Hydrological assessment and analysis of the Neales-Peake Catchment

DEWNR Technical note 2014/16

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Summary

This technical report describes the methodology and outcomes of a hydrological study undertaken for the Neales-Peake catchment. The main purpose of this study was to establish a hydrological model for the system to (i) aid in assessing the impacts on the flow regime if mining operations were to occur within the catchment and (ii) provide a tool that will aid in ecohydrological assessment of the region.

This study was undertaken by South Australian Department of Environment, Water and Natural Resources' (DEWNR) Science Monitoring and Knowledge (SMK) branch as part of the broader Lake Eyre Basin River Monitoring (LEBRM) project, which was formed to address knowledge gaps pertaining to the potential impacts of coal seam gas and large coal mining projects on the surface water resources of the Lake Eyre Basin (LEB). The Lake Eyre Basin has been identified as one of the six priority bioregions where coal seam gas and/or large mining developments are either planned or underway. Along with other partners, DEWNR has been contracted to address relevant hydro-ecological knowledge gaps within the LEB. The hydrological assessment and analysis of the Neales-Peake catchment forms part of this work.

The Neales-Peake catchment is an ephemeral, unregulated river system in the far north of South Australia, consisting of the Neales and Peake Rivers and associated tributaries, with a total catchment area of 34 415 km^2. Characterised by complex, multiple anastomosing channels, shallow channel definition, wide floodplains and waterholes, the ephemeral watercourses of the Neales-Peake system most commonly flow in response to the more localized thunderstorm-derived rainfall. Such in-channel flow events occur 1–2 times per year and are important in maintaining aquatic refugia but have limited influence on the connectivity between waterholes. The volume of the waterholes is often quite small compared with flow in the system and so small runoff events in the main channel system are capable of filling waterholes to their maximum cease-to-flow level. The larger rainfall events result in runoff through much of the channel system, recharging the alluvial/floodplain groundwater stores and allowing widespread migration of aquatic fauna.

The hydrological model used is a catchment model set up in the eWater Source IMS (integrated modelling system) that uses the Australian Water Balance rainfall/runoff Model (AWBM) to generate runoff for 177 sub-catchments and routes this flow through the system to discharge at Lake Eyre North, accounting for 20 waterhole storages. Detailed bathymetry of the waterholes in the system, in addition to observations regarding surface-water/groundwater interactions at the waterholes, was incorporated into the model, ensuring that waterhole dynamics were accurately represented by the model.

The model was calibrated by comparing modelled stage heights with those heights observed at four key waterholes. The limited and patchy nature of the data coverage over the study region means that traditional calibration statistics may be misleading. This being said, the model was able to reproduce observed stage, with an average difference of 6.5% between modelled and observed median stage height across the waterholes. This translated to an average difference of approximately 9% in average storage volume. Additionally, it was shown visually that the model tended to replicate the timing of events very well. At each waterhole the model struggled to identify some smaller flow events, in particular multiple flow events, however it did not register any false positives and as such was considered fit for purpose.

Although the model is able to reproduce the timing of observed events in the system very well, the model should be considered limited in its ability to estimate the magnitude of the events. The lack of volumetric information to calibrate the model means that it is not possible to estimate confidence surrounding simulated discharge volumes.

Recommendations for future work fall into two complementary categories, data collection and model refinement. By conducting flow gaugings at strategic locations throughout the system a measure of confidence in simulated flow volumes could be gained. Additionally, more detailed information regarding the surface-water/groundwater interactions at waterholes and throughout the system would enable a more complete representation of the hydrological dynamics of the catchment. Data that have been collected are often inconsistent owing to malfunctioning loggers, disturbance from local fauna, theft and varying installation and removal dates. Establishment of a more permanent monitoring network and the collection of data from such a network would enable continuous refinement of model parameters and deliver a better understanding of the hydrology of the system.

The Neales-Peake catchment has a varied geography, containing a diverse range of country – from the red sands of the Pedirka Desert to the hard packed clays of the Gibber Pans. Furthermore, the watercourses of the Neales-Peake are equally varied, ranging from well-defined incised channels to poorly channelized floodplains. As such, it is unlikely that the rainfall-runoff

response and transmission losses will be consistent throughout the catchment as considered in the model. More comprehensive data on land type, supplemented by hydrological observations, would allow the calibration of discrete rainfall-runoff and transmission loss models within subregions of the catchment that share similar geography and hydrology.

