Moodies Swamp flood regime determination

FINAL REPORT

- Final
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1. Background

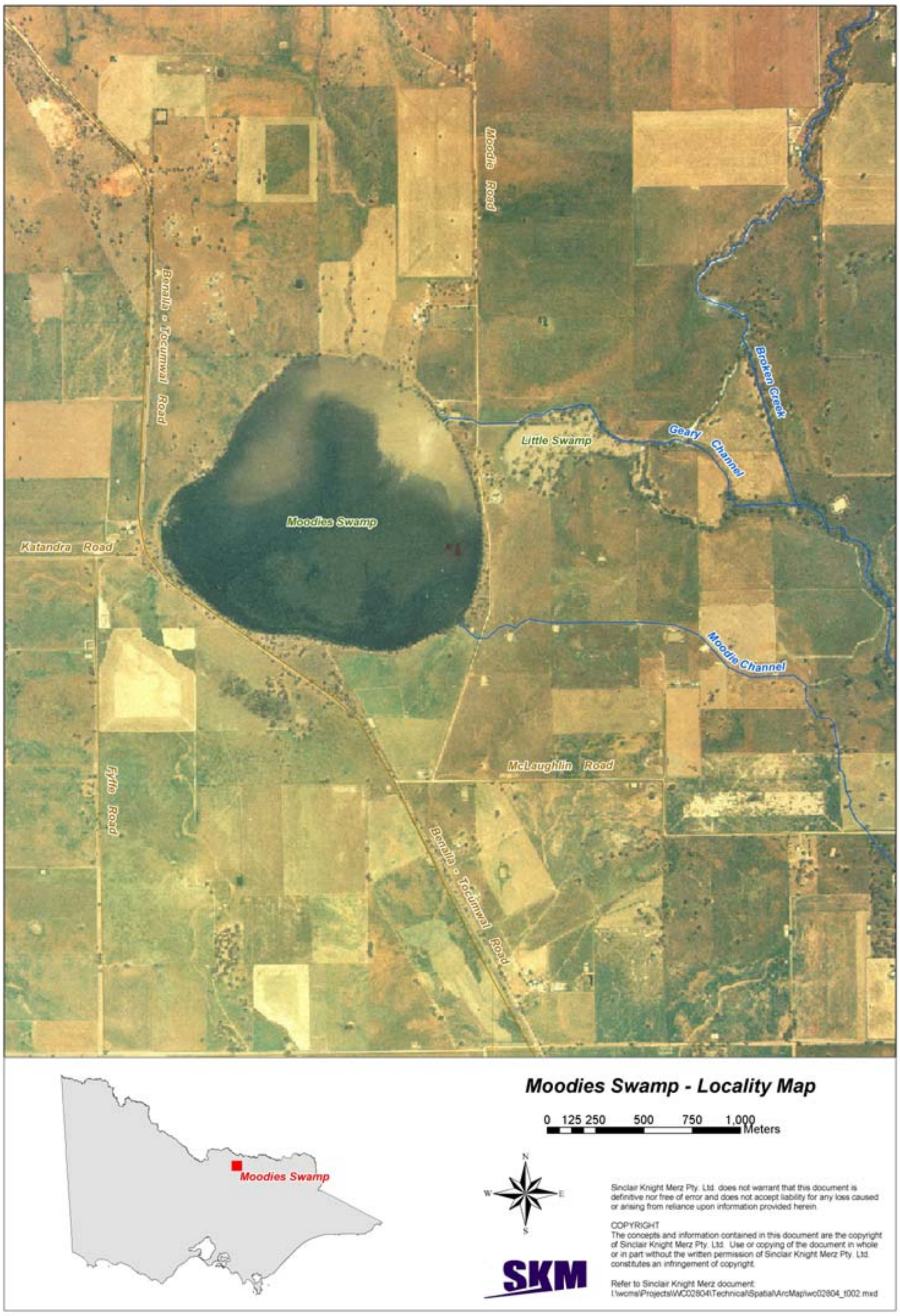
Moodies Swamp is a 180 ha (DCE undated), shallow freshwater marsh (DSE 2003) located between Moodies Road and the Benalla-Tocumwal Road approximately 40 km north of Benalla and 2 km north west of the locality Waggarandall (VicRoads Map 33, Reference E5) (Figure 1.1). The wetland is considered to be of national significance because of its size and the presence of a number of flora and fauna species threatened at the state and national levels (DEH 2007). The wetland lies adjacent to the Broken Creek and receives its water from the Broken Creek via the Geary and Moodie Channels and from local catchment runoff. As a result of water resource development within the region, the natural hydrology of the wetland has altered over time.

In recognition of the importance of the wetland and the potential threat that the perceived changed hydrology may pose on the values of Moodies Swamp a recent project was undertaken to provide water management recommendations for the wetland (SKM 2006a). The hydrology, hydrogeology, ecology, uses and values and threats to the wetland were described. Water regime objectives for the wetland were developed based on the ecological values and an appropriate water regime recommended. Water delivery options were recommended to deliver the recommended water regime. As a result of the current hydrology and morphology of Broken Creek it was recommended that a low weir (approximately 70-80 cm high) be constructed downstream of Geary Channel, the existing Geary Channel regulator be increased in width and works undertaken on the Geary channel to improve it's capacity to deliver water to Moodies Swamp. The low level weir and increased width of the Geary Channel regulator were aimed at increasing the amount of water that could be directed to Moodies Swamp for a given flow in Broken Creek (SKM 2006a).

The hydrology component of this previous study was based on the existing information at the time. Since that time, an environmental flows study for the Broken and Boosey Creeks has been undertaken (SKM 2007). The environmental flows study updated the hydrological information available for the system - improving the estimates of current and natural flows in the Broken Creek, and provided environmental flow recommendations for the Broken Creek.

The current project, to determine the flood regime requirement for Moodies Swamp, is required as a result of the modifications being undertaken in Broken Creek and the Geary Channel (as recommended in SKM 2006a), the updated flow series derived for the environmental flows study and the environmental flow recommendations for Broken Creek (in the event that they are adopted and the flow regime of Broken Creek is modified from current).

This project summarises the ecological information from the recent water management study (SKM 2006a) and the original management plan for the wetland (DCE undated). In particular, this document describes the wetlands flood dependent ecological values and describes the water regime considered necessary to support key ecological values. It includes updated hydraulic modelling of the current flood regime, describes the differences in the current regime compared to the recommended environmental flow regime for the Broken Creek and the ideal regime for the wetland, describes the likely impacts of current (and future) flows on ecological values in the wetland and identifies options for sourcing additional water, as occasionally required, to deliver a wetting regime that will maximise the likelihood of meeting ecological objectives.



- **Figure 1.1 Moodies Swamp location and features.**

2. Ecological values

The water regime dependant ecological values associated with Moodies Swamp have been taken from a recently completed report outlining water management recommendations for the wetland (SKM 2006a). The information contained in this document is a summary of that information and further background information associated with the ecological characteristics of the wetland can be found in that document.

All indigenous species found within the reserve are important given the decline in native flora and fauna since European settlement. However some species are considered significant at the regional level, rare or threatened and some are protected by legislation. Significant, rare or threatened and protected water regime dependant plant and animal species have been identified for Moodies Swamp (Table 2.1 and Table 2.2 respectively).

- **Table 2.1 Water regime dependant plant species (significant species only).**

Scientific name	Common name	FFG	VROTS	Regional	Comment/requirement
Alternanthera nodiflora	Common Joyweed		k		Floodplain (Walsh 1996)
Callitriche sonderi	Matted Starwort		k		Riverine floodplains or other areas subject to inundation (Jeanes 1999)
Digitaria divaricatissima	Umbrella Grass		v		Heavier soils prone to occasional flooding (Walsh 1994)
Eulalia aurea	Silky Browntop		r		Heavy alluvial soils of floodplains (Walsh 1994)
Poa fordeana	Forde Poa		k		Occasional on heavier soils prone to inundation (floodplains) (Walsh 1994)
Swainsona procumbens	Broughton Pea			Yes	Seasonally inundated clay soil depressions (Jeanes 1996)

Note: FFG – *Flora and Fauna Guarantee Act* 1988.
VROTS – Victorian rare or threatened species as determined by DSE (v – vulnerable, r – rare, k-poorly known but suspected to be rare or threatened).
Regional – considered regionally significant by Ryan (2002).

