srk consulting

Level 1, 10 Richardson Street
West Perth WA 6005, Australia

PO Box 943
West Perth WA 6872, Australia

T: +61 8 9288 2000
F: +61 8 9288 2001
E: perth@srk.com.au

www.asia-pacific.srk.com

Lake Disappointment Hydrology Modelling

Client:	Reward Minerals Pty Ltd	**Date:**	21/09/2018
Attention:	Greg Cochrane, Dan Tenardi	**From:**	Brian Luinstra
Project No:	REW001	**Revision No:**	0
Project Name:	Lake Disappointment Regulatory Support		
Subject:	Lake Disappointment Pond Persistence Modelling – Draft for Review		

1 Introduction

Reward Minerals Pty Ltd (RML) engaged SRK Consulting (Australasia) Pty Ltd (SRK) to develop a hydrological model to assess the persistence of surface water on Lake Disappointment, a large salt lake system in north-central Western Australia. This included a review of available hydrological and ecological studies completed for the lake and development of a hydrology model to assess surface water pond persistence under existing conditions and during extraction of brine from the lake. The objective of the exercise was to develop an understanding of the potential changes of surface water persistence resulting from the proposed development and determine the degree of impacts those changes may have on local fauna habitat.

1.1 The Problem

RML is seeking to develop the Lake Disappointment Sulphate of Potash project (the Project), a large brine deposit hosted within the sediments of the Lake Disappointment playa. As part of a pre-feasibility study (PFS) for the Project, extraction of brine hosted in shallow lake sediments is proposed via a network of trenches. Brine extraction via trenches will result in a reduced water table across the lake, and a resultant increase in available water storage in the unsaturated zone. Concerns have been raised that brine extraction will therefore lead to increased infiltration on the lake sediments, and an associated reduction in either the extent or duration of surface ponding on the playa.

The Banded Stilt (*Cladorhynchus leucocephalus*) is an Australian shorebird that has been known to breed on islands located in Lake Disappointment. The March 2017 survey by Bennelongia (2018) recorded 94,046 adult birds, 49,321 nests on 10 islands, and 7,388 young chicks on Lake Disappointment. This aligns closely with the 93,455 adult Banded Stilt population observed at Lake Disappointment in February 2017. Bennelongia estimates that these numbers represent between 25% (based on estimates from Watkins, 1993) and 46% (based on estimates from Wetlands International, 2018) of the entire species' population.

Banded Stilts require an ephemerally flooded, hypersaline wetland that persists for a minimum of 80–90 days to provide food sources to support successful fledgling of young (termed "recruitment"). Additionally, Banded Stilts typically nest on islands, and rely on sufficient water depth in ponds to act as physical barriers to prevent predation of their nests. Based on criteria discussed in Bennelongia (2018), a minimum surface water persistence of more than 80 days with a water depth greater than 10 cm is necessary to support a recruitment event.

Complicating the assessment is the general lack of long-term monitoring data for Lake Disappointment. There are no long-term records of rainfall and/ or pond development, and references to pond formation on the lake and Banded Stilt nesting and recruitment are anecdotal and infrequent.

1.2 Work Plan

To address the identified knowledge gaps in historic pond development on Lake Disappointment, SRK developed a deterministic hydrology model using GoldSim (v.12) software. A base case model was developed using all available information for the lake, and was used to estimate daily fluxes of water, pond volumes and ultimately to determine the length of pond persistence. Two additional scenarios were incorporated to assess the impact of the proposed development on pond formation frequency and persistence times.

1.3 Previous Studies

The following reports were available and used in the development of the model:

- Environmental Review document – Lake Disappointment Potash Project. Letter to Dr Michael Ruane (Reward Minerals Pty Ltd) from Peter Tapsell (DWER), March 2018.
- Lake Disappointment groundwater-dependent vegetation spectral data analysis – NDVI, NDWI and ET calculations. Memo to Dan Tenardi & Lisa Chandler (Reward Minerals Pty Ltd) from Phil Whittle (Hydrobiology), August 2017.
- Public Environmental Review for Lake Disappointment Potash Project – Environmental Scoping Document approval. Letter to Dr Michael Ruane from Tom Hatton (Environmental Protection Authority), October 2016.
- Draft Environmental Review Document for Lake Disappointment Potash Project. Prepared by Reward Minerals Pty Ltd, December 2017.
- Environmental Review Document comment table – Lake Disappointment. Summary prepared by reward Minerals based on information from DWER.
- Lake Disappointment SOP Project: Brine Collection, Evaporation Ponds and Residue Disposal Concept Study. Prepared by Knight Piésold Consulting, December 2016.
- Lake Disappointment – Hydrological Study. Prepared by Knight Piésold Consulting, January 2017.
- Lake Disappointment 2017 Flooding Hydrology Calculations. Memo to Daniel Tenardi from Phil Whittle.
- Lake Disappointment Fauna Assessment. Prepared by Bennelongia, 2018.

2 Modelling

2.1 Conceptual Model

A simple conceptual model for Lake Disappointment was developed to guide development of the deterministic numerical model and is provided in Figure 2-1. Runoff from the playa surface is only generated once the storage capacity of the unsaturated zone is filled. (In practice it is possible to generate runoff if the precipitation rate exceeds the infiltration rate; however, given the highly permeable nature of the lake bed sediments, it is assumed for the purposes of modelling that the infiltration rate is greater than the maximum precipitation rate.) Flow into the unsaturated zone is derived from both precipitation onto the lake bed, as well as runoff derived from creeks which outlet into the lake (also known as “run-on”). The only losses out of the unsaturated zone are from evaporation. Maximum storage in the unsaturated zone is calculated at each time-step as the total volume of the unsaturated zone (a function of the depth of the unsaturated zone multiplied by the area not inundated by the pond) multiplied by the specific yield of the unsaturated zone.

Once runoff is generated, a pond will form on the playa, after which precipitation and evaporation are the key processes governing the persistence of surface water in the pond. The key inputs into the pond are direct precipitation (while a pond persists) and runoff from the playa surface, with the only losses out of the pond from evaporation.

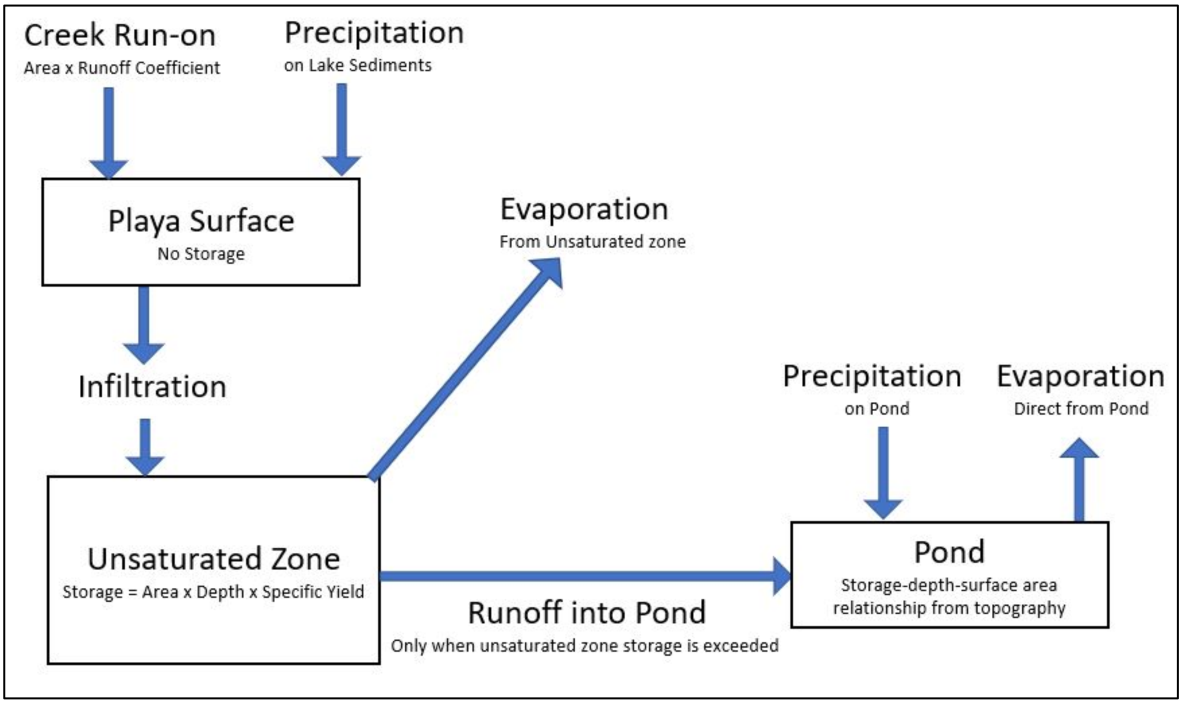

Figure 2-1: Conceptual hydrology model for pond development on Lake Disappointment

2.2 Data Inputs

2.2.1 Precipitation

Precipitation in the project area is characterised by long periods of drought, with occasional rain events (typically 1–2 per year) of varying intensity. RML has been recording precipitation for the project area, however, the available data record is not long enough to provide meaningful input into the model. Knight Piésold (2017) determined that the most applicable precipitation record is that of Telfer Airport (Bureau of Meteorology (BOM) Station # 13030). Daily rainfall records for 1974–present are available from the Telfer meteorological station. The record was reviewed and prepared for use in the model. Days with no record were assigned a nil recording, and partial data from 2018 was omitted. The final period of record for use in the model was established as 1974–2017, inclusive.