1 Introduction

1.1 Purpose and scope of the study

This technical report describes the methodology and outcomes of a hydrological study undertaken for the Neales-Peake catchment with the main purpose of this study being to:

- Establish a hydrological model for the Neales-Peake catchment to (i) aid in assessing the impacts on the flow regime if mining operations were to occur within the catchment and (ii) provide a tool that will aid in ecohydrological assessment of the region.

This study was undertaken by DEWNR's SMK branch as part of the broader Lake Eyre Basin Rivers Monitoring (LEBRM) project, which was formed to address knowledge gaps pertaining to the potential impacts of coal seam gas and large coal mining projects on the surface water resources of the Lake Eyre Basin (LEB), informing the Bioregional Assessment Programme. The broad scope of the study is encompassed by five key objectives:

1. Identify critical surface water sites and their characteristics (e.g. bathymetric relationship) within the study area
2. Disaggregate the study area into physically representative sub-catchments
3. Select appropriate rainfall data; select and calibrate appropriate rainfall-runoff model
4. Select and calibrate appropriate transmission loss function(s)
5. Validate model against observed understanding of system.

1.2 Project background

In responding to perceived uncertainties surrounding the potential water-related impacts associated with the increasing development in the unconventional petroleum sector in Australia, the Australian Government established the Independent Expert Scientific Committee (IESC) on Coal Seam Gas and Coal Mining Development. The Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (the IESC) is a statutory body under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) which provides scientific advice to Australian governments on the water-related impacts of coal seam gas and large coal mining development proposals.

Under the EPBC Act, the IESC has several legislative functions to:

- Provide scientific advice to the Commonwealth Environment Minister and relevant state ministers on the water-related impacts of proposed coal seam gas or large coal mining developments.
- Provide scientific advice to the Commonwealth Environment Minister on:
    1. bioregional assessments being undertaken by the Australian Government, and
    2. research priorities and projects commissioned by the Commonwealth Environment Minister.
- Publish and disseminate scientific information about the impacts of coal seam gas and large coal mining activities on water resources.

The Lake Eyre Basin has been identified by the IESC as one of the six priority bioregions where coal seam gas and/or large mining developments are either planned or underway. The Bioregional Assessment Programme is a transparent and accessible programme of baseline assessments that increase the available science for decision making associated with potential water-related impacts of coal seam gas and large coal mining developments. A bioregional assessment is a scientific analysis of the ecology, hydrology, geology and hydrogeology of a bioregion with explicit assessment of the potential direct, indirect and cumulative impacts of coal seam gas and large coal mining development on water resources. This programme draws on the best available scientific information and knowledge from many sources, including government, industry and regional communities, to produce bioregional assessments that are independent, scientifically robust, and relevant and meaningful at a regional scale.

This report is part of a series of studies forming part of the Lake Eyre Basin Rivers Monitoring (LEBRM) Project. LEBRM is one of three water knowledge projects undertaken by the South Australian Department of Water, Environment and Natural Resources (DEWNR) to inform the Bioregional Assessment Programme in the Lake Eyre Basin. The three projects are:

- Lake Eyre Basin Rivers Monitoring,
- Arckaringa and Pedirka Groundwater Assessment and
- Lake Eyre Basin Springs Assessment.

The hydrological assessment and analysis of the Neales-Peake catchment forms part of DEWNR's Lake Eyre Basin River Monitoring (LEBRM) project. Formed to address knowledge gaps pertaining to the potential impacts of coal seam gas and large coal mining projects on the surface water resources of the LEB, LEBRM is driven by five key aims, namely to:

- Collate and interrogate baseline knowledge regarding the surface waters and water dependent ecosystems of the Lake Eyre Basin
- Identify the locations and attributes of surface water assets, including ecological and cultural values and the attributes critical for maintaining those values
- Collect new hydrological, geomorphic, ecological and cultural knowledge to better inform our understanding of LEB surface water systems, and to fill gaps in current knowledge
- Identify and collate processes and mechanisms through which mining developments may impact upon surface water resources, assets, attributes and values
- Identify surface water assets, attributes and values that are especially vulnerable to the potential impacts of mining developments.