- **Table 2.2 Water regime dependant animal species (significant species only). Water requirement comments taken from Pizzey and Knight (1999). Species known to have bred at the wetland are indicated (#).**

Common name	Scientific name	CST	FFG	Treaty	Comment/requirement
Colonial nesting waterbirds					
Pied Cormorant	*Phalacrocorax varius*	LR			Large inland lake, stick nest in trees over water, breeds all seasons
Whiskered Tern	*Chlidonias hybridus*	LR			Vegetated and open wetlands, nests on floating vegetation or small island, breeds Sep-March
Sharp-tailed Sandpiper	*Calidris acuminata*			J, C	Wetlands, breeds in northern hemisphere
Latham's Snipe	*Gallinago hardwickii*	LR		J, C	Wet ground and shallow water with vegetation,

Common name	Scientific name	CST	FFG	Treaty	Comment/requirement
					breeds in Japan
Glossy Ibis	*Plegadis falcinellus*	LR		C	Well vegetated shallow wetlands, stick nest in trees, lignum, Cumbungi or reeds over water, breeds Oct-Dec
Royal Spoonbill #	*Platalea regia*	Vul			Well vegetated shallow wetlands, stick nest in trees, lignum, Cumbungi or reeds over water, breeds Sep-Nov
Little Egret	*Egretta garzetta*	End	L		Freshwater wetlands, stick nest over water in trees, sometimes far from water, breeds Oct-Feb
Intermediate Egret	*Ardea intermedia*	CEn	L		Freshwater wetlands, stick nest in association with riverine/woodland forest, breeds Nov-Jan
Great Egret	*Ardea alba*	Vul	L	J, C	Freshwater wetlands, stick nest over water in trees, breeds Nov-Feb
Nankeen Night Heron	*Nycticorax caledonicus*	LR			Wetlands, stick nest over water or in association with riverine/woodland forest, breeds Sep-Feb
Waterfowl and grebes					
Australasian Shoveler	*Anas rhynchotis*	Vul			Well vegetated larger wetlands, nest in grass on the ground or in vegetation near water or occasionally in a stump over water, breeds Aug-Nov
Freckled Duck	*Stictonetta naevosa*	End	L		Well vegetated larger wetlands, nest in lignum, tea tree or flood debris, breeds Sep-Dec
Hardhead	*Aythya australis*	Vul			Deep permanent wetlands and large open waters, nest in reeds, Cumbungi, lignum, shrubs or stumps, breeds Aug-Dec
Blue-billed Duck	*Oxyura australis*	End	L		Well vegetated larger wetlands and open waters, nests in Cumbungi, rush, lignum, tea tree over water or on the ground on an island, breeds Sep-March
Musk Duck	*Biziura lobata*	Vul			Well vegetated wetlands, nests in Cumbungi, rushes, grass on islands, under tea tree or tree hollows at water level, breeds Aug-Nov
Other					
Brolga #	*Grus rubicunda*	Vul	L		Shallow, well vegetated wetlands, nest constructed of wetland vegetation on small island, breeds July-March
Australasian Bittern	*Botaurus poiciloptilus*	End	L		Water and wetland vegetation, nest of trampled waterplants over water in reeds, breeds Sep-Dec
White-bellied Sea-Eagle	*Haliaeetus leucogaster*	Vul	L	C	Rivers and large wetlands and lakes, nests in trees near water, breeds June-Dec

Note: CST – Conservation status in Victoria as determined by DSE (CEn - critically endangered, End – endangered, Vul - vulnerable, LR - lower risk, near threatened).

FFG – *Flora and Fauna Guarantee Act* 1988.

Treaty – Species listed under the Japan-Australia Migratory Bird Agreement (J) or China-Australia Migratory Bird Agreement (C).

In addition to the significant species listed above, there are species present at the wetland which help to sustain the significant species and define the wetland and its ecology. Species present within the main wetland area when wet include Milfoil *Myriophyllum crispatum*, Marshwort *Nymphoides* sp., Bladderwort *Utricularia australis*, Swamp Lily *Ottelia ovalifolia* and Azolla *Azolla* sp. with Southern Cane Grass *Eragrostis infecunda* dominating (DCE undated). When dry, this zone consists of Cane Grass and pasture species such as bromes *Bromus* spp., dock *Rumex* sp., thistles (Family Asteraceae) and Wild Oat *Avena fatua* (*pers. obs*. of the authors). The wetland margins support a narrow band of vegetation including River Red Gum *Eucalyptus camaldulensis*, Grey Box *E. microcarpa*, Cane Grass, Tangled Lignum *Muehlenbeckia florulenta* and Spiny Flat-sedge *Cyperus gymnocaulis* (DCE undated). If a water regime is implemented to support the significant species this should in turn also sustain the associated flora and fauna species present.

The general consensus by the relevant agencies, and as stated in the proposed management plan (DCE undated), is to manage the wetland for Brolgas (*pers. comm.* R. Weber, DSE). The preferred conditions for Brolga breeding are the presence of extensive Cane Grass, shallow water and limited River Red Gum cover (Arnol *et al.* 1984, Herring undated thesis). Some River Red Gum cover may occur within the wetland as Brolgas have bred in wetlands with River Red Gum, however they largely require open water and significant emergent aquatic vegetation. Thus Cane Grass becomes a key water regime dependant plant, that if management appropriately, will support the significant ecological values in the wetland, specifically Brolga.

The objectives for the wetland stated in the proposed management plan (DCE undated) were based on the objectives of the Wetlands Conservation Program (WCP) and the Land Conservation Council (LCC) which set broad management guidelines for the Moodies Swamp Wildlife Reserve. The following LCC recommendations and WCP objectives were presented in the Moodies Swamp Wildlife Reserve proposed management plan (DCE undated):

> The LCC final recommendations for the Murray Valley Study Area recommended the following for the Moodies Swamp Wildlife Reserve:
>
> a) that it primarily be used for the conservation of native fauna habitat, particularly waterbirds, and
>
> b) that it be used for public recreation and education where this does not conflict with the primary aim.
>
> The relevant WCP objectives are:
>
> - That publicly owned wetlands are managed to fulfil Local, State, National and International obligations regarding conservation and management of plants and animals, set out in legislation, Government policy statements etc., and
> - Public appreciation of the many values of wetlands is encouraged and facilitated through education, scientific investigation and other means.

The management objectives for the wetland area of the reserve as proposed in the management plan (DCE undated) for the reserve are:

- To maintain the wetland as a Cane Grass dominated freshwater marsh, and
- To provide habitat for Brolga and other significant wildlife.

These are reflected in objectives from the recent water management study which recommended that Moodies Swamp be managed primarily for its conservation values, and in particular to support Brolga breeding (SKM 2006a). A secondary objective of duck hunting can be accommodated if it does not impact on the primary objective. This is further considered below in the discussion on water regime requirements.

3. Water regime requirements

3.1 Water regime requirements

The water regime requirements for the significant and important species present at Moodies Swamp have been identified (Table 3.1). The timing, frequency, duration and depth all relate to the flooding phase, although drying is also important in the water regime cycle of the wetland. The water regime requirements for primary objectives are based on the analysis undertaken in SKM (2006a), but they have been updated with respect to Brolga based on more recent discussion with Matt Herring at Charles Sturt University, who has been researching Brolga breeding and water regime requirements for the past few years.

The water regime objectives presented in Table 3.1 are consistent with the objectives for the reserve as stated in the proposed management plan (DCE undated), as outlined by the Wetlands Conservation Program and the Land Conservation Council and as recommended by SKM (2006a).

Table 3.1 Moodies Swamp water regime objectives (SKM 2006a, Matt Herring pers. com.).