The rainfall records show a distinct pattern of rainfall events, typically in the first quarter of the year, and on an annual to biannual frequency. Notably, there are extended periods lasting several years with no recorded rainfall, and alternative periods where significant (i.e. >50 mm) rainfall events occur on an almost annual basis.

SRK attempted to develop a predictive, stochastic rainfall module from the Telfer data using the WGEN weather generator with limited success. Although the WGEN-derived stochastic rainfall was able to successfully produce similar average rainfalls over the period of record (i.e. 1974–2017, inclusive), the frequency of rainfall events was much higher, and the intensity of events lower. This was considered unacceptable for use in assessing pond persistence – conceptually heavily dependent on large rainfall events – and was not used in the model.

As a result, a deterministic modelling approach was adopted using the existing cleaned rainfall record from the Telfer Airport BOM Station. Rainfall records used for the deterministic model are shown graphically in Figure 2-2.

2.2.2 Evaporation

Monthly average evaporation values are available from the Telfer Airport BOM Station and were used in the model. Daily rates are derived from the monthly values for each time-step. Evaporation used for the deterministic model are shown graphically in Figure 2-2.

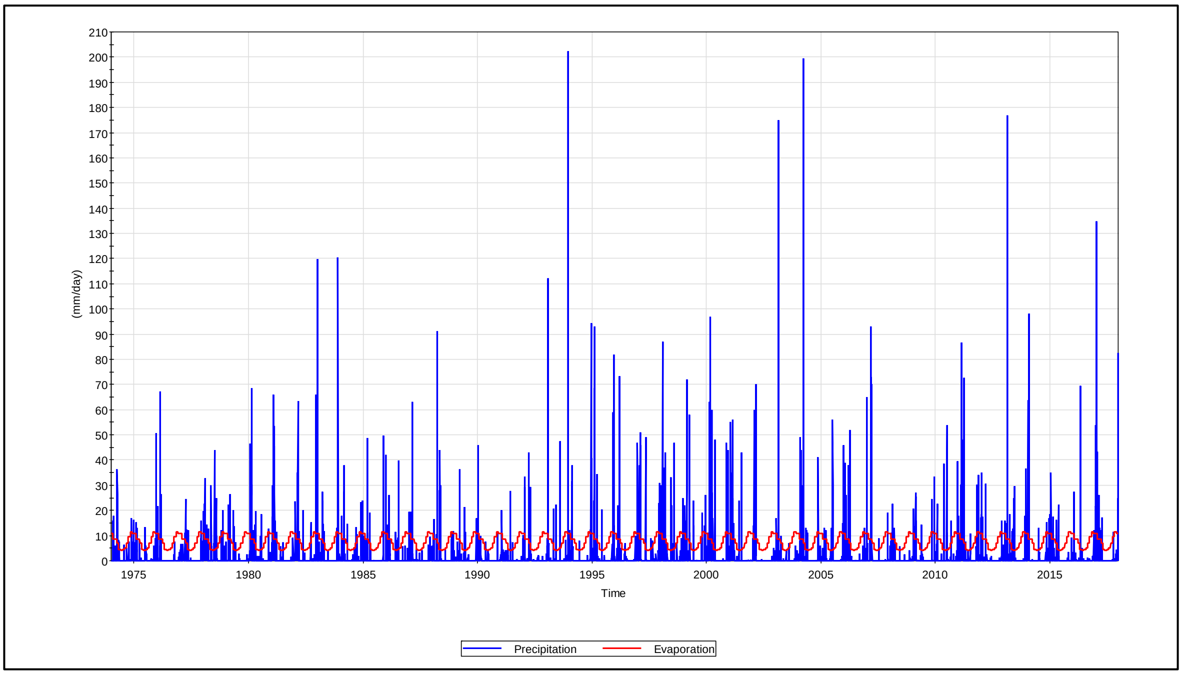

Figure 2-2: Deterministic daily rainfall and evaporation

2.2.3 Pond Storage

A stage-storage relationship for the Lake Disappointment pond was developed from available topography data and limited (~ 70–80) survey elevations collected by RML. The data was processed in AutoCAD, and a 3D model created from which the pond capacity (storage) and pond surface area was calculated for each 1 cm change in potential water depth in the pond (stage).

Due to the generally flat topography of the lake bed, small changes in elevation can result in large changes in surface area and thus water available for evaporation. At a conceptual level, evaporation is the only source of loss from the pond and it would be expected that the modelled pond persistence would be highly sensitive to changes in surface area. Given the accepted error of ±10 cm for the available elevation data, this is a source of potential uncertainty in the model.

2.2.4 Additional Hydrologic Inputs

Additional hydrologic inputs for the model were derived from existing reports and studies completed by RML and maintained within the model as an initial setting for consistency. Table 2-1 lists the parameters used, as well as a description of the parameter and the source of the information.

Table 2-1: Additional inputs into the model

Parameter	Value	Description	Source
Pan Factor	0.7	Adjustment from pan evaporation to actual evaporation	Estimated
Specific Yield (Sy)	0.20	Portion of unsaturated zone available for storage	Estimated from resource drilling results
Unsaturated Zone thickness	0.7 m	Thickness of the unsaturated zone	Estimated from available groundwater monitoring data
Unsaturated Evaporation Factor	0.25	Reduces evaporation from unsaturated zone as a portion of daily evaporation	Estimated
Lake Area	1,241 km^2	-	Knight Piésold flood study (2017)
Creek Effective Catchment area	2,318 km^2	Area within the catchment which contributes runoff to Lake Disappointment	Knight Piésold flood study (2017)
Runoff co-efficient	0.075	Used to estimate runoff for an area	Knight Piésold flood study (2017)

2.3 Calibration Targets

Due to the remoteness of Lake Disappointment there is a general lack of monitoring data for the period of record from which to develop calibration targets. Knight Piésold (2017) used satellite imagery to assist with calibration of single events, and more recent pond formation events have been recorded anecdotally. Anecdotal information from traditional histories indicate that pond formation occurs after large (i.e. >50 mm) rainfall events.

2.4 Modelled Scenarios

The model was established and run in deterministic mode for the period of record (1974–2017, inclusive) and calibrated to existing conditions where existing data allowed.

The following three scenarios were developed in order to assess pond persistence:

- Base Case Scenario: Developed to represent current conditions based on the extensive knowledge base for the Project developed by RM using the parameters outlined in Table 2-1. The base case was used to complete a high-level calibration of the model.
- Scenario 1: Involved increasing the depth of the unsaturated zone to represent the drawdown effects of brine extraction; a nominal depth of 1.5 m was used (base case: 0.7 m) and was estimated from trench pumping test data and numerical groundwater modelling from the Lake. The specific yield was also altered to reflect the larger unsaturated zone; as specific yields will decrease slightly with depth, a nominal specific yield of 0.15 was adopted (base case: 0.20).
- Scenario 2: Used identical parameters for the unsaturated zone as Scenario 1 (i.e. unsaturated depth of 1.5 m and specific yield of 0.15) and also reduced the overall runoff reporting to the pond by 20% in order to account for potential ponding and interruption of flow due to proposed site infrastructure.

