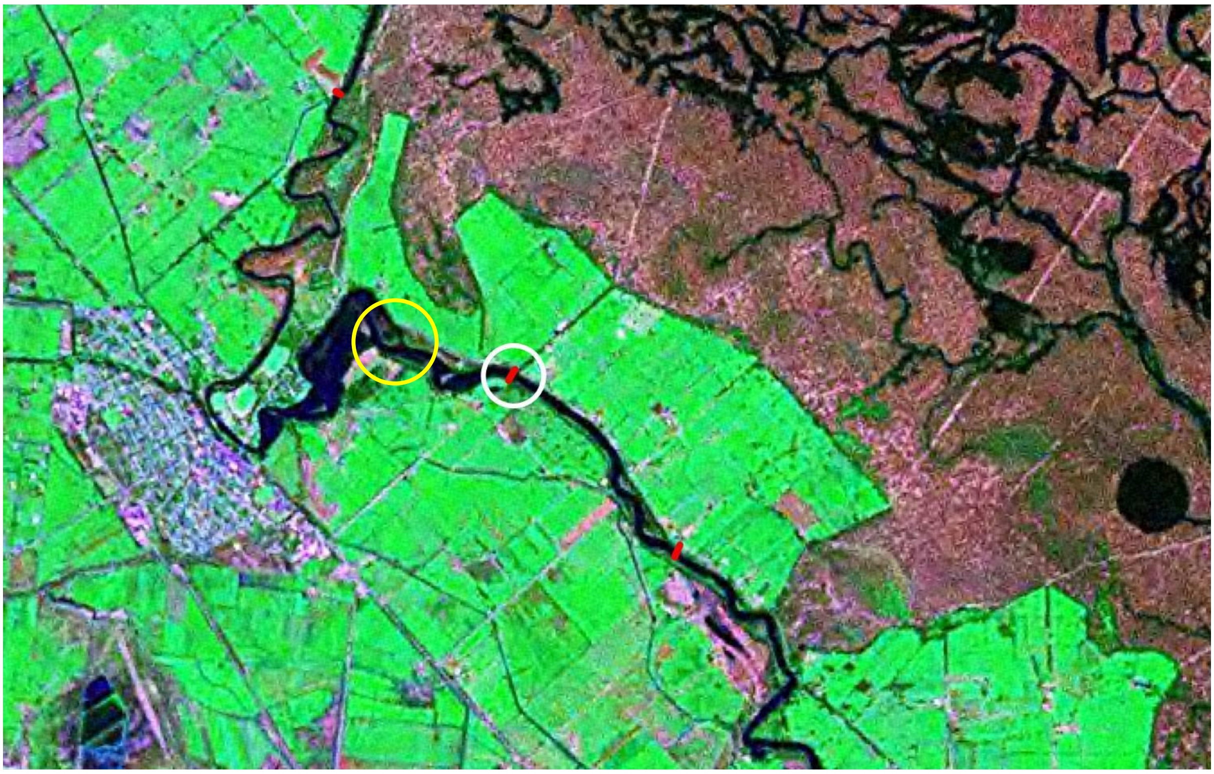

Figure 27. Location map for Site 4: Gunbower Creek @ Cohuna Weir Pool. The site at which field observations were made is shown by yellow circle; the location of adopted measured cross-section is indicated by the white circle.

Note that the location of the cross-section is actually just upstream of the weir pool. This location is transitional between the weir pool environment and the creek. The morphology of the cross-section resembles the inspection site, although the overcut bench was much more pronounced and probably about twice as wide (it was also on the right bank rather than the left bank).

The other important implication of using this cross-section is that the velocity and shear stress values will be larger than the values closer to the weir. Consequently, the thresholds provided in Figure 30 and Figure 31 will tend to predict a lower discharge than is actually required to entrain/erode sediment of a given calibre.

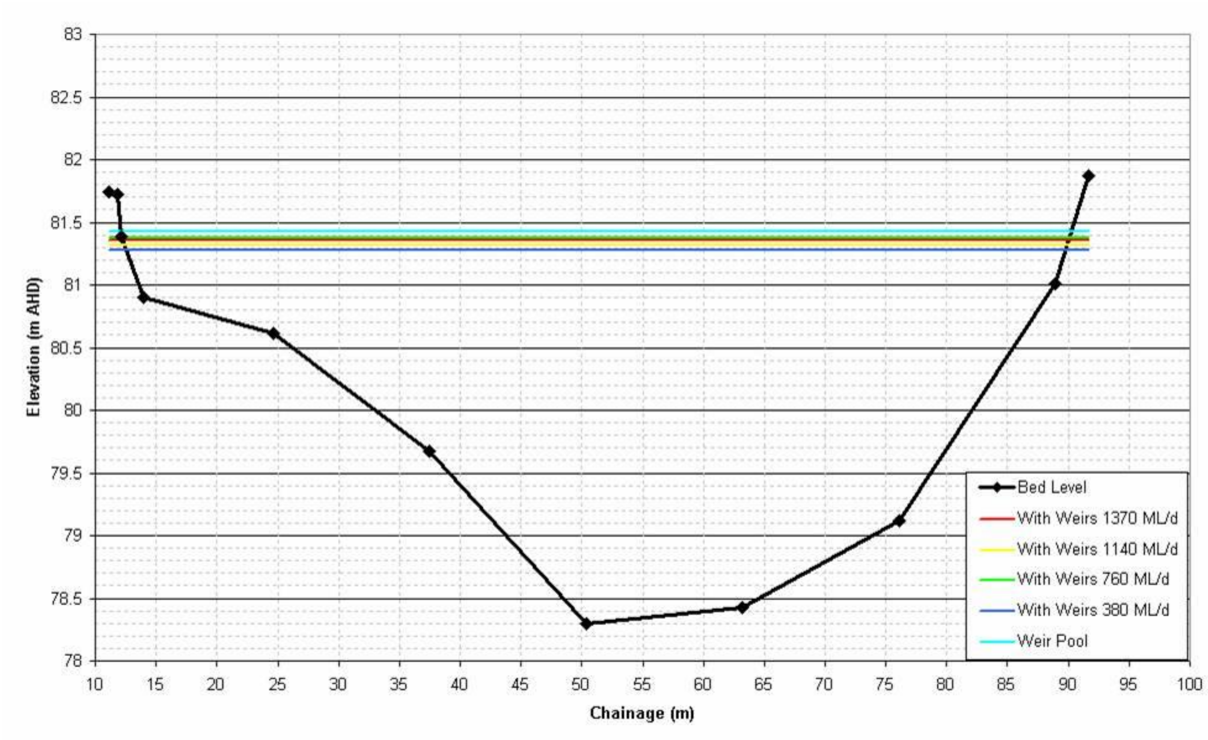

Figure 28. Gunbower Creek @ Cohuna Weir Pool (Site 4) showing flow depth variation with discharge under the current configuration (with weirs).