Value	Water regime requirement for flooding			
	Timing	**Frequency**	**Duration**	**Depth**
Primary conservation objectives				
Significant flora ▪ All species identified	Unknown	Unknown	Unknown	Shallow
Significant fauna ▪ Colonial nesting waterbirds	Spring to early summer	Not important	6 to 7 months	Various
▪ Waterfowl and grebes	Spring to early summer	Not important	6 to 7 months	Various
▪ Brolga	Autumn to early summer	Not important	2-6 months	<50 cm (ideal range 20-30 cm)
▪ Australasian Bittern	Spring	Not important	Unknown	Not important
▪ White-bellied Sea Eagle	Winter	Not important	7 months	Not important
Important species ▪ Cane Grass	Winter to early summer	Ideally annual	3-6 months	30 to 50 cm
Secondary recreational objective				
Duck hunting	Autumn (hunting season from mid March to mid June)	Annual	4 months	30 to 50 cm (for waderbility)

The frequency of inundation for water birds is not critical because they are mobile species and will in habitat wetlands across broad geographical regions according to seasonal climatic patterns. However, providing a near annual inundation regime to support Cane Grass will ensure that conditions are suitable for a range of waterbirds on a near annual basis and will therefore support the primary objective of protecting existing conservation values in the wetland.

With respect to Brolga breeding, recent discussion with Matt Herring indicate that the required duration of inundation ranges between 2 and 6 months as opposed to the previously suggested 6-8 months and that while a depth <50 cm is recommended a depth range of 20-30 cm is generally sufficient. More specifically, once a wetland becomes inundated Brolga relatively quickly court, build a raised nest and lay eggs. Eggs hatch after around 30 days and within 48 hours of hatching the chicks routinely leave the nest and can move around the wetland. Hence, a relatively stable water level is required for the first 1-2 months, but once the chicks leave the nest the specific water level is not critical so some drawdown is acceptable. To facilitate nest building a suitable supply of nesting material in the form of macrophyte stems is required; such a supply is best built up by regular, annual inundation, infrequent inundation means that Brolga may have to delay nest building until sufficient macrophyte biomass is generated. In this case the duration of inundation needs to be extended. Maintaining an elevated water level to reduce the risk of predation by foxes appears unwarranted; foxes have been observed swimming several 100 m into wetlands (M Herring pers. com). Fox management, as part of a broader wetland management plan, is the preferred method of fox control rather than manipulation of water levels. Based on the above, the revised water regime requirements for Brolga are:

- Near annual inundation commencing in autumn or winter.
- Stable water depth of 20-30 cm for around 2 months.
- Slow drawdown that extends the duration of inundation for a further 2 to 3 months.

Of note is an inconsistency in the water regime requirements for conservation values versus duck hunting. From Table 3.1 the preferred regime to maintain conservation values is for near annual flooding for around six months over the winter to early summer period. However, to facilitate duck hunting inundation is required to coincide with the hunting season in autumn. Under natural conditions the winter/spring period would have been the typical time of inundation. Following flow regulation in the late 1880s and the introduction of irrigation diversion in 1960, summer and autumn inundation would have been a frequent occurrence due to inflows associated with channel operations to provide dam fills and from rain rejection flows in the Broken Creek. Such a regime would have facilitated duck hunting and is reflected in the classification of Moodies Swamp as a State Game Reserve in 1991. However, the construction of the Geary Regulator and the dredging of Broken Creek in 1993, followed by management actions to minimise the entry of summer and autumn rain rejection flows, has likely minimised autumn inundation of the wetland and reduced the wetland's value as a duck hunting venue over the last 10 to 15 years (SKM 2006a).

3.2 Water regime recommendation

It is recommended that Moodies Swamp be managed for its conservation values with an appropriate water regime that provides for near annual inundation of two to six months in the winter/spring period to a depth <50 cm with an ideal range of 20-30 cm. Artificial inundation in summer and early autumn should be avoided; however, if natural flood events occur during the summer/autumn period then the swamp should be allowed to fill. Under these circumstances opportunistic duck hunting could occur within the hunting season.

4. Existing and potential water regimes

4.1 Previous hydrodynamic modelling and water delivery options

The existing water regime of Moodies Swamp has been modelled based on the MIKE11 hydrodynamic model described in SKM (2006a). Briefly, the model simulates river systems based on cross sectional survey undertaken in Broken Creek, Moodies Swamp and the channels linking Broken Creek and Moodies Swamp (Geary and Moodies Channels). The model was established to allow a number of different flow scenarios to be run through the model in order to determine the division of flow between Broken Creek, Moodies Channel and Geary Channel, and ultimately the volume of water entering Moodies Swamp. In particular, the current flow regime in Broken Creek was modelled to determine what water delivery options could be implemented to deliver the recommended wetting and drying regime.

Based on modelling undertaken in SKM (2006a) it was recommended that works be undertaken on Broken Creek and Geary Channel to enable the establishment of a near annual flooding regime as described in Section 3.2. Specifically, it was recommended that a small weir (~70 cm high) be constructed in Broken Creek downstream of Geary Channel. The weir has the effect of raising the running level of Broken Creek to compensate for the previous lowering of the bed level in the vicinity of the Geary Channel offtake. Water can then be delivered to the swamp via a regulator on the Geary Channel. In addition to the weir, levee works are needed along sections of Geary Channel to increase channel capacity. Other works required are the installation of a 1.2 m wide regulator at the start of Geary Channel to replace the existing 40 cm wide regulator and for the first 400 m of the Geary Channel to be lowered to 128.4 mAHD; the same invert level as the regulator.

Ideally, water should be allowed to enter the swamp to coincide with natural high flows in the Broken Creek and with runoff in the local Moodies Swamp catchment. Raising the running level of the creek through construction of the weir should enable a portion of naturally occurring high flow events to be delivered to the swamp via Geary Channel and limits the need to secure a specific environmental water allocation.

A regulator is still required at the inlet to the Geary Channel to prevent unseasonal high flows entering the swamp associated with rain rejection flows downstream of Waggarandall Weir that may occur during the irrigation season. The recommended regulator operational regime to limit unseasonal flows from entering the wetland is the same as for the current Geary Channel regulator:

- The regulator will be open fully between May and November to allow natural flood events to enter Moodies Swamp.

- The regulator will be set to prevent base irrigation flows and rain rejections entering Moodies Swamp between December and April of the following year. Summer and autumn floods events should be allowed to enter the wetland if they naturally occur.

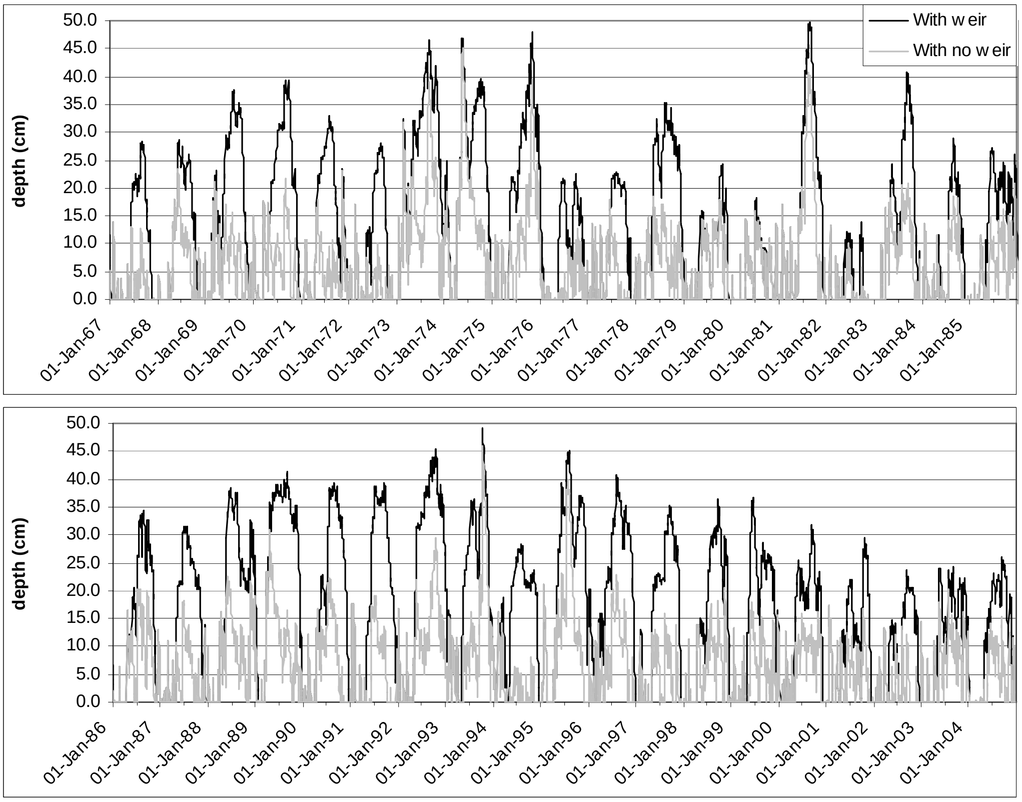
4.2 Revised hydrodynamic modelling

As part of the current project the previous hydrodynamic model has been revised and a number of additional flow scenarios modelled (natural, current and recommended Broken Creek environmental flow (SKM 2007)). The current flow regime with the current channel infrastructure in place and with the recommended weir and channel modifications has also been modelled. Appendix A provides specific details on the development of the flow scenarios and on the revision of the hydraulic model, including assumptions made for the current project.