3 Results

3.1 Scenarios

3.1.1 Base Case (Calibration)

The base case scenario was used to calibrate and refine the model against historical data. Given the lack of comprehensive calibration data, model outputs were compared against known information for the Project to evaluate the validity of the results. Results for the base case scenario are provided in Figure 3-1, Figure 3-2, Figure 3-3 and Figure 3-4. Water table depth (Figure 3-1) in the unsaturated zone ranges from 0 m to 1.0 m below ground surface and is broadly consistent with observed water levels, including seasonal changes, in the Lake Disappointment sediments (RML, personal communication). Modelled water table levels decline and storage in the unsaturated zone increases during dry periods via evaporation, consistent with estimated rates of decline after precipitation events (RML, personal communication).

Runoff from the lake bed (Figure 3-2) into the pond is generated in the model only when storage in the unsaturated zone is exceeded, and corresponds well with recorded rainfall events (Figure 2-2). Runoff (and pond development) typically occur after rainfall events of more than 50 mm/day, which is consistent with anecdotal and historical accounts.

After large rainfall and runoff events, pond persistence is governed by direct rainfall on the pond and evaporation rates from the pond, as shown in Figure 3-3. In Figure 3-4, pond persistence is presented as the duration of water depths (over years), which is again consistent with anecdotal and historical accounts. Within the model, the pond reaches maximum capacity for most runoff events. This is primarily due to constraints in the stage-storage relationship from the available topographical data which limit pond volume and area – the pond area and stage-storage relationship could not be effectively extended to the full surface area of the lake. However, the areas outside the pond would be expected to have very shallow water depths (i.e. less than 2 cm) and would not have significant impact on the results of the modelled pond persistence due to the high evaporation rates (typically 1 cm/day to 1.5 cm/day).