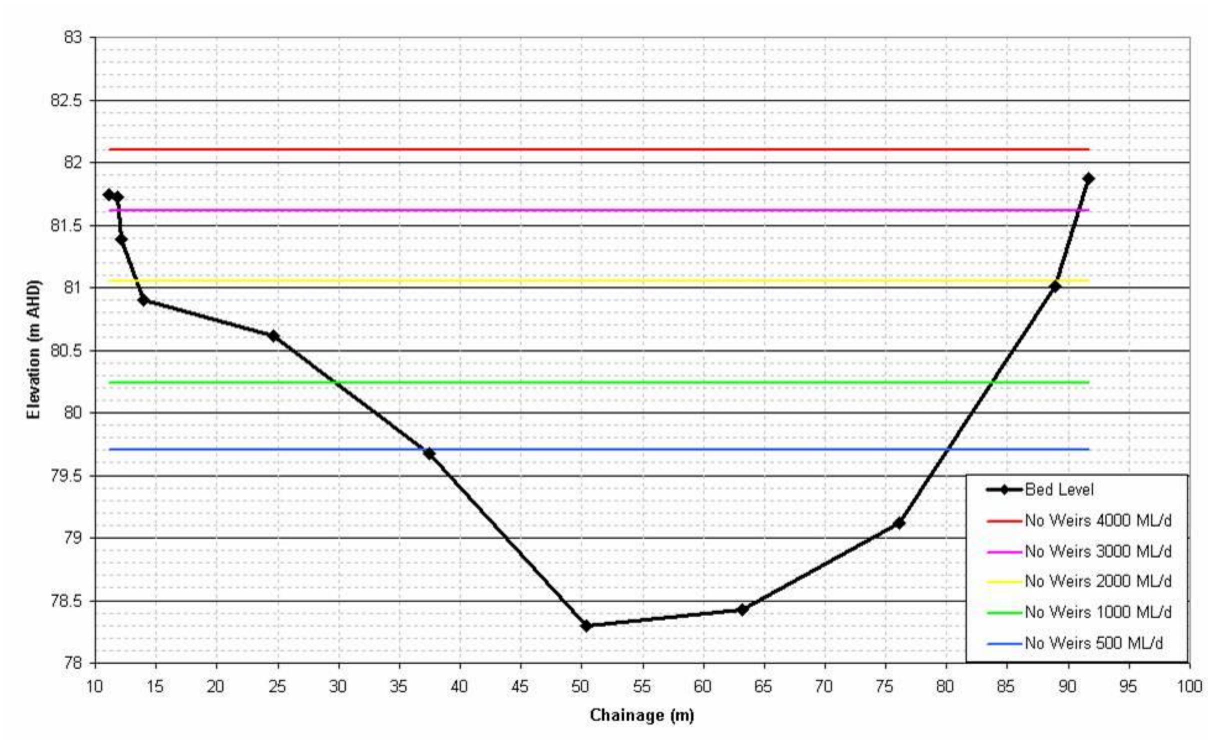

Figure 29. Gunbower Creek @ Cohuna Weir Pool (Site 4) showing flow depth variation with discharge under the configuration without weirs or irrigation effluents.

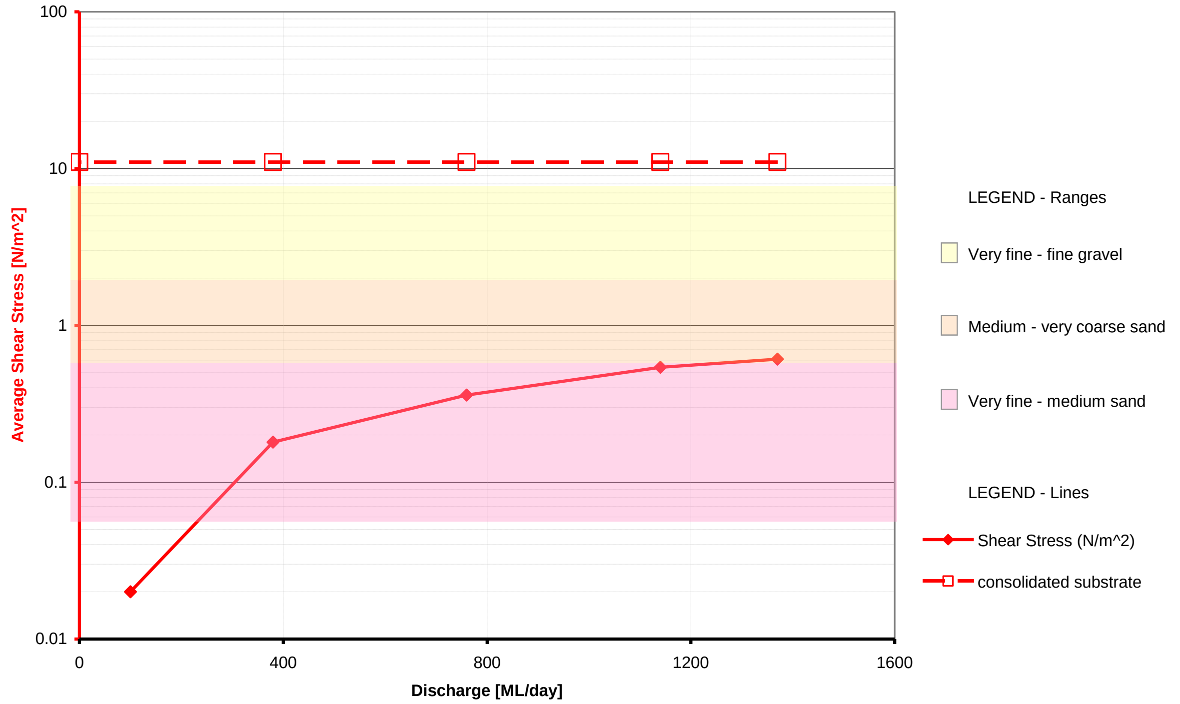

Figure 30. Gunbower Creek @ Cohuna Weir Pool (Site 4) showing the variation of shear stress (solid red line) with increasing discharge (simulation with weirs). A range of thresholds are shown either as a coloured range of values or as single-valued dashed lines. Note that shear stress is shown on a logarithmic scale.