2 Catchment description

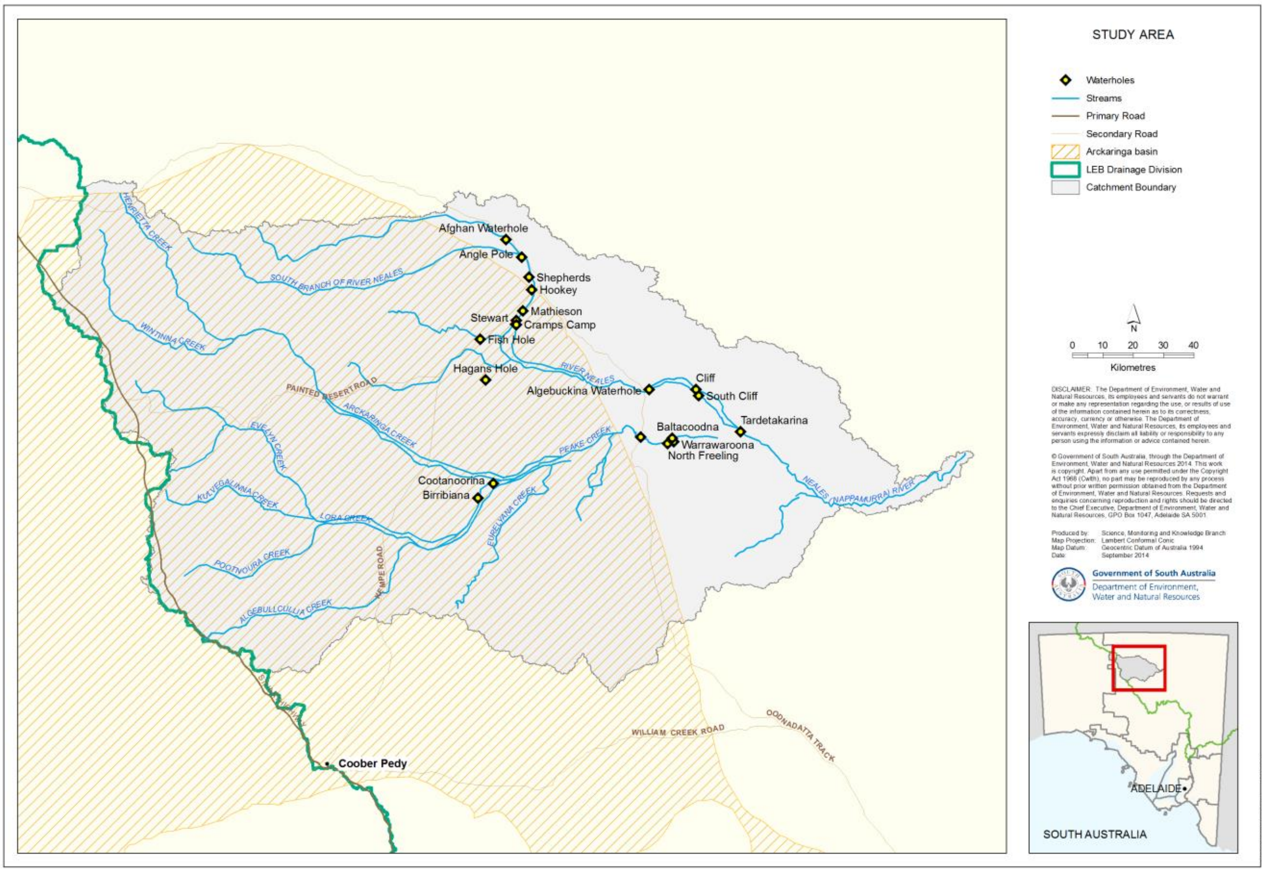
2.1 Overview

The Neales-Peake catchment (Figure 2.1) is an ephemeral, unregulated river system, consisting of the Neales and Peake Rivers and associated tributaries, with a total catchment area of 34 415 km^2. The headwaters of the catchment develop on the stony tablelands forming the western rim of the Lake Eyre Basin (LEB), at an elevation of 300–370 m, with the main drainage channel running 430 km before terminating at Lake Eyre North at approximately sea level (Costelloe et al., 2005).