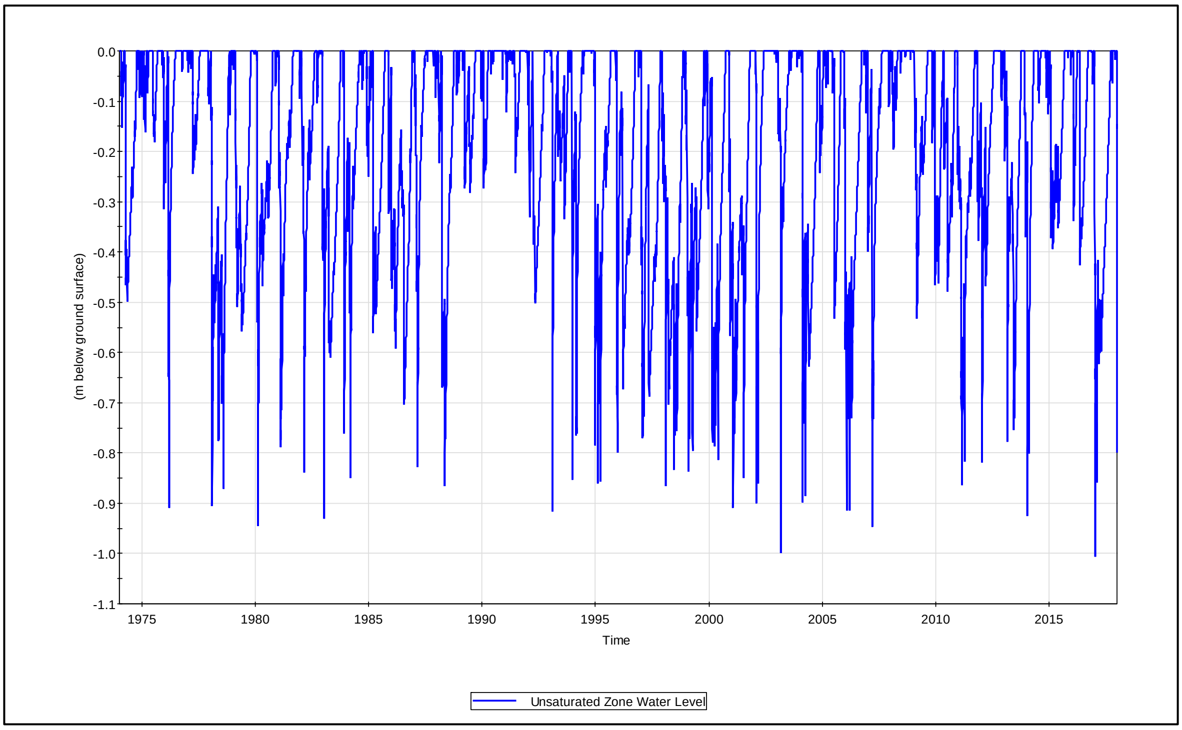

Figure 3-1: Unsaturated zone water levels – 1974-2017

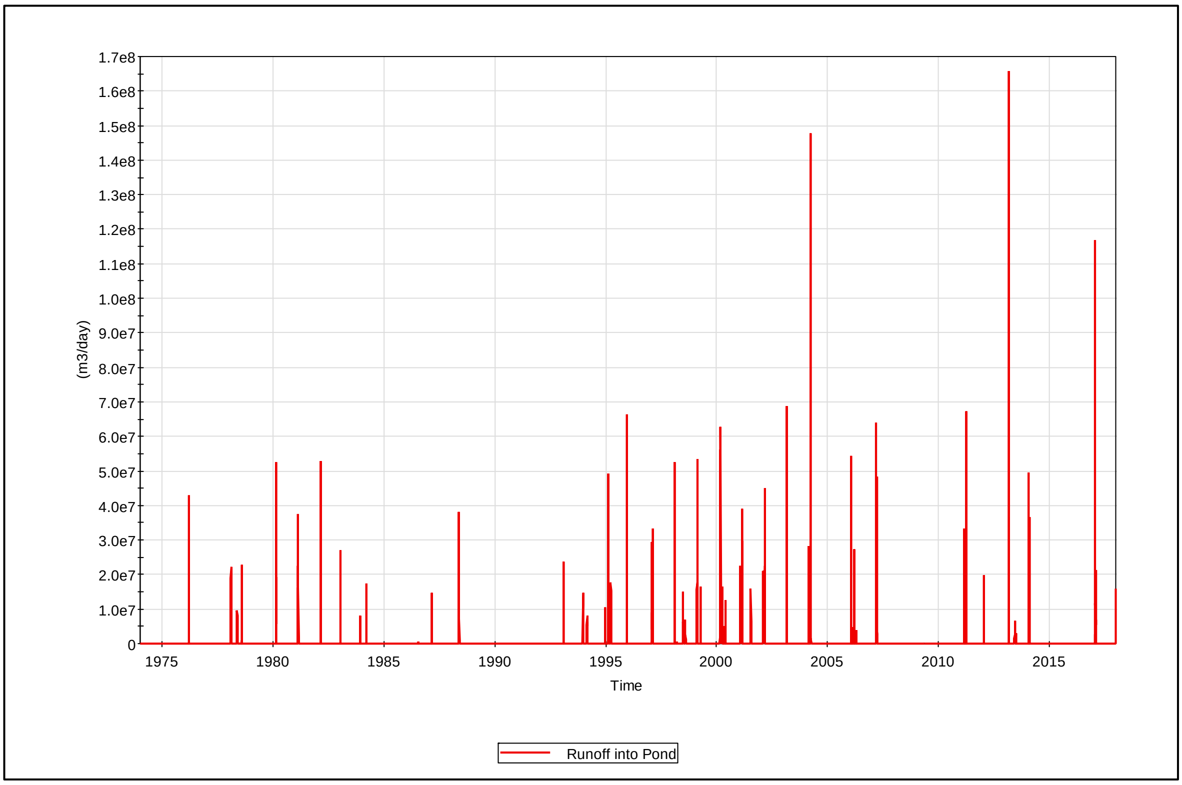

Figure 3-2: Runoff from Lake Disappointment surface to pond – 1974–2017

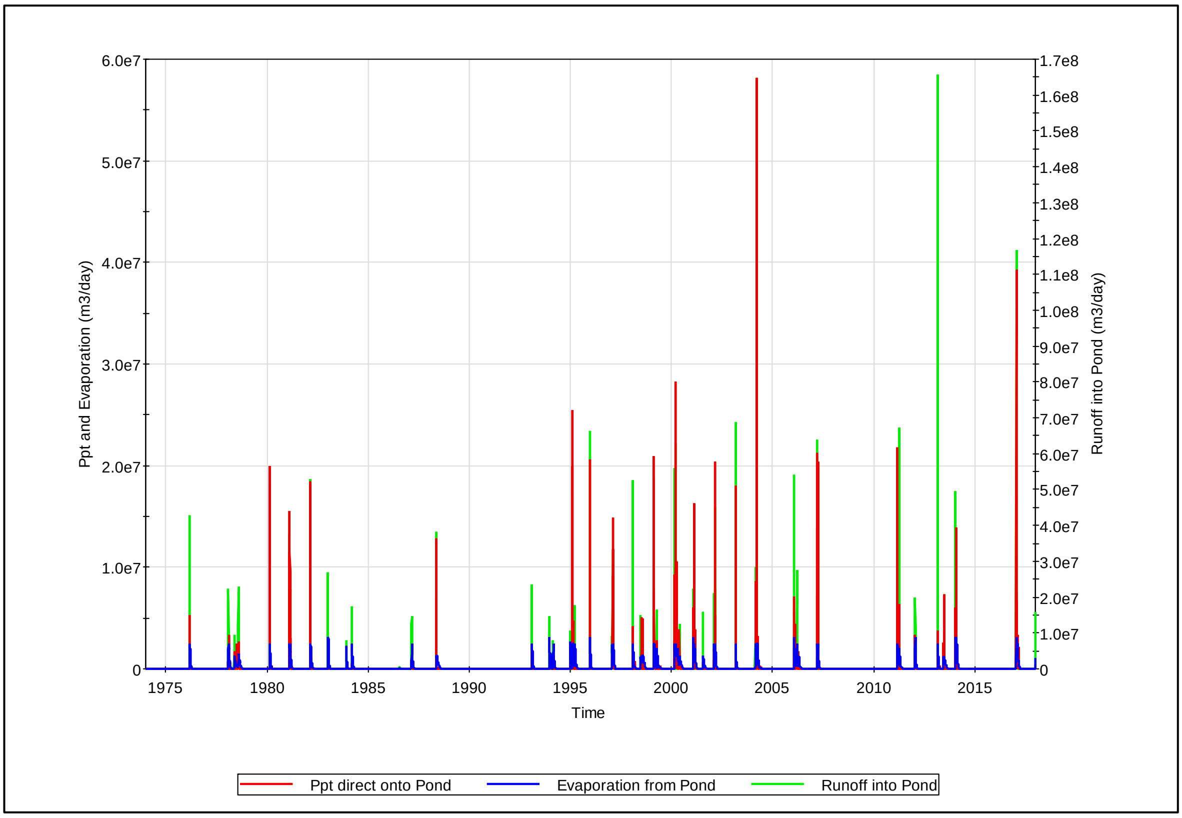

Figure 3-3: Inputs (direct rainfall and runoff) and outputs (evaporation) from pond – 1974–2017

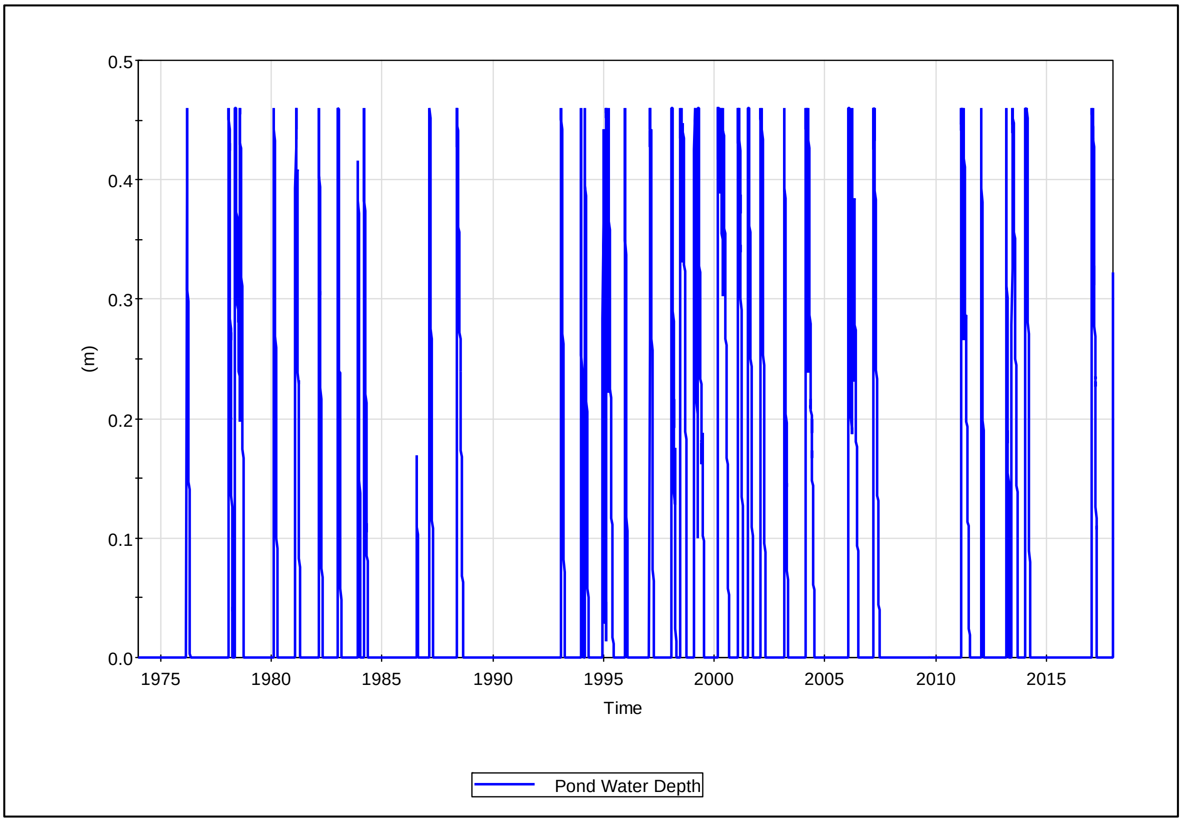

Figure 3-4: Water depths in pond – 1974–2017

Modelled pond persistence is provided in Table 3-1 for the base case scenario and is discussed in more detail in Section 3.2.

Overall, within the constraints of the available input and calibration data, the model appears to be simulating the lake hydrology system well under base case conditions.

3.1.2 Scenario 1

Scenario 1 was developed to assess the impact of drawdown within the Lake Disappointment sediments on pond persistence. Accordingly, the depth of the unsaturated zone (and thus available storage within the zone) was established at 1.5 m, and a specific yield of 0.15 was adopted in the model. Results for the Scenario 1 are provided in Figure 3-5, Figure 3-6, Figure 3-7 and Figure 3-8. Water table depth (Figure 3-5) in the unsaturated zone ranges from 0 m to 2.3 m below ground surface and is consistent with expected water levels during brine extraction from the Lake Disappointment sediments, derived from trench pumping tests and groundwater modelling.

Due to the increased available storage in the unsaturated zone, the frequency and magnitude of runoff events from the lake bed (Figure 3-6) is reduced, from 36 pond-forming events under base case conditions to 24 pond-forming events under Scenario 1 conditions. The reduction in modelled runoff events is typically noted for small, short-term precipitation events (i.e. <50 mm over a day) for Scenario 1 conditions. Although this represents an appreciable change from modelled base case results, the small events are unlikely to result in significant pond persistence and therefore are unlikely to have an impact on Banded Stilt recruitment events.

Modelled pond persistence is provided in Table 3-1 for Scenario 1 and is discussed in more detail in Section 3.2.