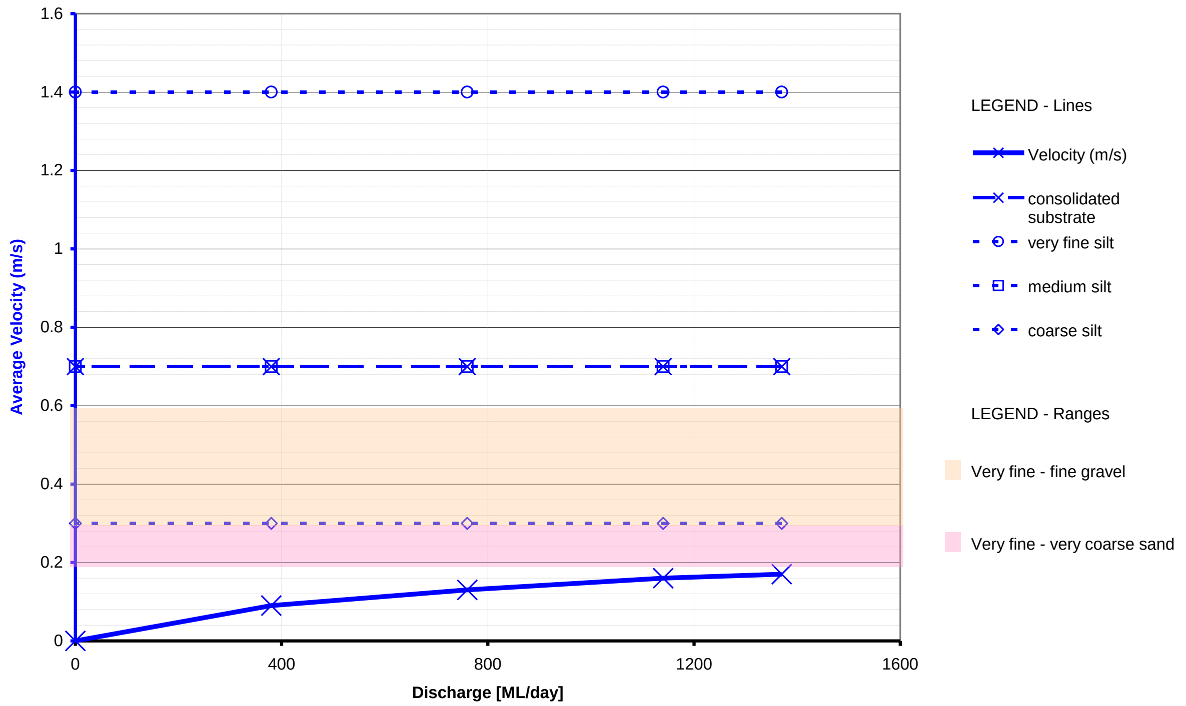

Figure 31. Gunbower Creek @ Cohuna Weir Pool (Site 4) showing the variation of velocity (solid blue line) with increasing discharge (simulation with weirs). A range of thresholds are shown either as a coloured range of values or as single-valued dashed lines.

7.5 Site 5: 'Tree Tops' Scout Camp

Figure 32. Location map for Site 5: Gunbower Creek @ 'Tree Tops' Scout Camp. The site at which field observations were made is shown by white circle; the location of adopted measured cross-section is indicated by the red dot within the white circle.

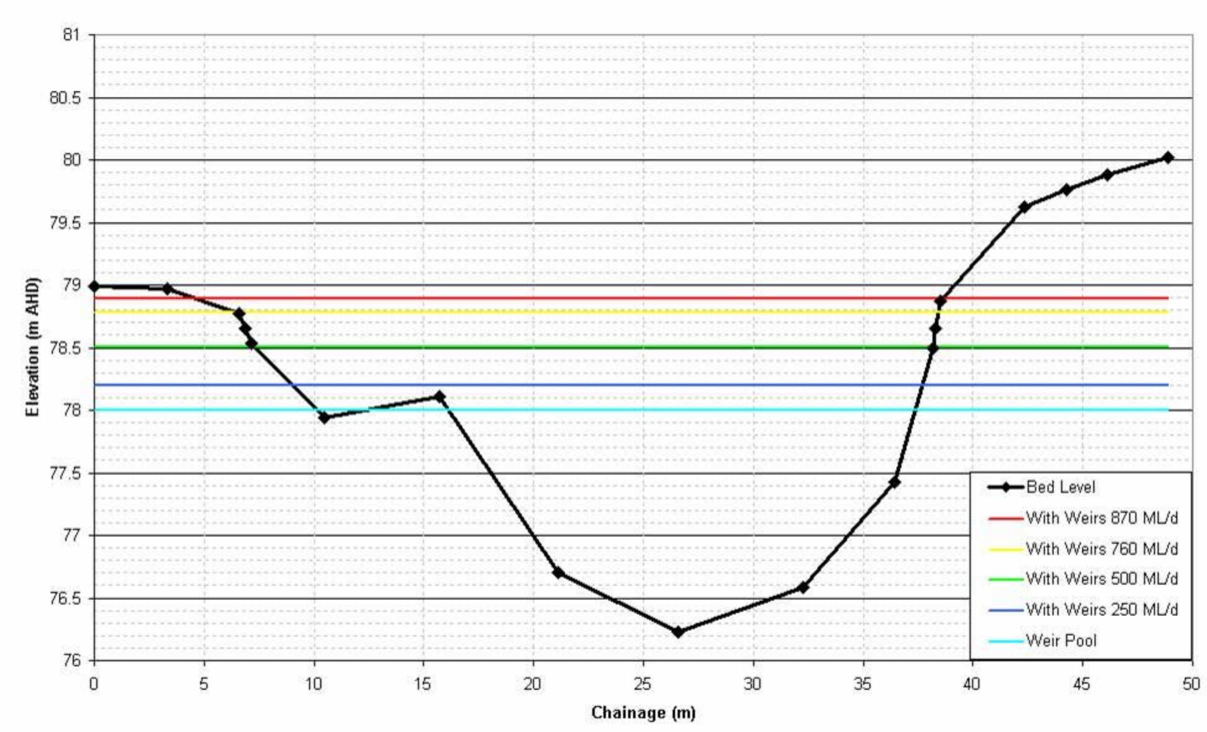

Figure 33 Gunbower Creek @ 'Tree Tops' Scout Camp (Site 5) showing flow depth variation with discharge under the current configuration (with weirs).

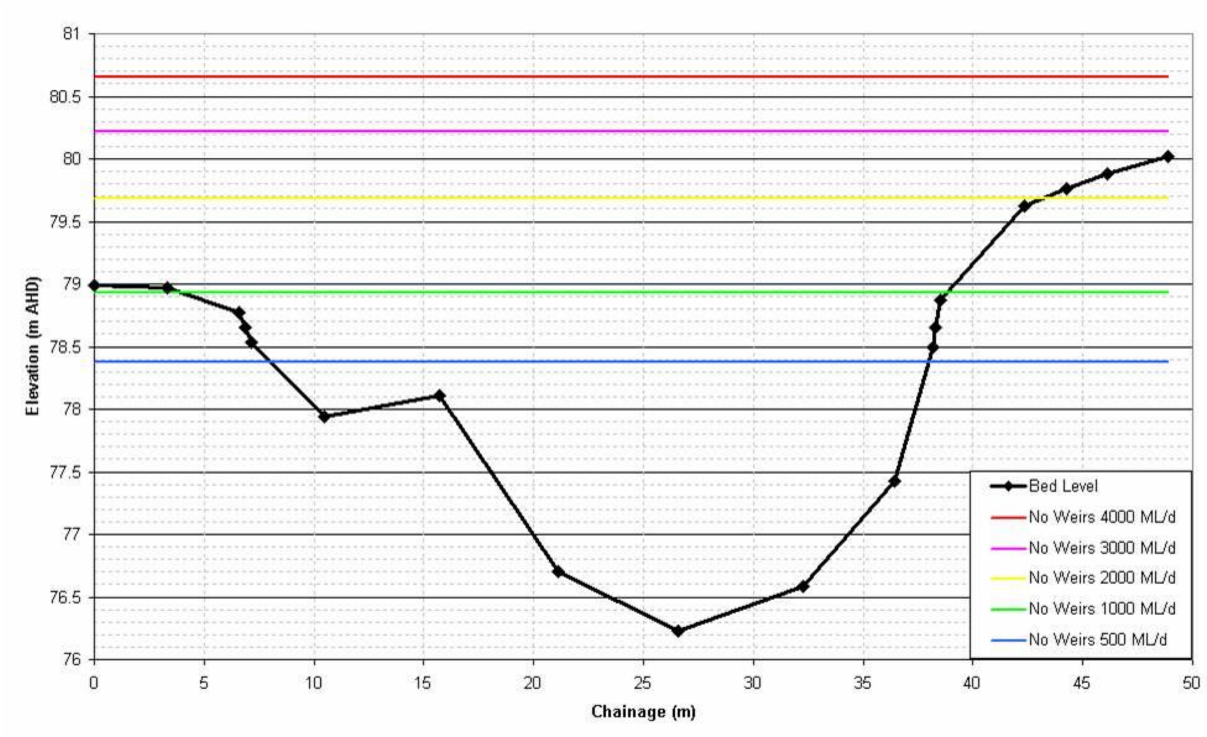

Figure 34 Gunbower Creek @ 'Tree Tops' Scout Camp (Site 5) showing flow depth variation with discharge under the configuration without weirs or irrigation effluents.