4.2.1 Current water regime

Preliminary modelling showed that with the weir in place and the existing operating rules for the Geary Channel regulator applied (i.e. regulator opened from May to November and closed at other times) all flow in Broken Creek from May to November up to 10 ML/d was directed into Moodies Swamp. Under these circumstances low flows in Broken Creek downstream of Moodies Swamp were reduced, or even eliminated. In order to protect low flows in Broken Creek operating rules for the Geary Channel were revised. The revised rules now require flows in Broken Creek during May to November to be higher than 10 ML/d before a portion of the creek flow can be directed to Moodies Swamp. During summer (December to April), flow in Broken Creek needs to be in excess of 50 ML/d before flow can enter Moodies Swamp. This new set of rules protects low flows in Broken Creek downstream of Moodies Swamp and also prevents rain rejection flows downstream of Waggarandall Weir from entering the swamp during summer but still allows natural high flow events to enter the swamp.

Under the current flow regime with no weir in place and assuming effective application of the existing operating rules for the Geary Regulator (i.e. historical conditions), Moodies Swamp would have received water during winter in most years (Figure 4.1). With the weir in place and revised operating rules for the Geary Channel regulator applied, Moodies Swamp would also receive water in most years, however, the depth of inundation and duration of inundation would be greater. In effect, the weir in Broken Creek enables water to enter Moodies Swamp at much lower flows in Broken Creek; hence the duration of inundation is extended. Also, because the duration of inundation is extended the swamp can fill to a deeper level. With no weir in place the swamp typically fills to around 15-20 cm. With the weir in place the swamp typically fills to around 25-35 cm. This is demonstrated in Figure 4.2, which shows that an event that is at least 20 cm deep for 40 days occurs nearly every year (~95 events in 100 years) with the weir in place but only once every five years with no weir in place (~18 events in every 100 years). Events that are 20 cm deep and last for 150-180 days occur around once every three with the weir in place and would never occur with no weir in place (based on the current infrastructure arrangement and operating rules).



■ **Figure 4.1 Time series of modelled wetting and drying regime in Moodies Swamp under the current daily flow regime in Broken Creek with and without the recommended weir downstream of Geary Channel.**

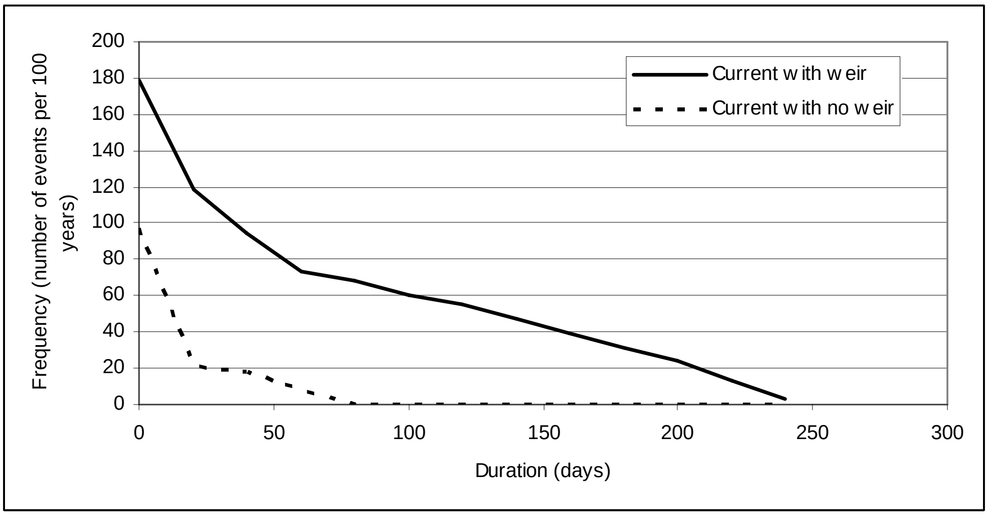


Figure 4.2 Frequency – duration plot for inundation events greater than 20 cm under the current flow regime in Broken Creek with and without the recommended weir downstream of Geary Channel.

4.2.2 Natural and future water regimes

In addition to the current regime, the natural flow regime and the potential future flow regime based on recent environmental flow recommendations for Broken Creek (SKM 2007) have also been modelled with the weir in place. The environmental flow recommendations for Broken Creek are based on the restoration of the natural flow regime; hence there is very little difference between the natural and future flow regime scenarios. Under the natural or future flow regime there is near annual wetting and drying although there is slight reduction in the duration and depth of inundation events in Moodies Swamp compared to current. This is because under the recommended environmental flow for Broken Creek actual creek flows will be less than current. The specific differences between current and future wetting and drying regimes are discussed in more detail in the next Section.

5. Water regime assessment against environmental objectives

5.1 Scenario comparison against water regime requirements

The frequency, timing, duration and depth of events under four scenarios (current with no weir, current with weir, natural with weir and Broken Creek flow recommendations with weir) are summarised in Table 5.1 and compared with the key water regime criteria determined in Section 3.1.

- **Table 5.1 Comparison of water regime scenarios for Moodies Swamp.**

Recommended regime						
Primary Objective		**Timing of inflow**	**Frequency and duration**			
Cane Grass		Winter - spring	Frequency: near annual Duration: 180 day (range 90-270 day) Depth: <50 cm (range 20-50 cm)			
Brolga		Autumn - spring	Frequency: not critical but near annual desirable for regional conservation objectives) Duration: 30-60 days at 20-30 cm deep plus a further 60-90 days 'wet' as swamp draws down			
Scenario regimes						
Flow Scenario	**Depth threshold**	**Timing of inflow**	**Number of events every ten years for a duration of:**			
			40 days	**60 days**	**120 days**	**180 days**
Current flow with no weir	**15 cm**	Any month, mostly May	3.2	2.6	0	0
	20 cm	Any month, mostly May	1.8	0	0	0
	30 cm	Not Jan or March, mostly July	0.3	0	0	0
Current flow with weir	**15 cm**	Any month, mostly May	10	8.7	7.4	4.7
	20 cm	Any month, mostly May	9.5	7.4	5.5	3.2
	30 cm	Not Jan or March, mostly July	5.5	4.7	1.3	0.5
Natural / future with weir*	**15 cm**	Any month, mostly April	7.6	5.8	3.7	1.6
	20 cm	Any month, mostly June and Aug	6	4.5	3.2	1.1
	30 cm	Not Jan, March or Nov, mostly July	3.4	2.6	0.5	0.3

* based on Broken Creek environmental flow recommendations (SKM 2007).