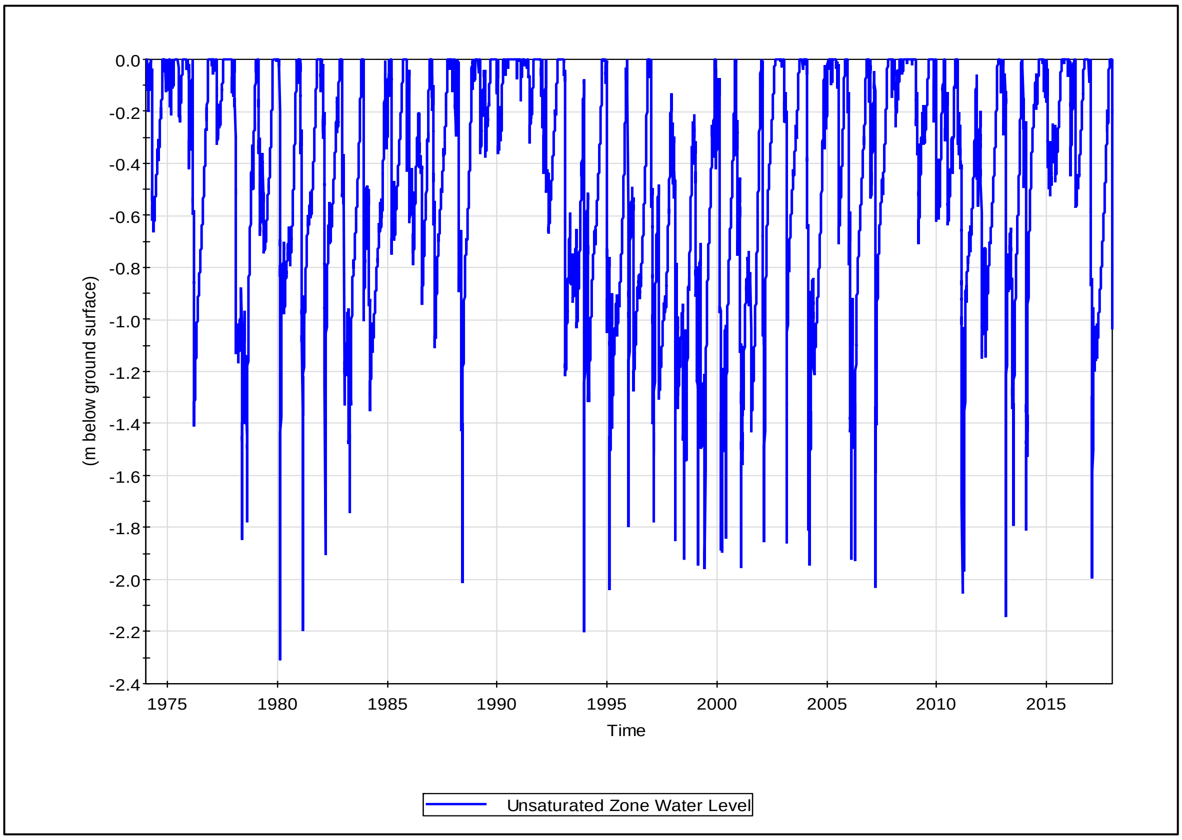

Figure 3-5: Unsaturated zone water levels – operational conditions (Scenario 1) – 1974–2017

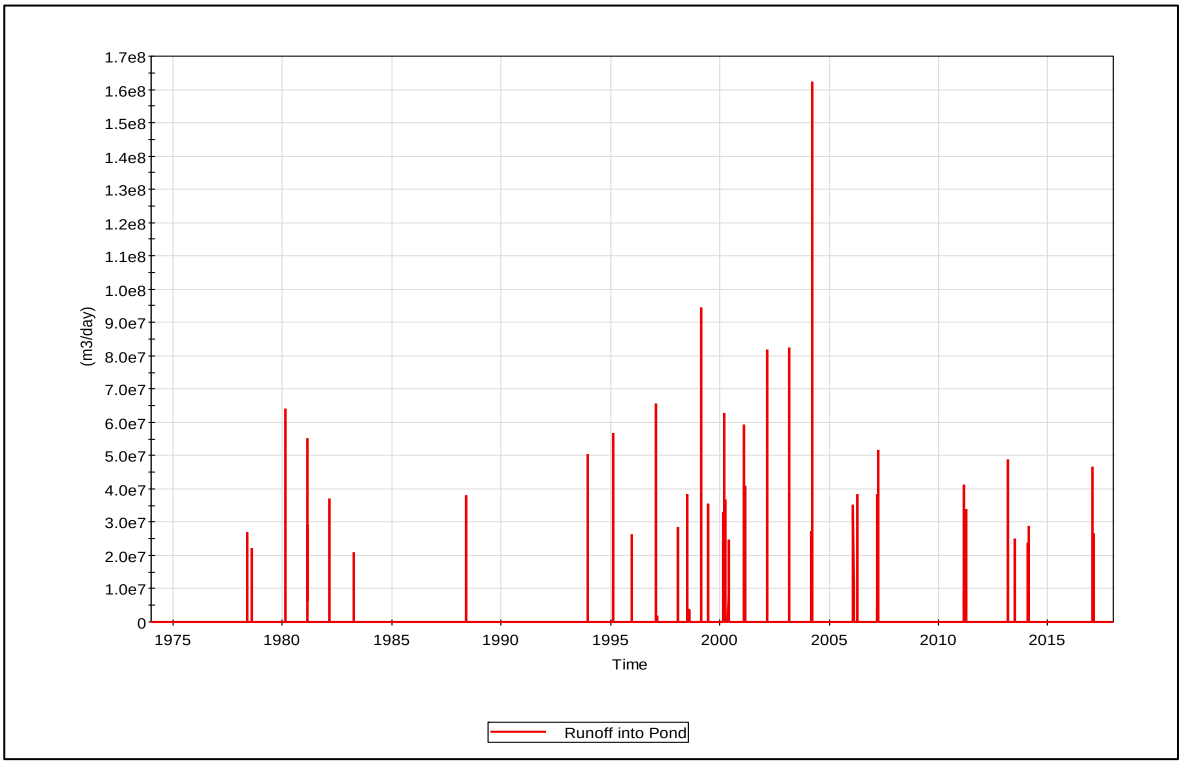

Figure 3-6: Runoff from Lake Disappointment surface to pond – operational conditions (Scenario 1) – 1974–2017

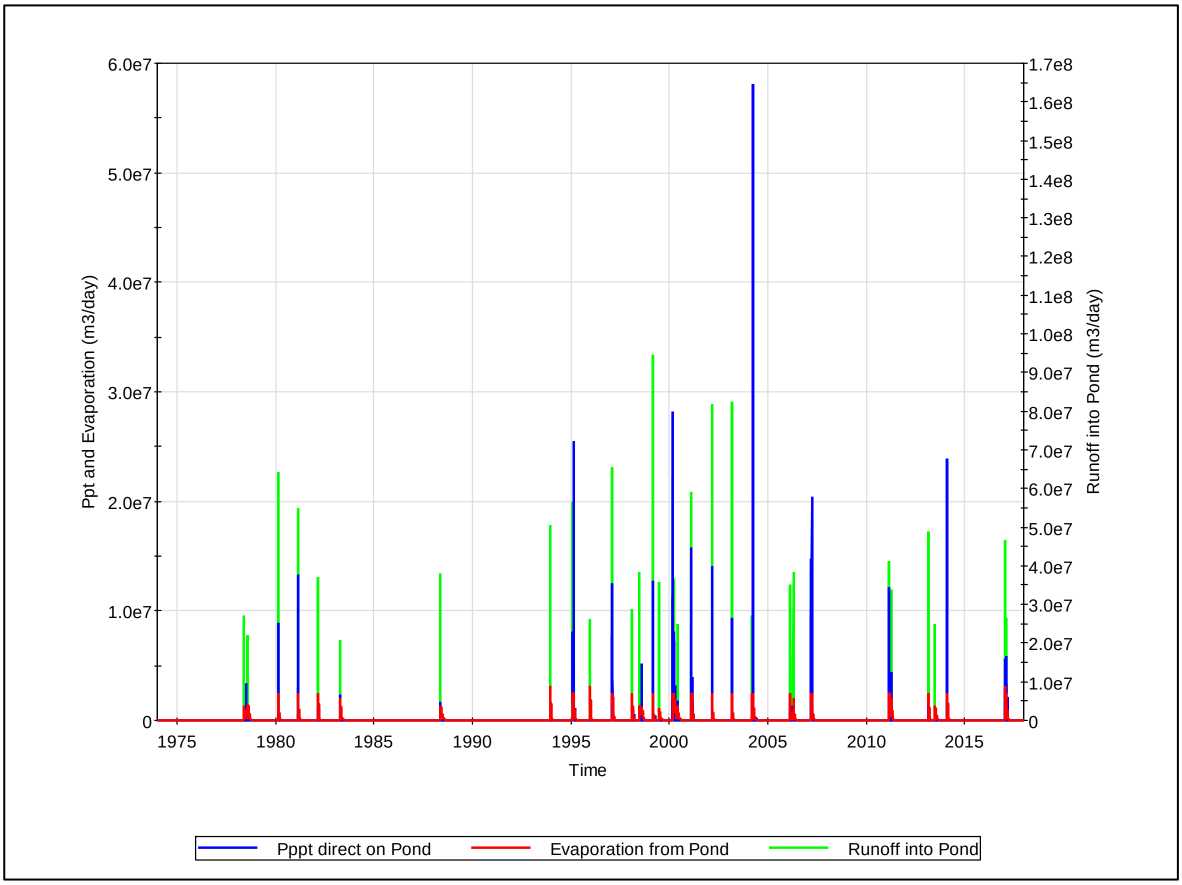

Figure 3-7: Inputs (direct rainfall and runoff) and outputs (evaporation) from pond – operational conditions (Scenario 1) – 1974–2017