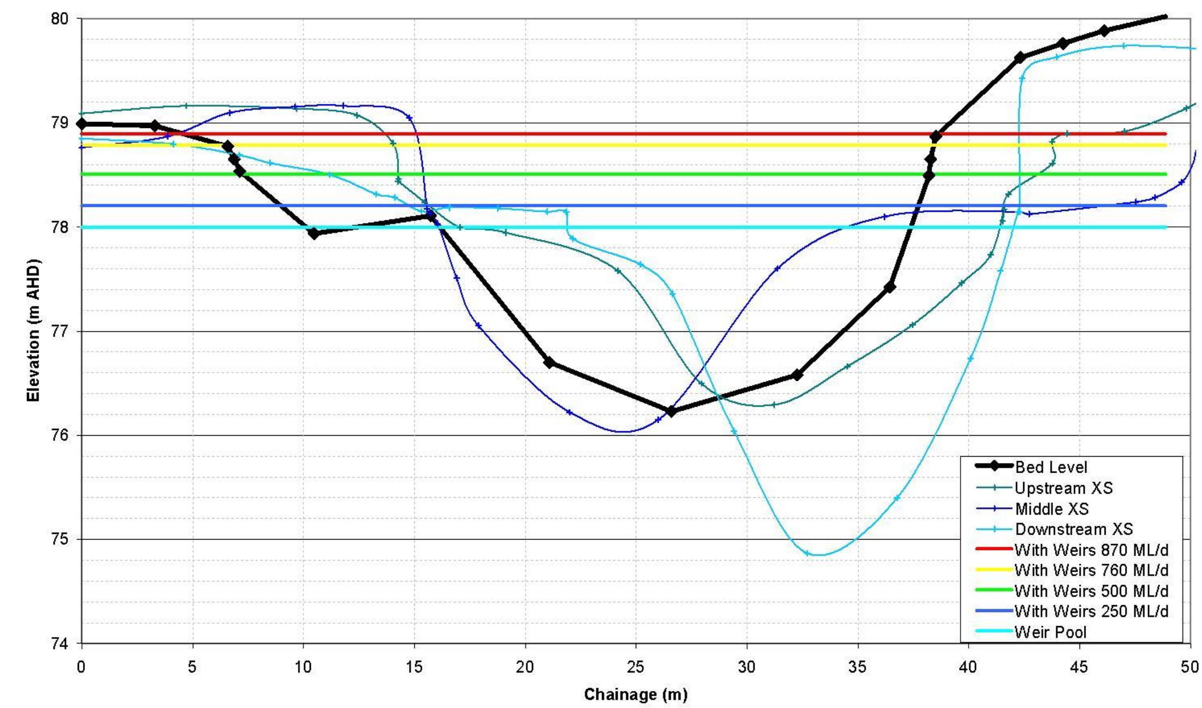

Figure 35 Gunbower Creek @ 'Tree Tops' Scout Camp (Site 5) showing the range of flow depth variation with discharge under the current configuration (with weirs). This plot shows the three additional cross-sections measured at the inspected location.

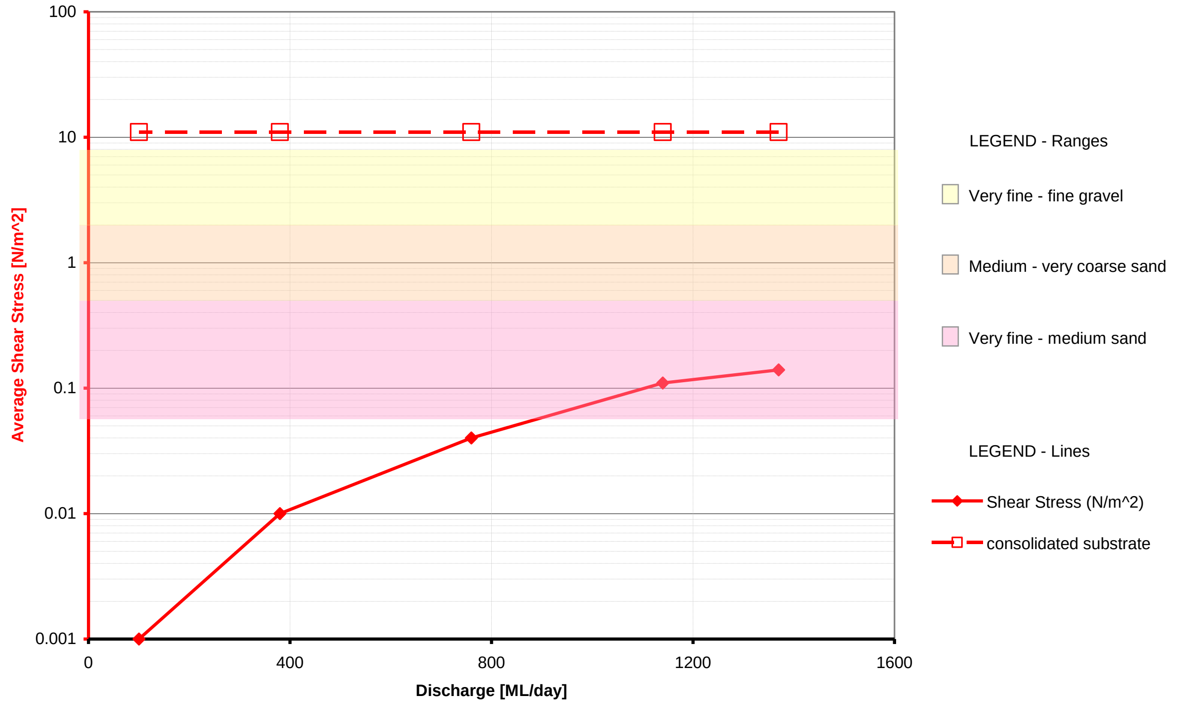

Figure 36. Gunbower Creek @ 'Tree Tops' Scout Camp (Site 5) showing the variation of shear stress (solid red line) with increasing discharge (simulation with weirs). A range of thresholds are shown either as a coloured range of values or as single-valued dashed lines. Note that shear stress is shown on a logarithmic scale.