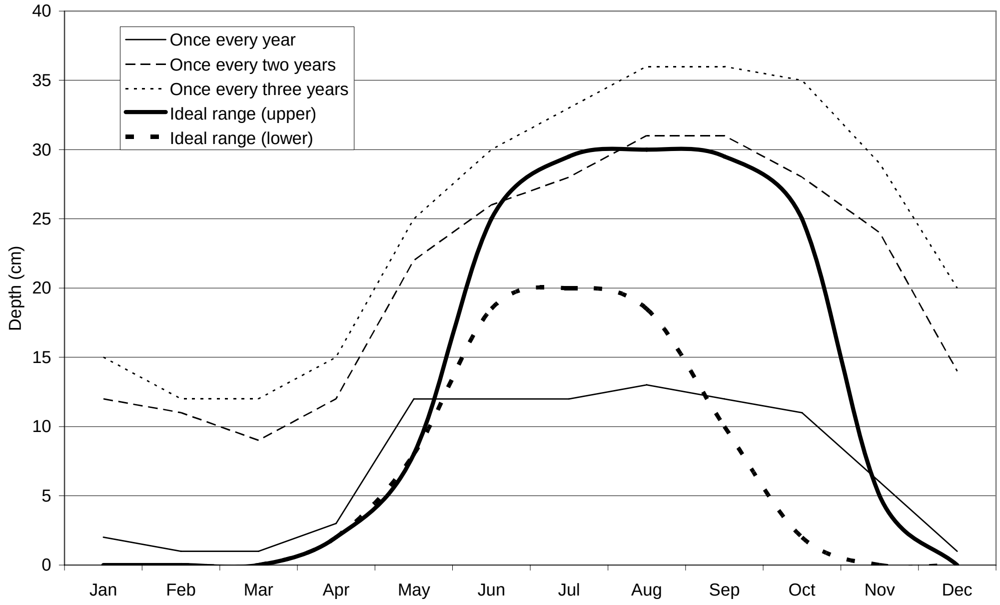
Under all flow scenarios with the recommended weir in place and revised operating rules in place an annual to near annual inundation event occurs in the wetland. The inundation event can occur in any month of the year but most events commence in late autumn or winter in response to increased winter flows in Broken Creek. Under the current water regime there is a slightly higher frequency of events in the wetland at all depths compared with the natural or future regime.

Under the current regime (with weir in place), an event that reaches 15 cm deep in the swamp for 40 to 60 days occurs nine to ten times every ten years (i.e. about once per year). Under the recommended environmental flow regime the frequency of this event would reduce to approximately six to eight times every ten years (i.e. slightly less than once per year). Under current conditions, an event that reaches 20 cm deep for 40-60 days occurs 7.4 to 9.5 times every ten years (i.e. slightly less than once per year, or around three times every four years). Under the environmental flow regime the frequency of this event reduces to around five events every ten years (i.e. every second year). Under the current regime, an event that reaches 30 cm deep for 40 to 60 days occurs approximately five times in every ten years (once every two years) and this reduces to approximately three times every ten years (once every three years) under the recommended environmental flow regime. For longer duration events (e.g. 120 and 180 days) the frequency of occurrence of an event for a given depth decreases across all scenarios. For example, under current conditions an event that reaches 20 cm for 120 days occurs every second year and for 180 days occurs every third year. Under the recommended environmental flow this reduces to once every three years and once every ten years for the 120 day or 180 day duration event respectively.

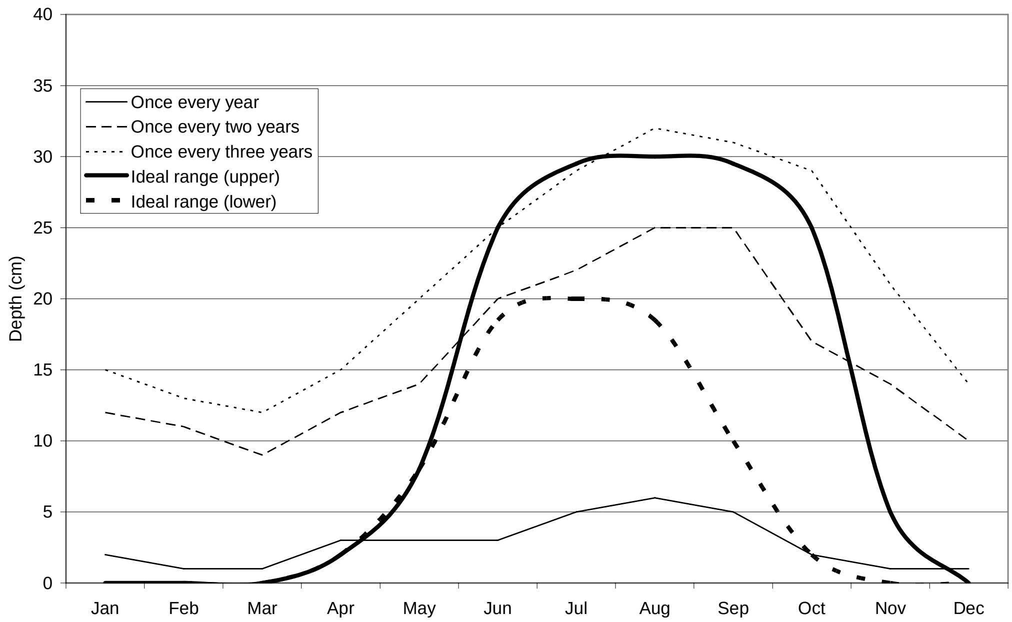
Cane Grass requires near annual inundation of 20 to 50 cm for three to nine months over winter and spring. Based on the discussion above, such an event occurs about every two to three years under the current flow regime and once every three to ten years under the environmental flow scenario.

Brolga require an inundation event of around 20 to 30 cm to last for 40 to 60 days before water levels recede. Based on the above discussion, such an event would occur around two times every three years under the current flow regime and slightly less frequently at around once every two years under the recommended environmental flow regime. For most events that reach 20 to 30 cm deep the drawdown duration extends the overall duration of the inundation event to an extent sufficient for Brolga chicks to successfully fledge (approximately 150-180 days in total).

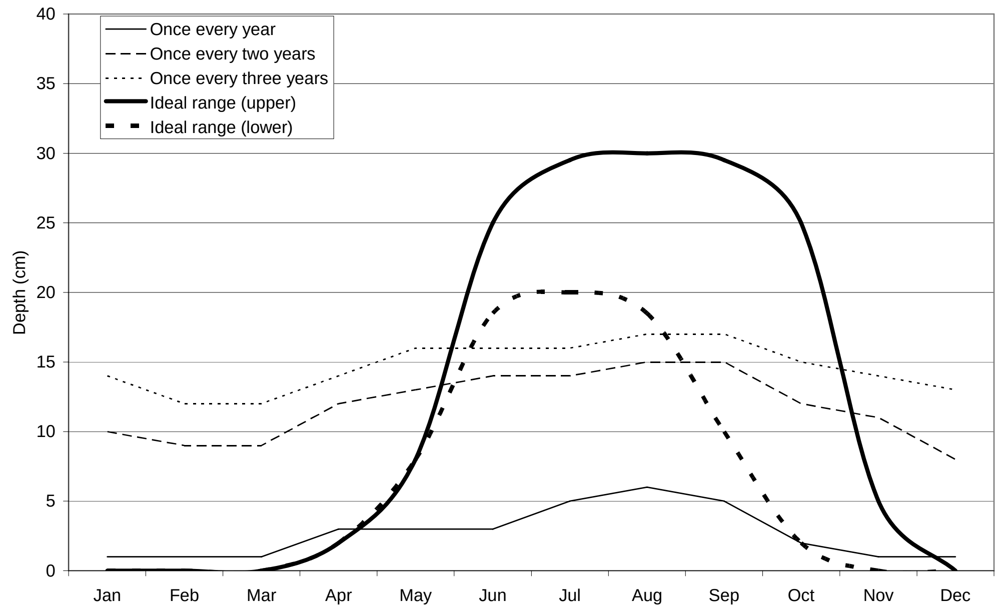
The above points are further demonstrated in the following plots that show with the weir in place the ideal inundation regime occurs once every once to two years under current conditions (Figure 5.1) and once every two to three years under the future environmental flow regime conditions (Figure 5.2). Without the weir in place the ideal inundation regime will occur less than once every three years under both the current and environmental flow recommendation scenarios (Figure 5.3 and Figure 5.4 respectively).