The Neales River is approximately 270 km long from the upstream reaches to the delta apex. Its upstream reaches are divided into two branches (north and south) flowing easterly. Downstream from the confluence, the river follows a reverse-S shaped path, near Oodnadatta (the only population centre in the catchment). The Neales cuts through the north-northwest trending Peake/Denison Ranges in a narrow gap near Algebuckina Waterhole.

Downstream from the ranges, the Neales is joined by the Peake River. The Peake River is larger than the Neales in both length and drainage area. The Peake's main tributaries are Lora and Arckaringa Creeks (Wakelin-King, 2011).

Investigation of the Digital Elevation Model (DEM) shows the height and slope of the land within the LEB. Its elevation ranges from 374 m Australian Height Datum (AHD) at the western catchment boundary and 412 m AHD in the Davenport Range, down to -12 m AHD at the mouth of the Neales Delta (Figure 2.2).



Produced by: Science, Monitoring and Knowledge Branch
Map Projection: Lambert Conformal Conic
Map Datum: Geocentric Datum of Australia 1994
Date: September 2014

Figure 2.1 Neales-Peake catchment locality map

Characterised by complex, multiple anastomosing channels, shallow channel definition, wide floodplains and waterholes, the ephemeral watercourses of the Neales-Peake system most commonly flow in response to the more localized thunderstorm-derived rainfall. Such in-channel flow events occur 1–2 times per year and are important in maintaining aquatic refugia but have limited influence on the connectivity between waterholes. The volume of the waterholes is often quite small compared with flow in the system (approximately 5–280 ML; Costelloe et al, 2008) and so small runoff events in the main channel system are capable of filling waterholes to their maximum cease-to-flow level. The larger rainfall events result in runoff through much of the channel system, recharging the alluvial/floodplain groundwater stores and allowing widespread migration of aquatic fauna. The waterholes range from shallow (<1.0–2.5 m) ephemeral waterholes that only contain water for some months following a flow event, to rare deeper waterholes (2.5–4.5 m) that are near permanent (most notably, Algebuckina Waterhole).