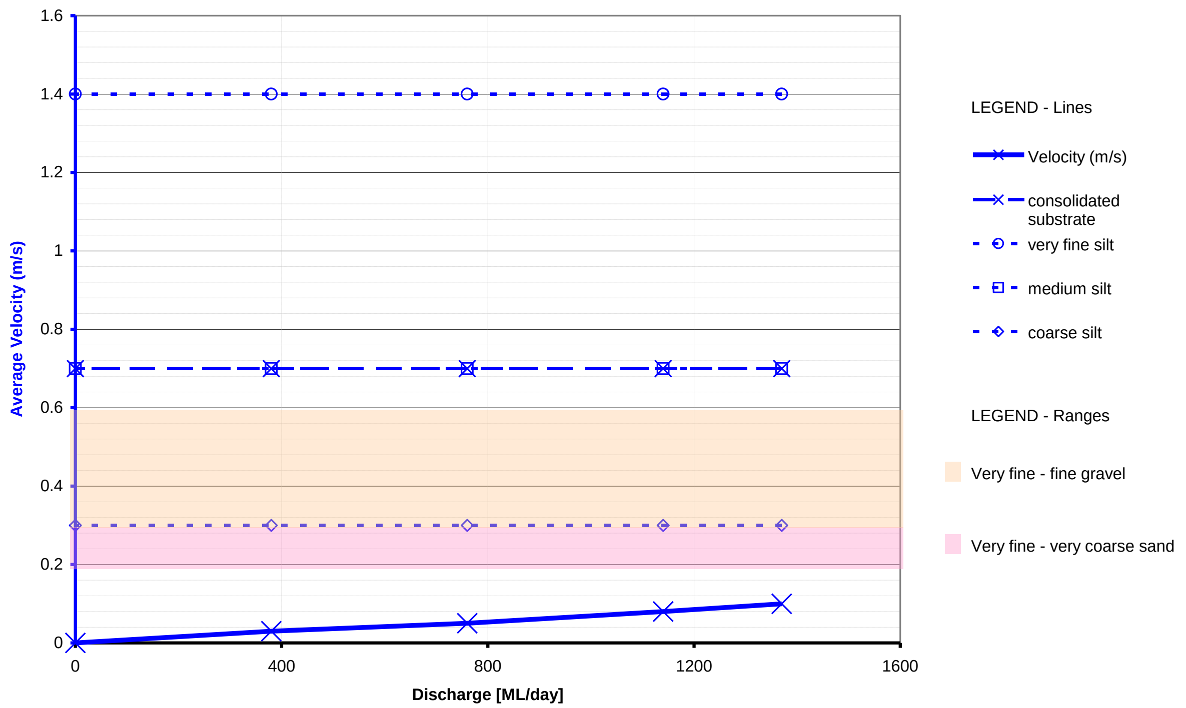

Figure 37. Gunbower Creek @ 'Tree Tops' Scout Camp (Site 5) showing the variation of velocity (solid blue line) with increasing discharge (simulation with weirs). A range of thresholds are shown either as a coloured range of values or as single-valued dashed lines.

7.6 Site 6: Safes Lagoon

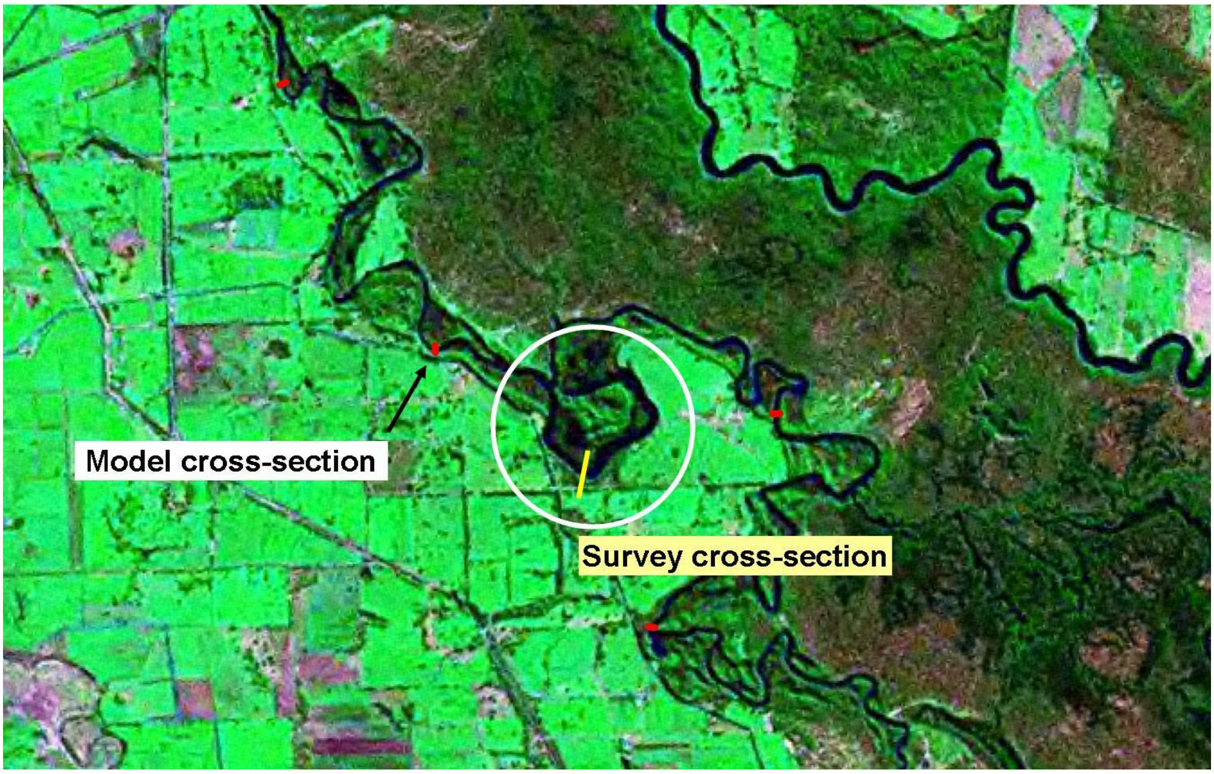

Figure 38. Location map for Site 6: Safes Lagoon. Field observations were made near the locations indicated by the yellow line which also indicates the location of the lagoon cross-section. The black arrow indicates the model cross-section at which water surface elevation results were taken and referred into the lagoon itself.

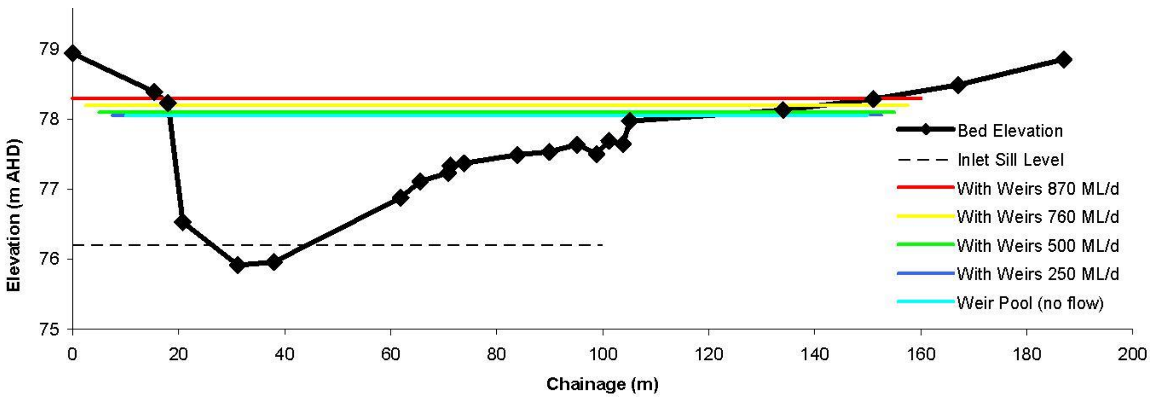

Figure 39. Safes Lagoon (Site 6) showing depth variation with discharge in Gunbower Creek under the current configuration (with weirs).

Note that Figure 39 indicates that Safes Lagoon has a very low inlet sill and that as a result disconnection from the creek only occurs under the present operating regime when Koondrook Weir is drawn down.