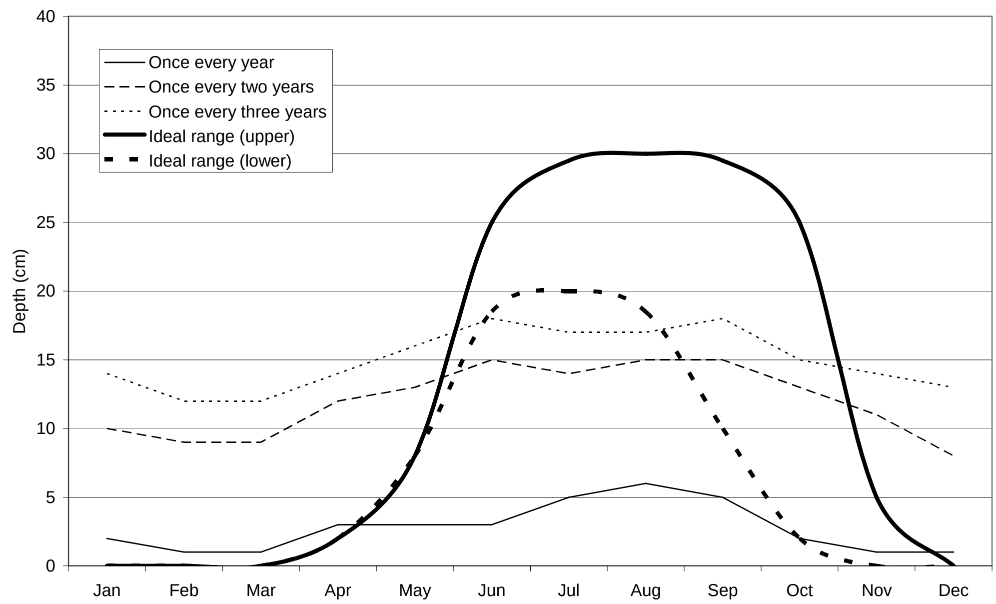
■ **Figure 5.1 Plot showing typical depth and duration for the 1 in 1, 1 in 2 and 1 in 3 year event under the current flow scenario with the weir in place. The thick black lines show the upper and lower limits for the ideal inundation event that would provide suitable conditions for Brolga breeding and Cane Grass subsistence.**



■ **Figure 5.2 Plot showing typical depth and duration for the 1 in 1, 1 in 2 and 1 in 3 year event under the environmental flow recommendation scenario with the weir in place. The thick black lines show the upper and lower limits for the ideal inundation event that would provide suitable conditions for Brolga breeding and Cane Grass subsistence.**



- **Figure 5.3 Plot showing typical depth and duration for the 1 in 1, 1 in 2 and 1 in 3 year event under the current flow scenario with no weir in place. The thick black lines show the upper and lower limits for the ideal inundation event that would provide suitable conditions for Brolga breeding and Cane Grass subsistence.**



- **Figure 5.4 Plot showing typical depth and duration for the 1 in 1, 1 in 2 and 1 in 3 year event under the environmental flow recommendations scenario with the no weir in place. The thick black lines show the upper and lower limits for the ideal inundation event that would provide suitable conditions for Brolga breeding and Cane Grass subsistence.**

5.2 Impact of current and future water regime on ecological values

There is no scenario which fulfils the ideal Cane Grass requirements for all water regime components, however, given Cane Grass is relatively robust and drought tolerant once established and adaptable to a varied regime, and given that it is already persistent in Moodies Swamp under the historical regime, it is likely to persist under the future regime. With respect to Brolga, suitable inundation events that fulfil breeding requirements occur under all scenarios, although not necessarily every year.

Despite a slight reduction in the frequency of suitable inundation events under the environmental flow scenario compared to current, the future regime, assuming it is successfully implemented (including construction of the weir in Broken Creek, modifications to Geary channel and delivery of the environmental flow recommendations to Broken Creek), provides a much more regular frequency of inundation compared to the historical regime. Under current conditions, inundation events, while modelled to occur every year, often did not because of ineffective application of existing operational rules for the Geary regulator, the impacts associated with previous dredging of the Broken Creek or interference in channel flows by landholders. This is somewhat demonstrated in the comparison with the current regime with and without the Broken Creek weir, which showed a significant reduction in the frequency of suitable inundation events compared to both current and the possible future regimes.

Although the requirements for Cane Grass and Brolga may be delivered through the current and future scenarios relatively frequently, there are some broader regional issues that need to be considered when deciding whether the current or future regime is acceptable without augmentation to deliver the ‘ideal regime’ every year.

Under optimal conditions, Cane Grass would be expected to maintain a dense, healthy and regenerating stand. Under sub-optimal conditions the stand may begin to die back and reproduction cease. There is some evidence to suggest that Moodies Swamp was once a Red Gum dominated wetland but clearing in the late 1800s and early 1900s and the probable introduction of a wetter water regime following the establishment of the local stock and domestic and irrigation water supply systems may have promoted colonisation by Cane Grass (SKM 2006a). It may be that the current density of Cane Grass is suppressing the re-establishment of River Red Gum and that if a drier water regime was introduced, that still enabled Cane Grass to persist but resulted in a less dense sward, then river Red Gum could re-establish. A consequence of this may be that the vegetation structure of the wetland becomes less suitable for Brolga, who prefer open wetland areas with limited tree cover, particularly in the central parts of the wetland (M herring pers. com.). Thus, the maintenance of a suitable wetland vegetation community structure for Brolga is important, even if Brolga do not breed every year. This means that it may be desirable to manipulate the water regime in such a way as to ensure that conditions for Cane Grass are optimal, this could involve extending the duration of some inundation events from time to time, particularly if there had been a sequence of short duration inundation events.

In addition to establishing a suitable water regime for Cane Grass and Brolga there are a range of other management activities that need to be considered, these include fox control and potential burning of the Cane Grass to create a mosaic of patches within the wetland area. Further discussion of these issues is beyond the current study but have been considered in SKM (2006a).

6. Opportunities to deliver shortfall water

The analysis of current and future water regimes suggests that a suitable wetting regime can be delivered to Moodies Swamp relatively frequently (every two to three years) to sustain Cane Grass and provide for regular Brolga breeding events, although longer duration events that may help optimise Cane Grass growth (i.e. inundation to around 20 cm for 180 or more days) are relatively infrequent (about once every five to ten years).

In order to optimise the water regime and provide occasionally more frequent longer duration inundation events it may be necessary from time to time to artificially manipulate the water level in the wetland by making additional diversions to the swamp to 'top up' an existing event and prolong it's duration. Water would need to be supplied from the Broken River via diversion to Broken Creek at Caseys Weir and then into the wetland via the Geary regulator.

We assessed the amount of water that may be required to provide 'top up' events from time to time based on a number of triggers events. Before water could be diverted to the wetland a natural event had to occur and the wetland had to reach a threshold level of 15, 20 or 30 cm from April onward. Top up water was then provided to maintain the wetland at the threshold level for 150 or 180 days. Applying the above rules meant the Broken Creek, the wetland and connecting channels would be already wet, thus minimising transition losses.

Table 6.1 presents the shortfall volumes. It should be noted that these volumes represent the maximum amount of water that could be required to extend the duration of inundation for a particular depth threshold. It is extremely unlikely that the wetland would need to be maintained at the deeper levels for the full duration (i.e. 30 cm deep for 180 days) to support Brolga breeding. However, it may be desirable from time to time, but not necessarily every year, to extend the duration of a 20 or 30 cm event to promote Cane Grass growth. Monitoring of the wetland should take place and top ups only provided if there has been a prolonged sequence of short duration events that appear to have resulted in reduced vigour and density of Cane Grass or if Brolga are observed breeding and the rate of water level draw down is deemed to threaten breeding success (for example, if eggs are laid but a stable water level is not maintained during the incubation period).

From Table 6.1 it can be seen that average amount of water required in any one year is relatively small (~50 ML to extend a 15 cm deep event to 150 days and up to ~200ML to extend a deeper and longer duration event). In addition, top up diversions are not required in every year.