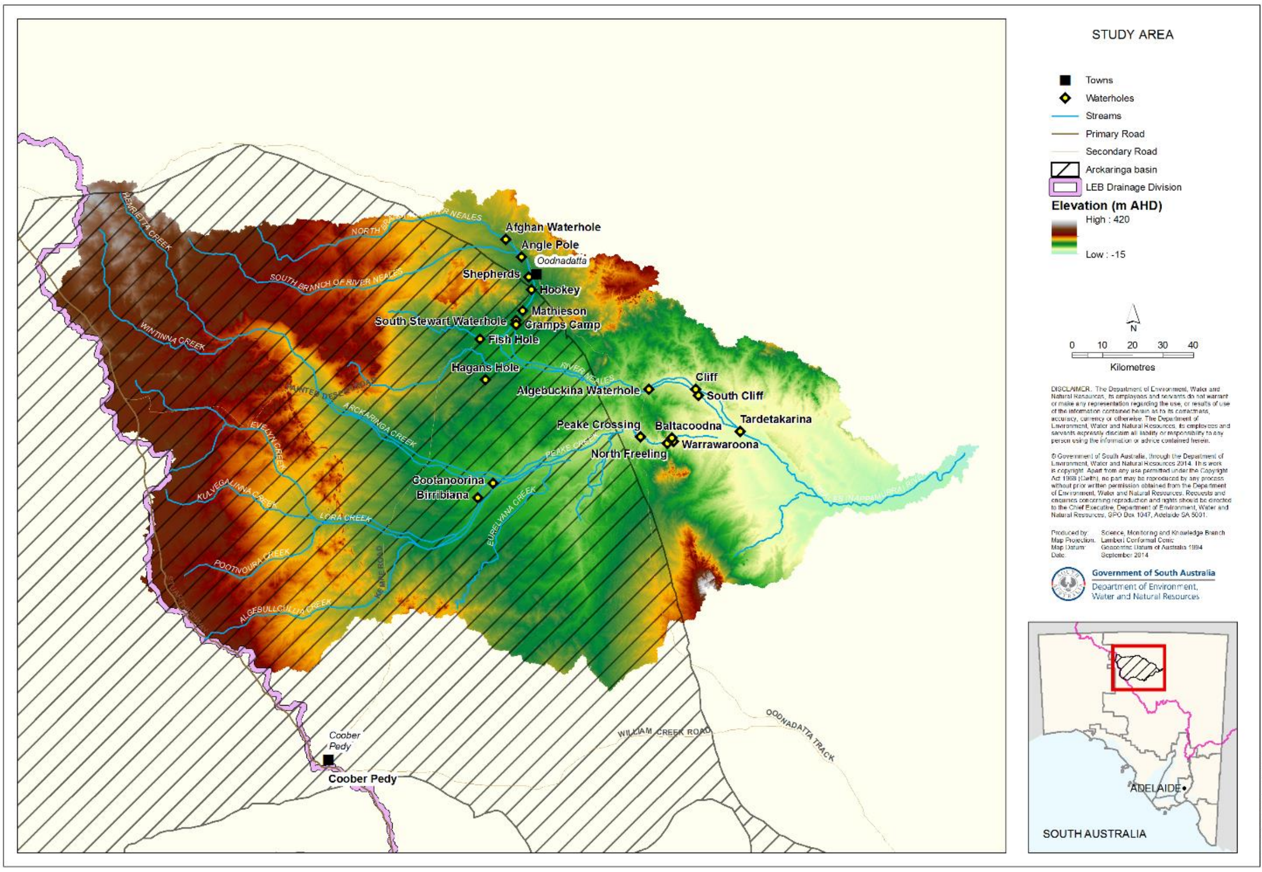


Figure 2.2 Digital elevation model (DEM) for the Neales-Peake catchment

2.2 Land use

The primary land use in the Neales-Peake catchment is pastoral.

2.3 Catchment delineation

For the purpose of modelling, the entire catchment was divided into discrete sub-catchments. Sub-catchment boundaries were derived using the ESRI Arc Hydro GIS extension based on the 1 second (~30 m) DEM of the region. Sub-catchment boundaries were delineated based on a number of factors, including location of in-channel waterholes, water level loggers and substantial contributing catchments where it was expected routing of upstream flows was required. This delineation was undertaken to assess the potential local impacts on the flow regime at a finer scale. The details of development and calibration of these models is provided in this section.

Figure 2.3 shows the delineated sub-catchments for the Neales–Peake catchment as constructed using ArcHydro. These sub-catchment areas form the basis of the hydrological model in Source. The set-up of the sub-catchments in Source (eWater Ltd., 2013; referred to as Source in this report) is outlined in Section 4.4.