7.6.1 Evaporative Loss Results

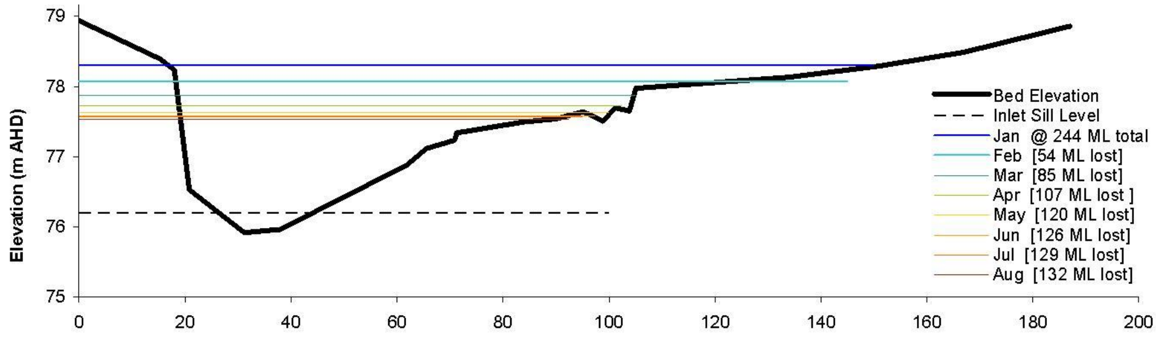

Figure 40. Safes Lagoon (Site 6) showing a first estimate of water level decrease in Safes Lagoon due to evaporation. This scenario starts with the lagoon full in January and decreasing until August. The approximate volume of water lost to evaporation is also reported in the legend.

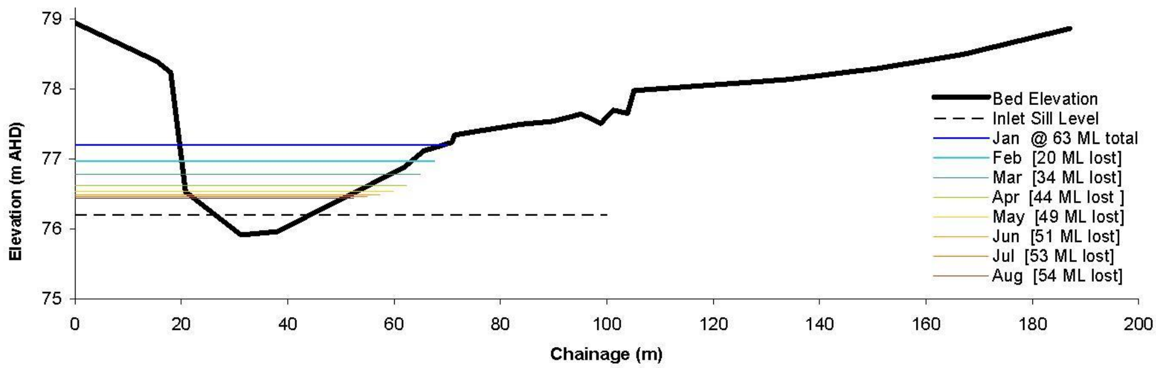

Figure 41. Safes Lagoon (Site 6) showing a first estimate of water level decrease in Safes Lagoon due to evaporation. This scenario starts with the lagoon emptied to the sill level at the start of January and decreasing until August. The approximate volume of water lost to evaporation is also reported in the legend.

7.7 Site 7: Downstream of Koondrook Weir

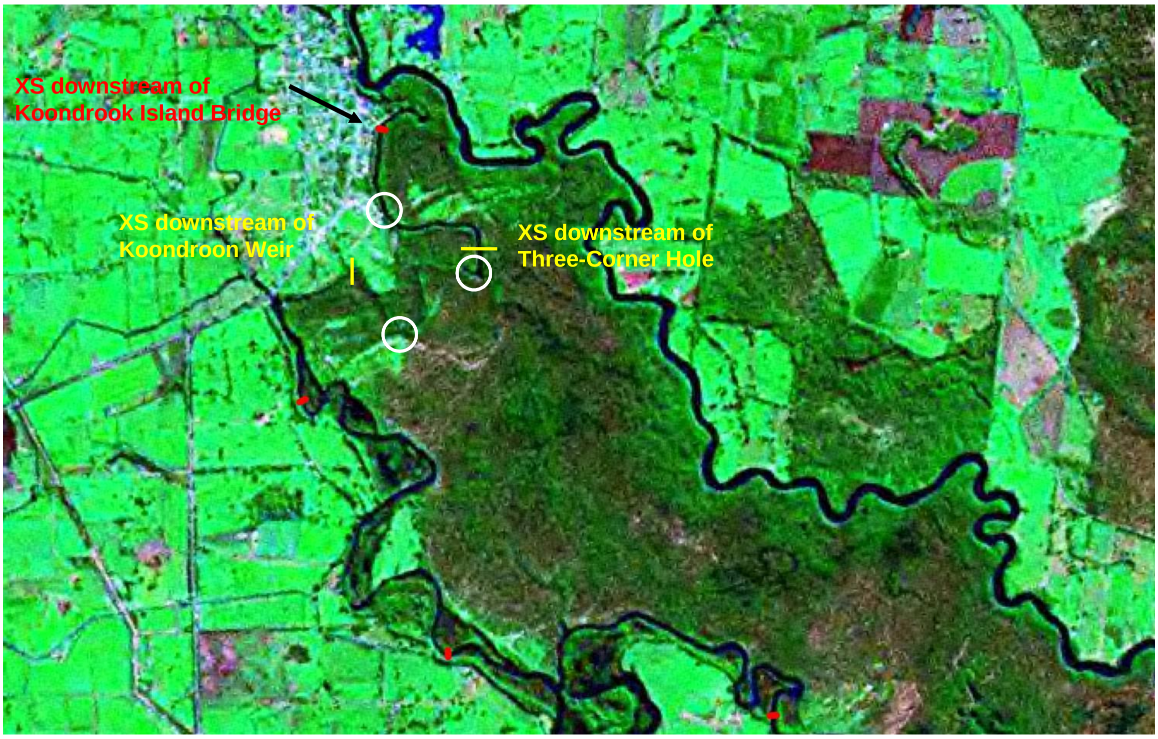

Figure 42. Location map for Site 7: Gunbower Creek downstream of Koondrook Weir. Field observations were made at locations indicated by the white circles. An existing cross section (black arrow with red text) and two new cross-sections (yellow text and yellow lines) were used to model and examine this reach.

The reach downstream of Koondrook Weir has two distinct sections. The first section from Koondrook Weir down to approximately Three Corner Hole (right-most white circle in Figure 42) has a relatively steep grade and smaller cross-sectional area. Downstream of this location the channel grade is very flat all the way to the junction with the River Murray and as a result this region is far more influenced by backwater from the Murray.

Charts are presented in this section for two different parts of the reach:

- the 'upper reach' (represented by XS downstream of Koondrook Weir); and
- the 'lower reach' (represented by two cross-sections: the cross-section downstream of Three-Corner Hole and the cross-section downstream of Koondrook Island Bridge).

The hydraulic results are also influenced by the water level in the River Murray. Two scenarios were run:

- first, tailwater level of the River Murray @ Barham = 72.5 mAHD; and
- second, tailwater level of the River Murray @ Barham = 74 mAHD.

These tailwater levels represent the general operating range of the River Murray at Barham.

Note that the hydraulic model results were prepared for the cross-section downstream of Gunbower Island Bridge. Thus, water surface elevations in the lower reach plus the shear stress and velocity data are accurate only at this cross-section.