Table 6.1 Total volume of water (ML) required in each modelled year to maintain the wetland at the specified depth threshold (15, 20 or 30 cm) for 150 or 180 days. N/A indicates that the wetland did not receive a natural inundation in that year so the initial filling trigger was not met, 0 indicates that the wetland filled but remained above the trigger for the specified duration

Modelled Year	150 DAYS			180 DAYS		
	15 cm	20 cm	30 cm	15 cm	20 cm	30 cm
1968	30.7	87.0	205.3	48.0	96.0	219.3
1969	47.1	98.6	N/A	47.1	102.6	N/A
1970	46.4	83.7	245.4	46.4	83.7	257.4
1971	69.1	N/A	N/A	69.1	N/A	N/A
1972	N/A	N/A	N/A	N/A	N/A	N/A
1973	33.1	70.8	25.0	33.1	70.8	25.0
1974	43.0	0.0	88.5	43.0	0.0	88.5
1975	0.0	70.3	218.2	45.5	N/A	237.2
1976	N/A	N/A	N/A	N/A	95.4	N/A
1977	109.8	148.1	N/A	139.8	178.1	N/A
1978	18.4	37.5	N/A	60.7	80.9	N/A
1979	105.9	136.5	213.5	135.9	166.5	230.5
1980	66.6	107.3	291.4	74.6	126.3	311.4
1981	47.6	82.0	226.5	72.8	104.9	252.5
1982	N/A	N/A	N/A	N/A	N/A	N/A
1983	18.7	0.0	153.8	18.7	0.0	195.9
1984	108.3	144.0	N/A	134.3	170.0	N/A
1985	42.7	87.4	N/A	42.7	116.4	236.4
1986	62.9	90.7	215.4	62.9	98.7	N/A
1987	97.0	113.4	N/A	102.0	121.4	N/A
1988	51.9	70.2	208.6	51.9	85.8	210.0
1989	0.0	30.3	34.4	0.0	30.3	90.6
1990	20.8	55.3	225.3	20.8	55.3	250.3
1991	53.9	93.5	238.6	83.9	123.5	254.6
1992	0.0	31.4	137.9	0.0	31.4	137.9
1993	37.6	84.7	214.6	47.7	90.7	214.6
1994	N/A	N/A	N/A	N/A	N/A	N/A
1995	0.0	64.2	196.8	40.5	77.3	196.8
1996	36.9	79.3	205.9	63.0	103.3	226.9
1997	100.9	139.5	N/A	121.9	159.5	N/A
1998	42.6	94.2	N/A	42.6	113.2	N/A
1999	47.7	84.9	N/A	55.7	92.9	N/A
2000	39.1	77.2	N/A	55.9	101.0	N/A
2001	N/A	N/A	N/A	N/A	N/A	N/A
2002	N/A	N/A	N/A	N/A	N/A	N/A
2003	38.3	79.4	N/A	47.5	92.6	N/A
2004	58.9	N/A	N/A	65.9	N/A	N/A
AVERAGE	**47.6**	**80.7**	**185.8**	**60.4**	**95.5**	**202.0**

The small volumes of water required and the relative infrequency with which it would ultimately be required means that securing a specific environmental water allocation for Moodies Swamp is probably unwarranted. In particular, if the environmental water requirements were required to be met by release from storage (or by utilising river flows that would otherwise be allocated for irrigation), a water entitlement from the Broken system would need to be purchased.

Based on the small volumes, it is likely that the environmental water requirements for the wetland can be met by diverting unregulated flow in the Broken River at Casey's Weir which would not be otherwise used by irrigators. Under this circumstance there would be no need to seek a specific allocation in storage and there would be no impact on Broken River reliability of supply to irrigators, although there may be a very small impact on River Murray reliability of supply. In this case the issue of supplying environmental water would largely be a trade off between environmental benefits of that water which would continue to flow down the Lower Broken, Lower Goulburn and the Murray Rivers versus the environmental benefits of supply to Moodies Swamp. In the context of the volumes in question, an occasional reduction in unregulated flow in Broken River up to 200 ML per year (<15 ML/d) under the worst case scenario is unlikely to have a measurable impact on river health downstream of Casey’s Weir but could have a significant benefit for Moodies Swamp.

7. Summary

The primary ecological objectives for Moodies Swamp are maintenance of Cane Grass and support for Brolga breeding. Revised hydraulic modelling of recommended water management options for Moodies Swamp (a new weir on Broken Creek downstream of Geary Channel and upgrades to Geary regulator and the channel itself), and an assessment of the implications of the recommended environmental flows for Broken Creek on the water regime for the wetland show that a near annual inundation event (once every two to three years) is likely to occur of a suitable depth and duration to support the primary objectives.

In some years it may be necessary to artificially extend the duration of an inundation event in order to ensure the success of a particular Brolga breeding event or to provide optimal growth conditions for Cane Grass, for example following a sequence of dry years. However, the volumes of water required are very small and would best be sourced from unregulated flows in the Broken River. Diverting a small volume of unregulated Broken River flows to Broken Creek and then into Moodies Swamp would not impact on the reliability of supply to irrigators in the Broken system and would not measurably impact on downstream river health conditions in the Broken, Goulburn or Murray Rivers.

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Appendix A Water balance modelling

A.1 Development of daily flow time series

The following steps and assumptions were made to derive a daily time-series of water depth in Moodies Swamp for the period 1/12/1966 – 31/12/2004:

A daily time-series of flow in the Broken Creek at the Geary Channel offtake (inlet to Moodies Swamp) was derived for natural, environmental flow (e-flow) and current conditions. The approach and assumptions made to derive these time-series are described in detail in SKM (2006b) and summarised below. Flow gauges and environmental flow site locations referred to in the following discussion are shown in (Figure 8.1).

A.1.1 Natural and e-flow rec time series

The 'Natural' and 'e-Flow Rec' daily flow series for the Broken Creek at Geary Channel have been assumed to equal the flow series derived for environmental flow Site 2 in the Broken and Boosey Creek environmental flow determination project (SKM 2006b). This site is located on Broken Creek at Geary Road, approximately 2 km downstream of Geary Channel. Specifically:

- Natural (Broken Creek at Geary Channel) = Natural (Broken Creek at Site 2)
- e-Flow Rec (Broken Creek at Geary Channel) = Natural (Broken Creek at Site 2, but with cross-catchment transfers from the Broken River to Broken Creek at Casey's Weir limited to 200 ML/d)