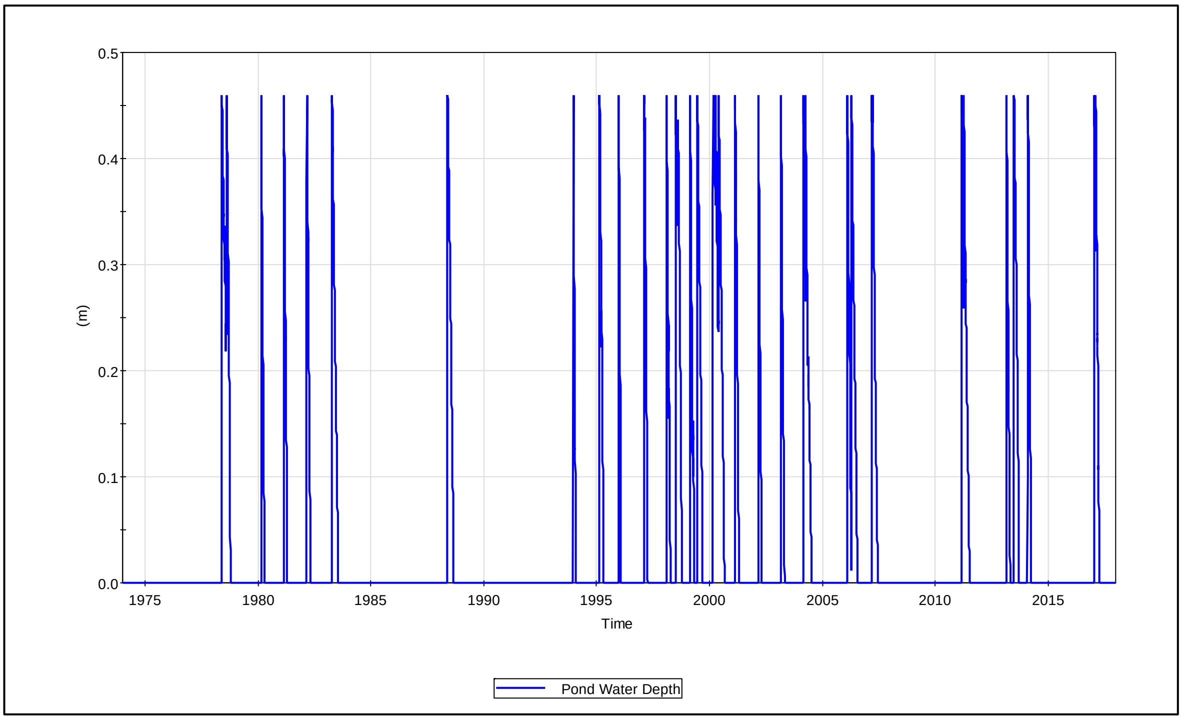

Figure 3-8: Water depths in pond – operational conditions (Scenario 1) – 1974–2017

3.1.3 Scenario 2

Scenario 2 was developed to assess the impact of drawdown within the Lake Disappointment sediments on pond persistence, and also reduced the overall runoff reporting to the pond by 20% (in order to account for potential ponding and interruption of flow due to proposed site infrastructure). Accordingly, the depth of the unsaturated zone was maintained at 1.5 m, and a specific yield of 0.15 was adopted in the model. Results for Scenario 2 are provided in Figure 3-9, Figure 3-10, Figure 3-11 and Figure 3-12. Results for water table depth (Figure 3-9) in the unsaturated zone, the frequency and magnitude of runoff events from the lake bed (Figure 3-10) and pond persistence (Figure 3-12) are broadly consistent with results from Scenario 1. There is a slight decrease in pond persistence times (Table 3-1). Similar to Scenario 1, the majority of impact on the runoff and pond forming events is for smaller precipitation events (i.e. <50 mm), which are unlikely to have resulted in recruitment.

Modelled pond persistence is provided in Table 3-1 for Scenario 2 and is discussed in more detail in Section 3.2.

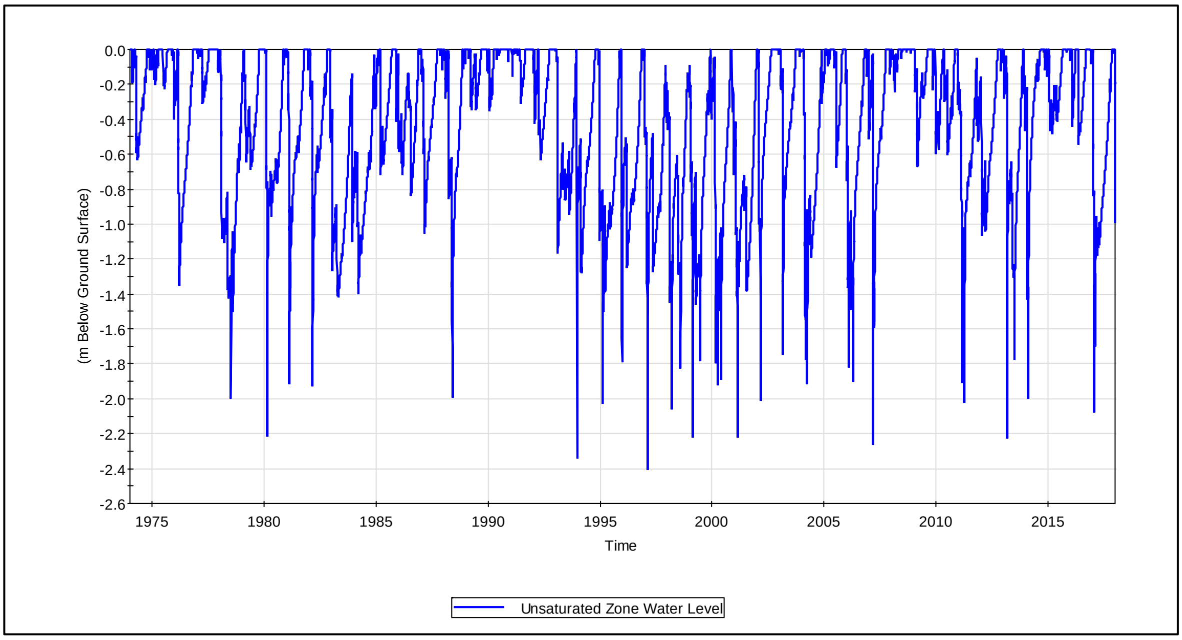

Figure 3-9: Unsaturated zone water levels – operational conditions (Scenario 2) – 1974–2017