7.7.1 Results for the Upper Reach

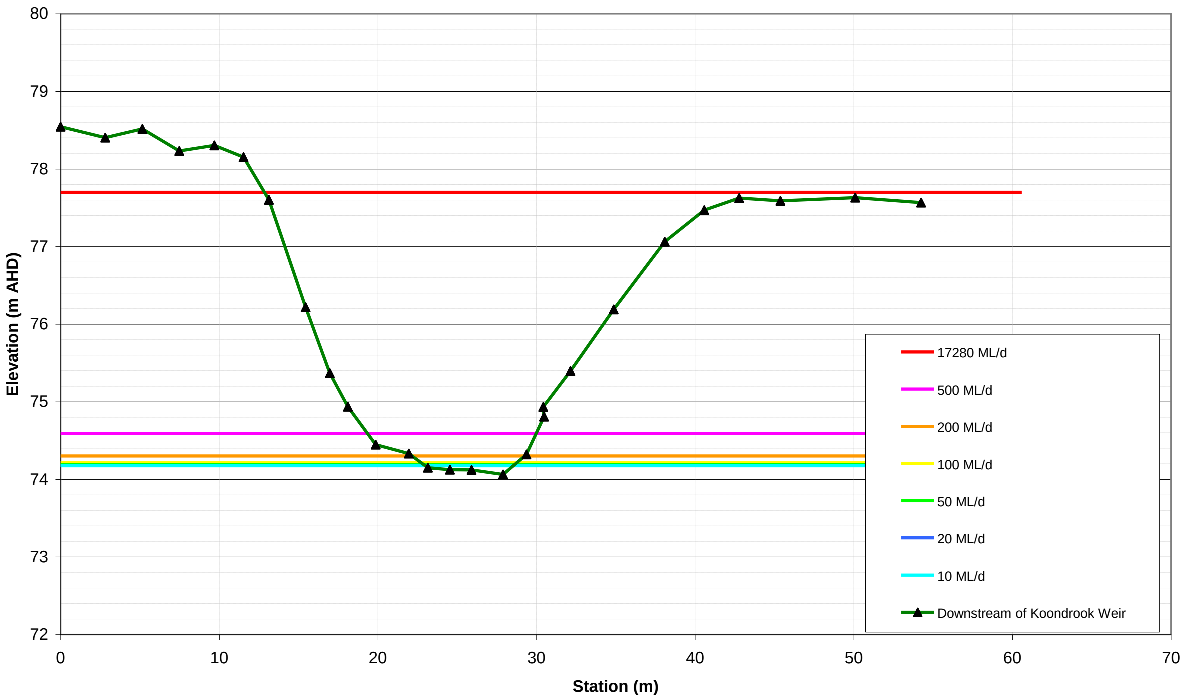

Figure 43 Upper reach of Gunbower Creek downstream of Koondrook Weir (Site 7) showing flow depth variation with discharge. The results are not significantly influenced by the River Murray @ Barham level (either 72.5 or 74 mAHD).

7.7.2 Results for the Lower Reach

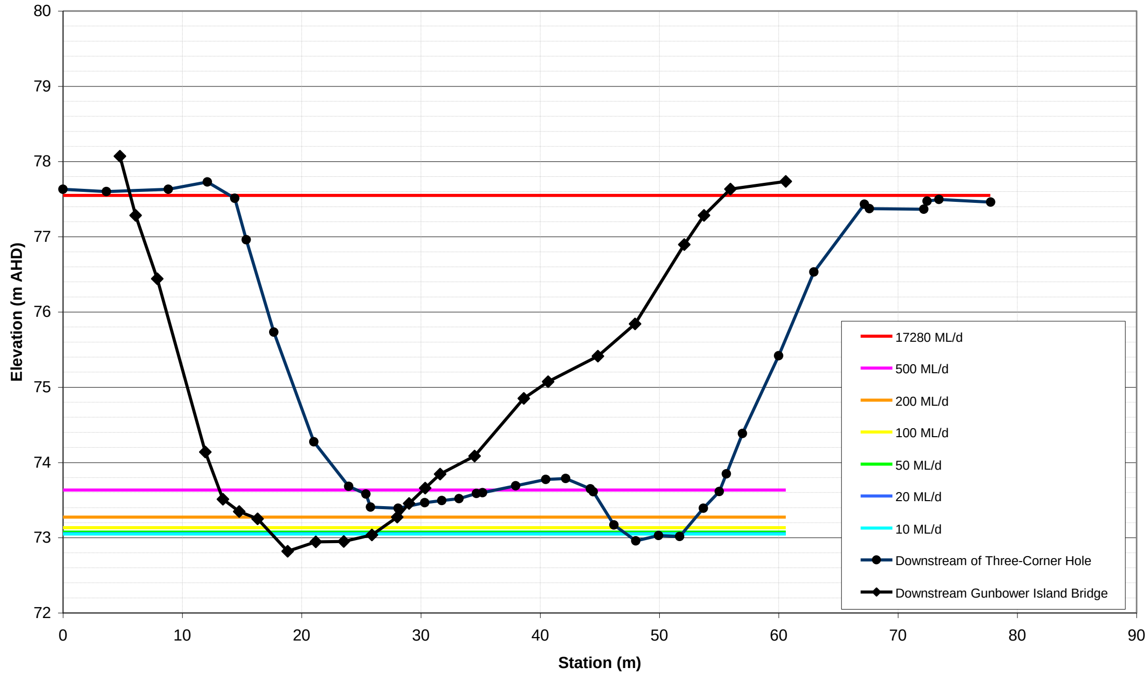

Figure 44 Lower reach of Gunbower Creek downstream of Koondrook Weir (Site 7) showing flow depth variation with discharge (River Murray @ Barham = 72.5 mAHD). Note: water surface elevations are plotted for the cross-section downstream of Koondrook Island Bridge, the cross-section downstream of Three-Corner Hole is shown for context.