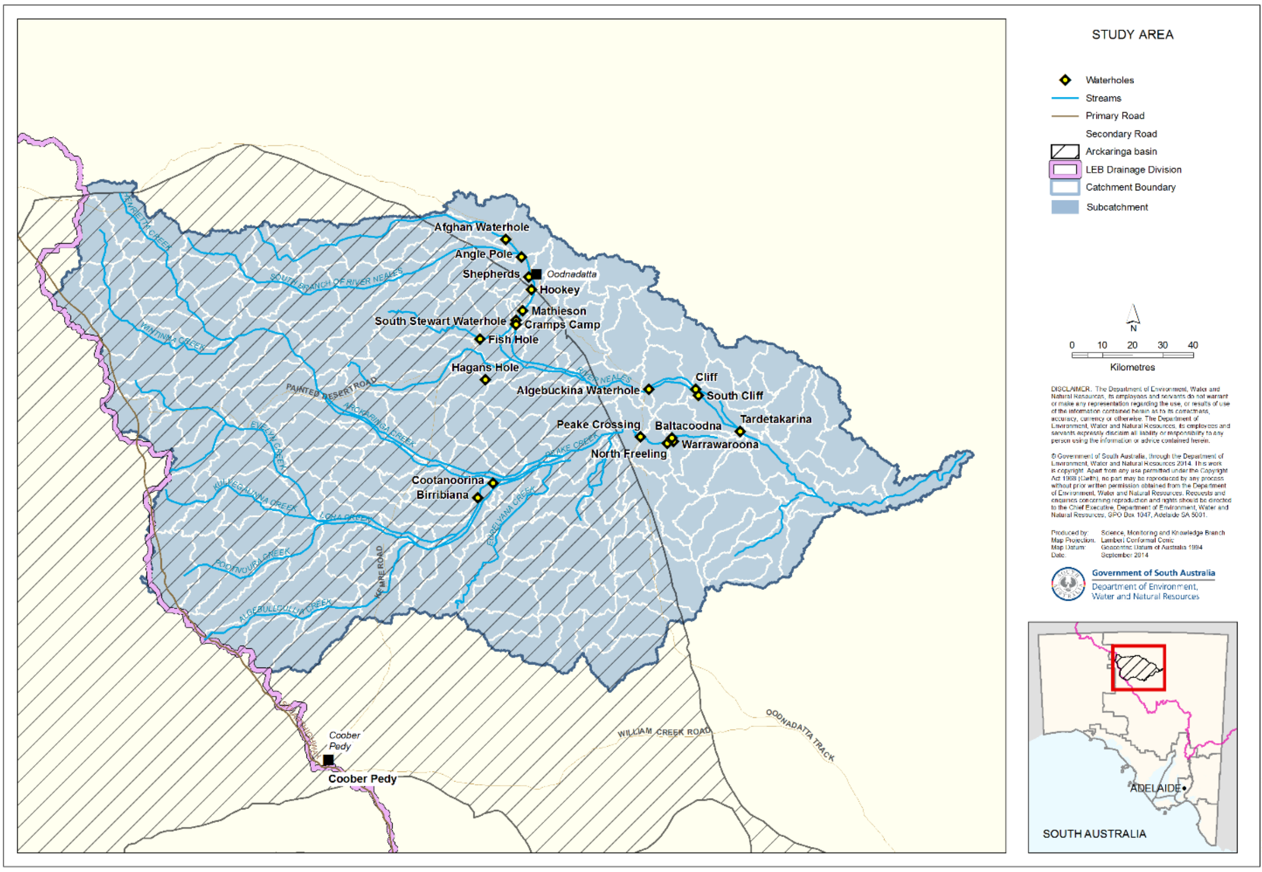


Figure 2.3 Delineated catchments for the Neales-Peake hydrological model

2.4 Waterholes

Previous work has surveyed 20 waterholes in the Neales-Peake catchment that have been identified as significant ecological refugia (Costelloe et al., 2004; 2005a; 2011a). The waterholes are shown in Figure 2.2 and their physical characteristics summarized in Table 2.1. In addition, depth–area–volume relationships for 20 waterholes were derived from previous surveys (Costello et al., 2004; 2005a; 2011a) (Appendix A).

The maximum depth of a waterhole when flow ceases (cease-to-flow depth; CTFD) has been found to be an important measure of how long water will persist in a waterhole (Costelloe et al., 2007), with persistence being of great significance to local biota. From Table 2.1 it can be seen that the CTFD of the key waterholes in the Neales-Peake tends to vary over time. This is likely a normal part of the long-term flood cycle, where large floods will scour some of the bed sediments of the waterholes, increasing CTFD, and smaller floods will deposit suspended sediments leading to increasing sedimentation of the waterholes and a decrease in CTFD. The precise mechanics of these processes are not fully understood at this time and therefore, data from the latest surveys are used in this hydrological modelling exercise.

Table 2.1 Physical characteristics of waterholes of the Neales-Peake catchment

Waterhole	2004 Survey Cease to flow depth (m)	2009–10 Survey Refugia cease to flow depth (m)	Bankfull width (m)	Bankfull depth (m)
Afghan (AF)	nm	1.20	32	2.2
Angle Pole (AN)	nm	2.16	24	2.7
Shepherds (SH)	nm	1.70	22	2.3
Hookey (HO)	nm	2.56	34	3.9
Mathieson (MA)	2.50	2.73	59	3.3
Stewart (ST)	2.60	3.23	52	3.7
South Stewart (SS)	2.40	2.53	23	3.9
Cramps Camp (CC)	2.60	3.85	44	4.4
Fish Hole (FH)	1.16	nm	47	1.8
Hagan Hole (HH)	nm	1.20	nm	nm
Algebuckina (AL)	4.50	3.45	70	7.9
South Cliff (SC)	2.50	2.40	85	3.3
The Cliff (CL)	0.86	1.28	24	2.2
Tardetakarinna (TA)	2.20	nm	40	3.6
Warrawaroona (WA)	nm	2.00	55	4.7
North Freeling (NO)	nm	0.30	nm	nm
Baltucoodna (BA)	nm	2.30	37	4.4
Peake (PE)	1.50	1.50	54	4.7
Cootanoorina (CO)	2.10	nm	50	2.5
Birribiana (BI)	1.80	nm	83	2.5