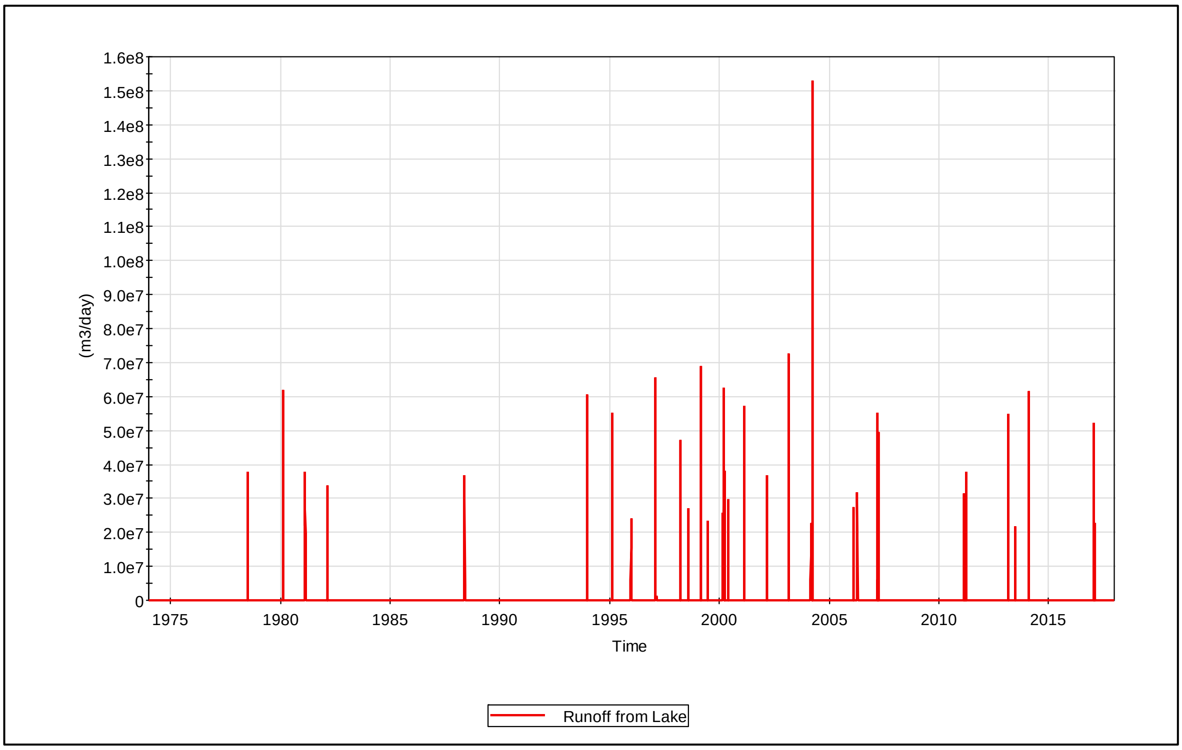

Figure 3-10: Runoff from Lake Disappointment surface to pond – operational conditions (Scenario 2) – 1974–2017

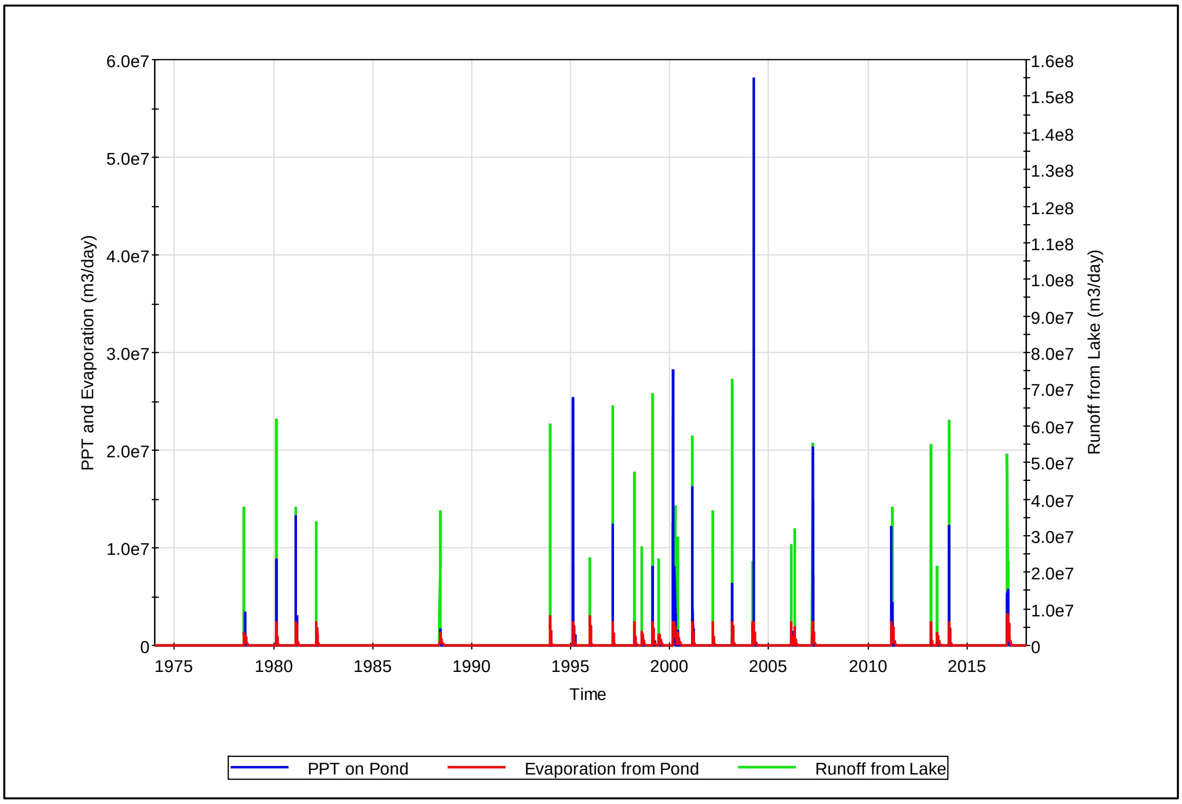

Figure 3-11: Inputs (direct rainfall and runoff) and outputs (evaporation) from pond – operational conditions (Scenario 2) – 1974–2017

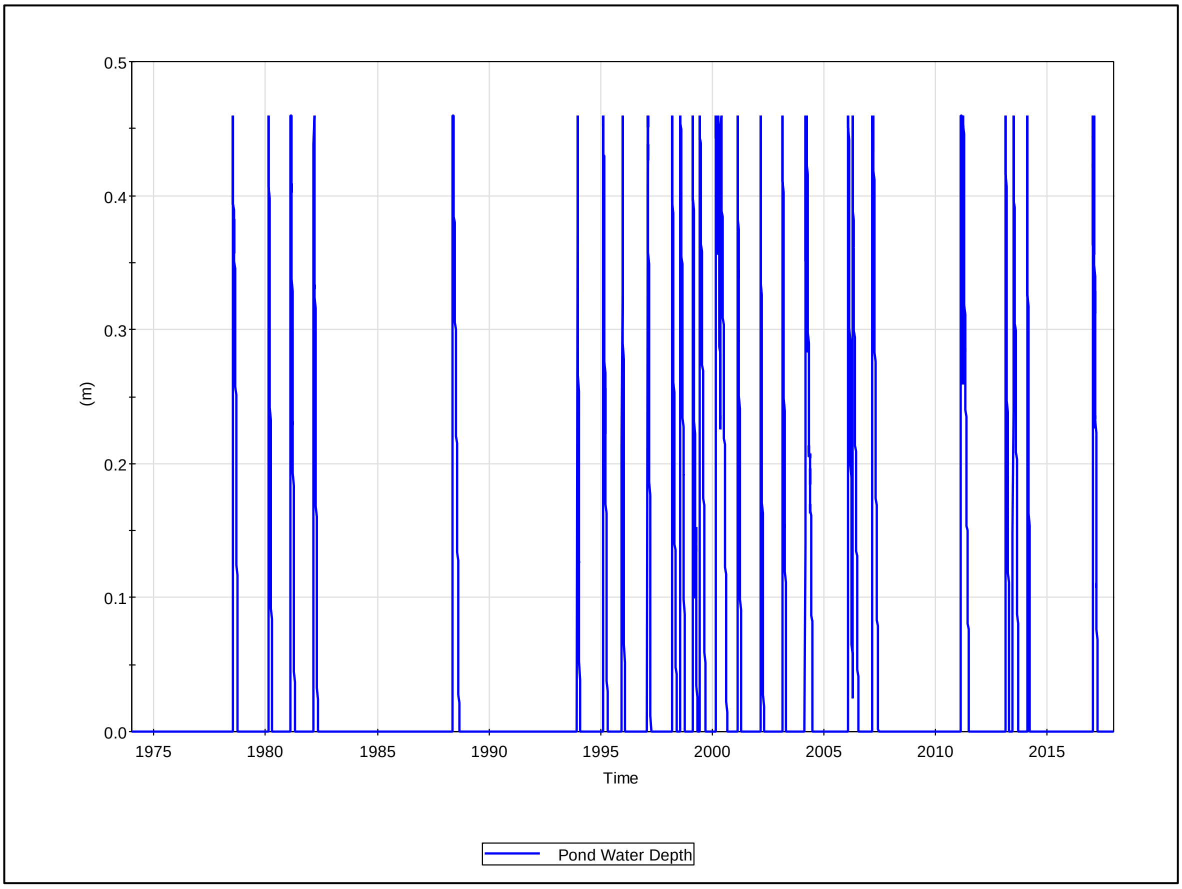

Figure 3-12: Water depths in pond – operational conditions (Scenario 2) – 1974–2017

3.2 Discussion

Modelled pond persistence is provided in Table 3-1 for all scenarios. Pond persistence is presented as the duration (in days) where depth in the pond remains above 10 cm for any given pond development event.