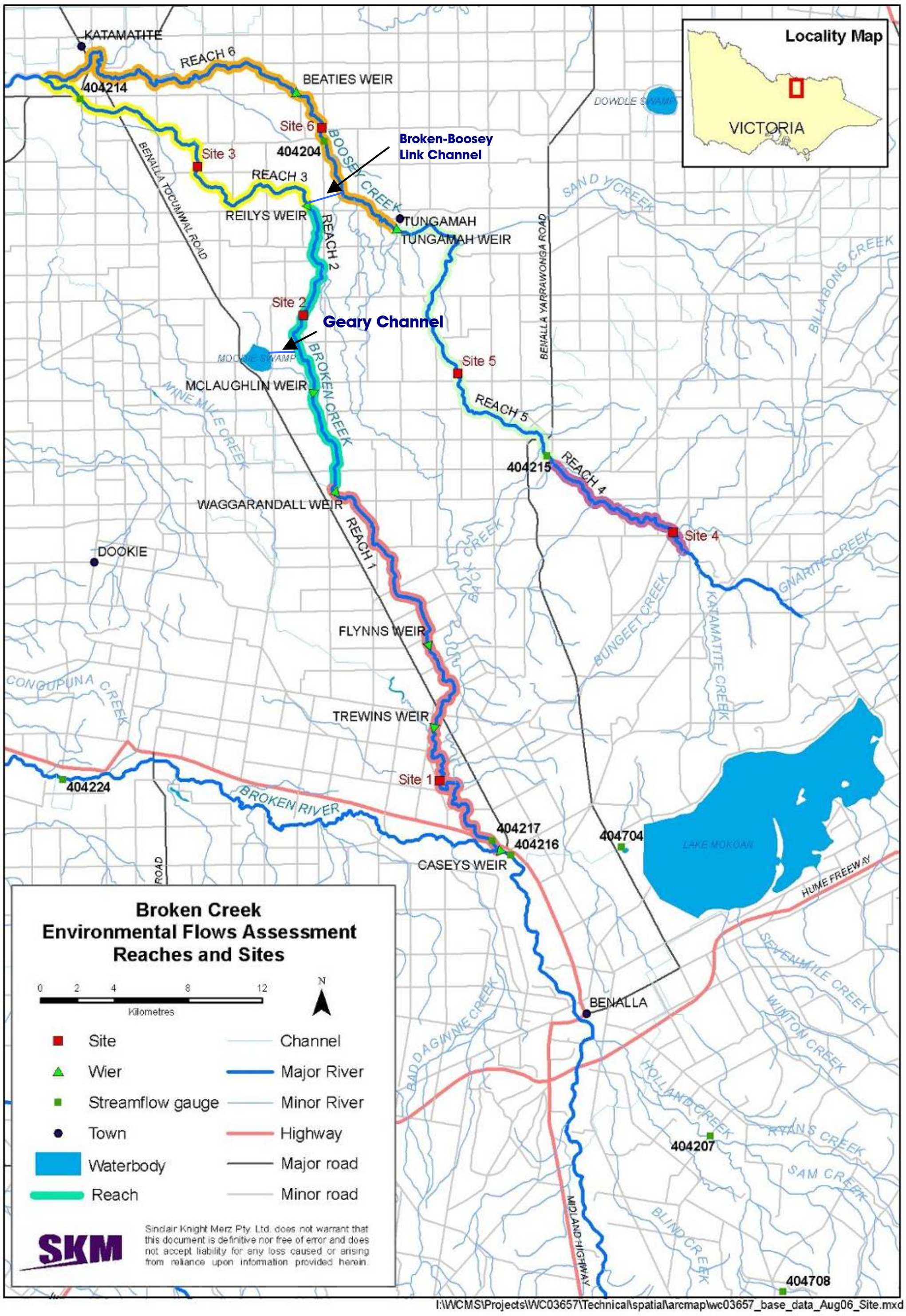
The routing, mass-balance, rainfall-runoff modelling, hydraulic modelling and farm dam modelling undertaken to derive the natural flows for the Broken Creek at Site 2 are explained in detail in the environmental flows issues paper SKM (2006b).

A.1.2 Current time series

The steps and assumptions taken to estimate 'Current' flows at Site 2 were:

- The difference between 'gauged' and 'natural' at 404204 (Boosey Creek downstream of the Broken Boosey link channel) (prior to incorporation of rainfall-runoff and farm dam impact modelling) was assumed to equal the transfers from Broken Creek to Boosey Creek along the link channel at Reilly's Weir (downstream of Site 2).
- Parameters for routing flows at gauge 404204 to match gauge 404214 (Broken Creek at Katamatite) were then developed. It was then assumed that these parameters could be used to route the 'transfers' from Reilly's Weir to 404214 ... i.e. to estimate what the 'transfers' would have 'looked like' at 404214 if allowed to pass down Broken Creek.

- Flows at 404214, and the 'transfers' (routed to 404214) were routed to Site 2, using the parameters developed for the environmental flow study to route natural flows at Katamatite to Site 2.
- Flows at 404214 (routed to Site 2) were factored by the ratio of catchment areas if (from the hydrograph) it appeared they were the result of 'natural' local catchment inflow (and not artificial transfers From the Broken River to Broken Creek at Casey's Weir)
- The flows at 404214 (routed to Site 2), factored where appropriate, were added to the 'transfers' (routed to Site 2) to provide an estimate of 'Current' flows at Site 2.



■ **Figure 8.1 Environmental flow reaches and assessment sites**

A.2 Hydraulic modelling

A hydraulic model has been developed for Broken Creek, Moodies and Geary Channel and Moodies Swamp (SKM 2006a). The model was originally used to identify water management options for the swamp and to assess the effectiveness of installing a low level weir downstream of Geary Channel. For the current study the hydraulic model was re-run with and without the proposed weir in Broken Creek to confirm the relationship between flow in the Broken Creek versus flow to Moodies Swamp (Table 8.1 and Table 8.2).

- **Table 8.1 Flow in Broken Creek versus flow to Moodies Swamp, with proposed weir in the Broken Creek**

Flow in Broken Creek (ML/d)	Discharge to Geary Channel (ML/d)	Discharge to Moodies Channel (ML/d)	Total Discharge to Moodies Swamp (ML/d)
200	14.0	0.8	14.8
100	12.0	0.2	12.2
50	10.0	0.1	10.1
10	6.5	0.0	6.5
5	5.0	0.0	5.0
1	1.0	0.0	1.0

- **Table 8.2. Flow in Broken Creek versus flow to Moodies Swamp, without the proposed weir in the Broken Creek (i.e. under existing conditions)**

Flow in Broken Creek (ML/d)	Discharge to Geary Channel (ML/d)	Discharge to Moodies Channel (ML/d)	Total Discharge to Moodies Swamp (ML/d)
200	9.1	0.0	9.1
100	2.1	0.0	2.1
50	0.0	0.0	0.0
10	0.0	0.0	0.0
5	0.0	0.0	0.0
1	0.0	0.0	0.0

Using the daily time-series of flow in the Broken Creek at Moodies Swamp, combined with Table 8.1 and Table 8.2, a time-series of daily flows to Moodies Swamp was developed for 'with weir' and 'no weir' scenarios. The assumptions were:

a) Linear interpolation of the relationships in Table 8.1 and Table 8.2 was appropriate for determining flows to Moodies Swamp for the full range of flows in Broken Creek.

b) The volume of water to fill Broken Creek to the level where a steady-state relationship existed between flow in Broken Creek and flow in to Moodies Swamp was small enough to be ignored.

c) By re-running the model, it was noted that with the new weir in place, if flow in Broken Creek was less than 10 ML/d then a large proportion of that flow would be diverted to Moodies Swamp if the Geary regulator was open. This would significantly reduce the downstream flow in Broken Creek under low flow conditions. Hence operating rules for the regulator have been altered to ensure low flows in Broken Creek downstream of Geary Channel are protected. The revised operating rules for the regulator are:

- For the Geary regulator to be closed in summer months (December – April) unless the flow in the Broken Creek at Geary Channel exceeds 50 ML/d (this is to prevent rain rejection flows downstream from Waggarandall Weir from entering the swamp but to allow natural high flow events to enter the swamp in summer and autumn), and
- For the Geary regulator to be open in winter months (May – November) if flow in the Broken Creek at Geary Channel exceeds 10 ML/d (the 10 ML/d rule protects low flows in Broken Creek downstream of Geary channel but still allows a large portion of moderate to high flows to enter Moodies Swamp).

Using the time-series of daily flows to Moodies Swamp, a daily water-balance was derived for Moodies Swamp, for the 6 possible combinations of ‘natural’, ‘e-flow’ and ‘current’ flows, under ‘weir’ and ‘no weir’ scenarios. The assumptions were:

a) Rainfall on and evaporation from Moodies Swamp was adequately represented by rainfall measured at Goorambat (081017) and evaporation measured at Lake Mokoan (081116). Net evaporation from Moodies Swamp was modelled using a pan coefficient of 0.8.

b) Water seeped from Moodies Swamp at a rate of 5 mm/d (Keith Collett, pers. comm.).

c) The local catchment area of Moodies Swamp is 630 ha (6,300,000 m^2), and 10% of rainfall becomes run-off.

d) The proportion of flows to Moodies Swamp from Broken Creek which actually enter Moodies Swamp decreases as Moodies Swamp fills. These proportions were based on a MIKE11 run at 200 ML/d (Table 8.3). Otherwise, no losses were assumed to occur along the channels which connect Broken Creek and Moodies Swamp.

e) Water would only enter Moodies Swamp via the channels connecting Broken Creek and Moodies Swamp. That is, contributions from overland flow during floods were ignored.

f) For the purposes of calculating water depths in Moodies Swamp, an invert level of 127.69 m AHD was used.

- **Table 8.3. The proportion of flow to Moodies Swamp from Broken Creek which actually enters Moodies Swamp**

Moodies Swamp Storage	‘Filling’ Factor
< 326 ML	1.00
< 590 ML	0.33
< 620 ML	0.05