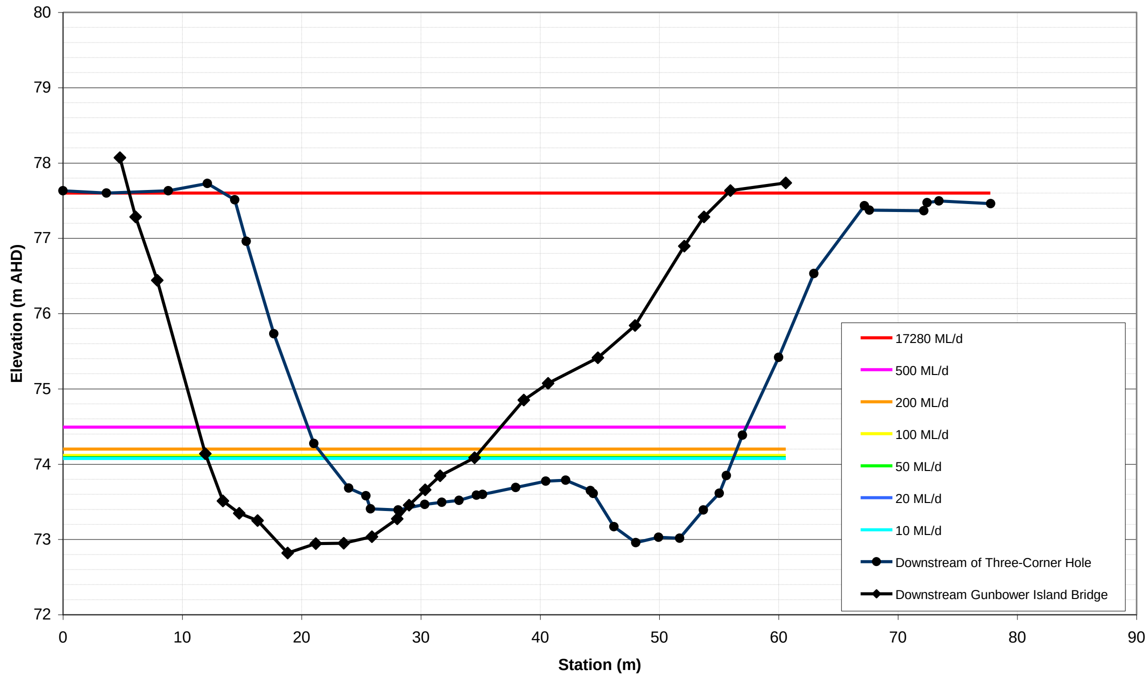

Figure 45 Lower reach of Gunbower Creek downstream of Koondrook Weir (Site 7) showing flow depth variation with discharge (River Murray tailwater 74 mAHD). Note: water surface elevations are plotted for the cross-section downstream of Koondrook Island Bridge, the cross-section downstream of Three-Corner Hole is shown for context.

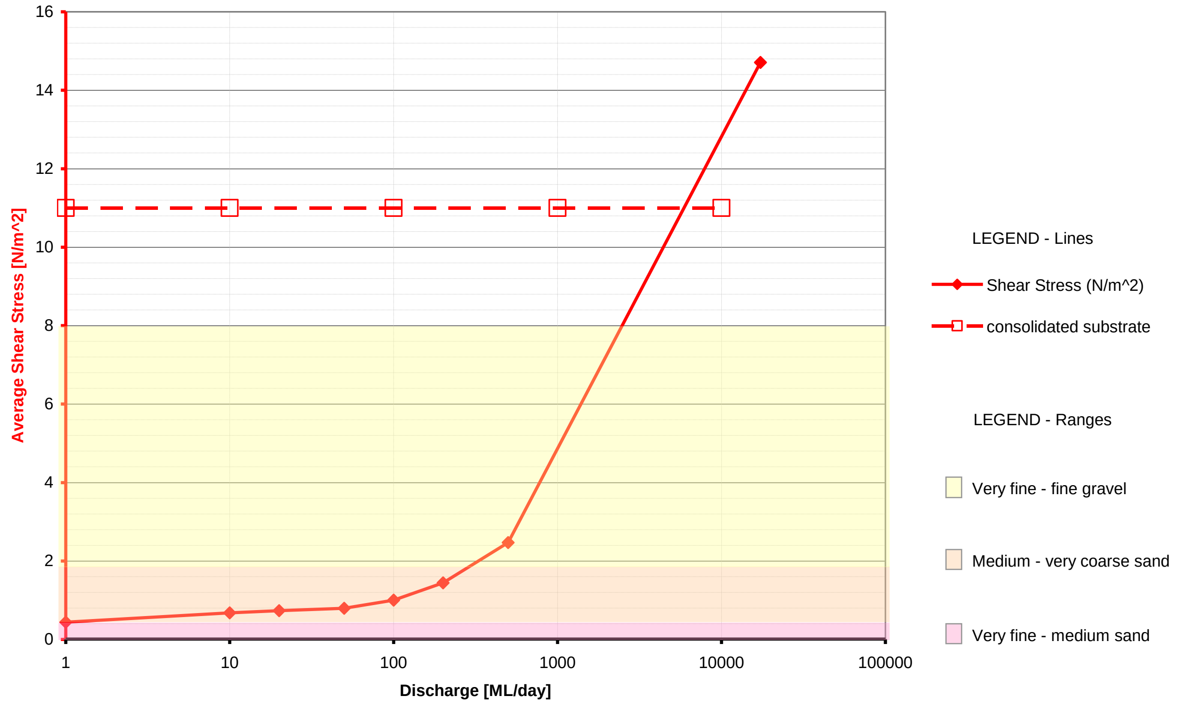

Figure 46. Gunbower Creek downstream of Gunbower Island Bridge (Site 7) showing the variation of shear stress (solid red line) with increasing discharge (simulation with weirs). A range of thresholds are shown either as a coloured range of values or as single-valued dashed lines. Note that shear stress is shown on a logarithmic scale.

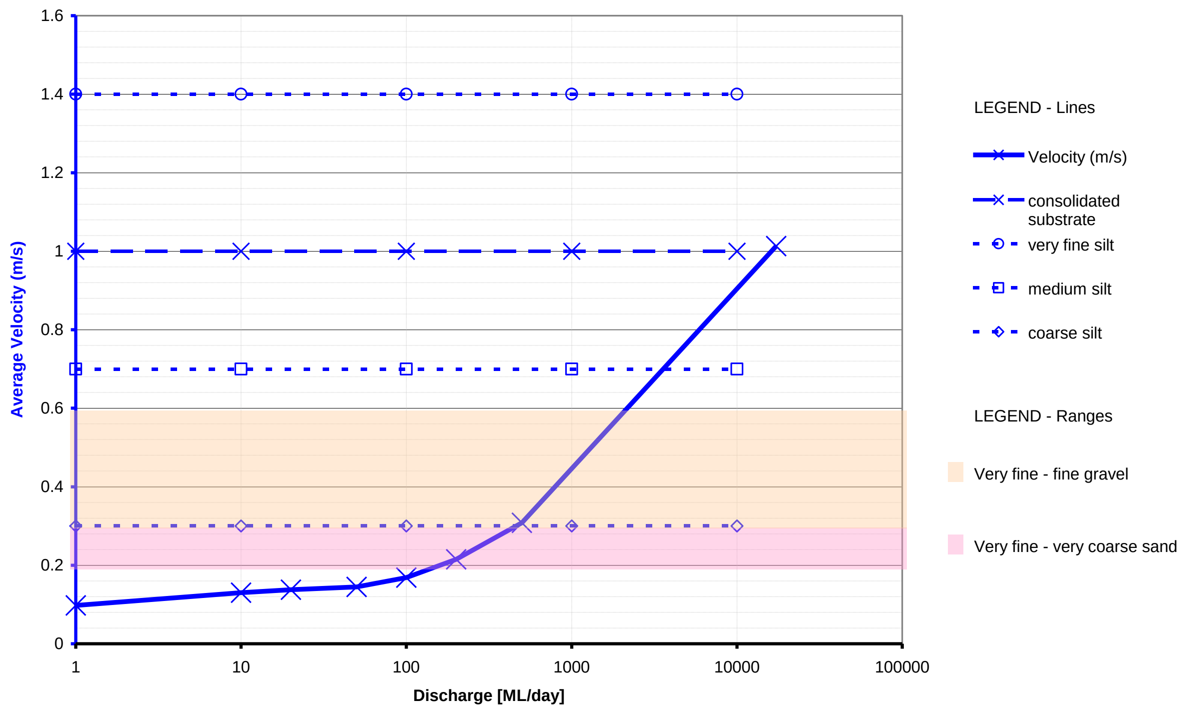

Figure 47. Gunbower Creek downstream of Gunbower Island Bridge (Site 7) showing the variation of velocity (solid blue line) with increasing discharge (simulation with weirs). A range of thresholds are shown either as a coloured range of values or as single-valued dashed lines.

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