In addition to the recruitment event documented in February–May 2004, base case model results have identified five additional likely recruitment events in May–September 1978, February–May 1999, February–May 2000, March–April 2006 and February–May 2011. Marginal events, those with persistence durations near the established 80–90 days criterion, have also been noted in Table 3-1, but uncertainty within the model has resulted in them being designated as “possible”. Possible recruitment events were noted in May–July 1998, February–May 1995, January–March 1998, and June 2013.

With the exception of one (May–September 1978), all of the likely and possible recruitment events are modelled to occur in the summer/ wet season of northern Australia and are typically associated with extremely large rainfall events; this suggests a high dependency on cyclonic rainfall events. Pond formation events do occur at different times of the year but tend to be short-term events – a direct correlation with lower rainfall amounts. Recruitment events appear to be becoming more frequent through the period of record.

Under Scenario 1 and Scenario 2 conditions, there is a reduction in the overall frequency of pond-forming events, from 36 events to 24 events. However, of the pond-forming events under base case conditions for which no pond is formed under Scenario 1 and 2 conditions, all are short duration events unlikely to support recruitment. There does appear to be some potential impact on pond persistence for the “possible” and “likely” recruitment events. In general, Scenario 1 and 2 conditions have a 5%–10% reduction in duration of pond persistence with minimal impact on potential recruitment. Three possible exceptions are the May 1978, February 1995 and January 1998 events. In each case, pond persistence was reduced significantly under one or both of the operational scenarios.

For the May 1978 event, under base case conditions the pond persists for 140 days, and 134 days for the Scenario 1 conditions. Under Scenario 2 conditions, pond persistence is reduced to 97 days (likely still sufficient for recruitment but a notable change). For the January 1998 event, a similar pattern is modelled (104, 92 and 61 days, respectively). Analysis of the precipitation data suggests that these occurred after extended dry periods, resulting in high storage availability in the unsaturated zone. Based on the reduction in duration between Scenario 1 and 2, pond persistence is very sensitive to a reduction in runoff to the pond, which highlights the need to preserve flow paths across the lake. It is important to note a 20% reduction of runoff was modelled for Scenario 2, which is extremely conservative given the proposed water management structures proposed by Knight Piésold (2017). In reality, it is expected that less than 5% of flow will be interrupted. The February 1995 event similarly occurred after an extended period of dry weather, and is the only event modelled where any impact on recruitment would be anticipated.

The apparent increase in frequency of recruitment events is also likely important when assessing potential impact on the Banded Stilt population. Table 3-2 shows the frequency of possible and likely recruitment events by decade. Although difficult to confirm given the short climatic record, there appears to be an increase in recruitment events over that period. Further analysis (Figure 2-2) also suggests that rainfall events are getting more intense with higher precipitation totals per event, which would have a positive impact on pond persistence.

Table 3-1: Modelled pond persistence results

Event Date	Pond persistence (in days)			
	Base case	Scenario 1	Scenario 2	Notes
March 1976	47	-	-	
February 1978	49	-	-	
May 1978*	140	134	97	Likely recruitment event
February 1980	47	45	45	
February 1981	63	52	52	
February 1982	49	48	49	
January 1983	39	-	-	
December 1983	34	-	-	
March 1984	51	-	-	
July 1986	16	-	-	
February 1987	47	-	-	
May 1988*	96	85	85	Potential recruitment event
February 1993	45	-	-	
December 1993	34	34	34	
February 1994	50	-	-	
December 1994	36	-	-	
February 1995*	101	59	59	Potential recruitment event
December 1995	36	36	37	
February 1997	60	55	53	
February 1998	55	53	57	
January 1998*	104	92	61	Potential recruitment event
February 1999*	146	135	134	Likely recruitment event
February 2000*	175	169	169	Likely recruitment event
January 2001	77	73	71	
July 2001	67	-	-	
February 2002	65	64	62	
March 2003	47	48	48	
February 2004*	120	115	115	Documented successful recruitment
March 2006*	146	138	137	Likely recruitment event
March 2007	77	73	73	
February 2011*	118	111	111	Likely recruitment event
January 2012	45	-	-	
February 2013	48	42	42	Nesting noted but no successful recruitment
June 2013	91	74	73	Potential recruitment event
January 2014	62	50	44	
January 2017	71	70	69	Nesting noted but no successful recruitment

*Events likely to lead to successful fledgling of Banded Stilts. Note that nesting events were noted in June 2015 and February 2016, but no lake formation is modelled; this is due to the use of Telfer precipitation data (no rain was recorded at Telfer over those periods).

Table 3-2 Summary of Recruitment Events

Period (years)	Likely recruitment events	Possible recruitment events	Total
1974–1983	1	-	1
1984–1993	0	1	1
1994–2003	2	2	4
2004–2013	3	1	4
2014–2017	-	-	-

3.3 Model Limitations

The model is limited primarily by the quality and quantity of data inputs. Some key considerations when interpreting the results of the modelling include the following:

- Precipitation records are from the Telfer Airport BOM station, located approximately 150 km from the site and do not accurately reflect site conditions. Specifically, a pond-forming event was documented in June of 2015, while no rainfall was recorded at the Telfer site.
- Evaporation records are also from the Telfer Airport BOM station and may underestimate evaporation at Lake Disappointment.
- The quality of topography data has limited the development of the stage-storage relationship for the pond. The pond is highly sensitive to changes in elevation due to the flat topography of the lake bed, and the posted margin of error in elevation error is a source of uncertainty in modelling pond persistence.
- No comprehensive calibration dataset is available for the model of the hydrologic parameters used therein. Parameters were estimated using best fit data from available RML studies for the site, and modelled results correspond generally with anecdotal and historical records from the site.

4 Summary

In order to assess the potential impact on Banded Stilt recruitment from the proposed Lake Disappointment project, SRK developed a deterministic hydrology model using GoldSim (v.12) software. This model was developed using all available information for the lake, and was used to estimate daily fluxes of water, pond volumes and ultimately to determine the length of pond persistence, seen as critical for successful Banded Stilt recruitment.

The model was established and run in deterministic mode for the period of record (1974–2017, inclusive) and informally calibrated to existing conditions to the degree possible. Three scenarios were developed in order to assess pond persistence:

- Base Case Scenario: developed to represent current conditions
- Scenario 1: involved increasing the depth of the unsaturated zone to represent the drawdown effects of brine extraction
- Scenario 2: reduced the overall runoff reporting to the pond by 20% in order to account for potential ponding and interruption of flow due to proposed site infrastructure.

In addition to the recruitment event documented in February–May 2004, base case model results have identified five additional likely recruitment events in May–September 1978, February–May 1999, February–May 2000, March–April 2006, and February–May 2011. Four possible recruitment events were identified in May–July 1998, February–May 1995, January–March 1998, and June 2013.

Under operational (i.e. Scenario 1 and Scenario 2) conditions, a relatively modest reduction in pond persistence was noted, with only a single event modelled to move from “likely” to “potential”. The impacts are potentially mitigated by an increase in the frequency of large pond-forming (and recruitment) events suggested by the rainfall record and model results.

Project Number: REW001
Memo Title: Lake Disappointment Pond Persistence Modelling

Yours faithfully

SRK Consulting (Australasia) Pty Ltd

Signed by:	**Signed by:**
Brian Luinstra	**Russell Staines**
Principal Hydrogeologist	Principal Geochemist