nm = not measured

3 Catchment hydrology

3.1 Climate data

3.1.1 Data availability

Rainfall data relevant to the study area take the form of either point data (e.g. at gauge locations) or spatially interpolated products. The sparse rain gauge network across central Australia means that for catchment modelling purposes it is necessary to use a spatially interpolated rainfall product. In a report produced for DEWNR, Ryu et al. (2014) evaluate four spatially distributed rainfall products for use in the Neales-Peake catchment. Along with three widely used remotely sensed products (TRMM, CMORPH and PERSIANN), the authors evaluate data produced through the Australian Water Availability Project (AWAP) that is interpolated via splines fitted to gauged data. Ryu et al. (2014) determined that TRMM data were the best performing remotely sensed data both in ability to replicate gauged events and in terms of a rank analysis of rainfall and streamflow stage. However, AWAP data were found to better replicate observed rainfall totals than all remotely sensed data and were used as the rainfall data source in this report.

The hydrological modelling of the Neales-Peake also requires potential evapotranspiration (PET) data in order to account for evaporation and water use from channels and waterholes throughout the catchment. PET data used in this report are Morton's Lake PET for the SILO station at Oodnadatta. SILO is an enhanced meteorological data bank providing data for over 4500 Bureau of Meteorology, BOM, stations around Australia from 1889 to present (Jeffrey et al., 2001). It is hosted by the Queensland Department of Science, Information Technology, Innovation and the Arts (DSITIA). SILO patched point data are original historical climate data for a particular BOM station where missing data or aggregated data have been in-filled (or "patched") using interpolated values. SILO data are available for Oodnadatta and this is the preferred source of PET data for this project because it is a consistent and continuous long term PET record which is independently verifiable and defensible.

3.1.2 Data analysis

In order to construct the Neales-Peake catchment model it was necessary for each sub-catchment to have a time series of rainfall data. These were calculated by considering the overlay of the AWAP grids on the sub-catchments layer and performing an area-weighted average of the rainfall files for the relevant overlying rainfall cells for each sub-catchment. PET for Oodnadatta was used for all sub-catchments.

3.2 Waterhole data

3.2.1 Data availability

There are no consistent discharge data available for the Neales-Peake catchment. Opportunistic flow measurements at Algebuckina Waterhole, have been collected during field trips in periods of flow recession and, in November 2000, a moderate flow event was observed (Costelloe et al., 2011a). This flood was sub-bankfull but utilised several channels in the anastomosing channel reach upstream of the waterhole. This enabled the development of a partial rating curve that was used in converting daily water level data into daily discharge estimates for the period April 2000 – February 2002 (Costelloe et al, 2005a). However, in that case the rating curve was deemed unreliable above the maximum gauged level (9000ML/d) as larger flows also enter another channel that bypasses Algebuckina Waterhole. As water level data are a function of channel morphology, this rating curve cannot be applied to other waterholes for the same time period, or indeed to stage data for Algebuckina Waterhole itself at a different time owing to the inherent variability of cease-to-flow depths (CTFDs) in the catchment.

Although there are limited flow data, stage data of varying quality and length have been collected for four waterholes over the period 2000-2013 for the Neales-Peake catchment. Owing to malfunctioning loggers, disturbance from local fauna, theft and varying installation and removal dates, there is little consistency in data collected across waterholes and no single waterhole has continuous data for that period (JF Costelloe (University of Melbourne) 2010 pers. comm.), however the data collected are invaluable and were utilized in this hydrological analysis.

Stage data for Algebuckina Waterhole represent the most complete set of water level data in or nearby the region and are shown in Figure 3.1. Data shown represent a merging of data collected through multiple loggers installed through the ARIDFLOW project (Costelloe et al., 2004), Critical Refugia Project (Costelloe, 2011a) and a telemetered gauge installed by DEWNR in 2011, with post-processing necessary to ensure consistency throughout the period of record (JF Costelloe (University of Melbourne) 2010 pers. comm.).

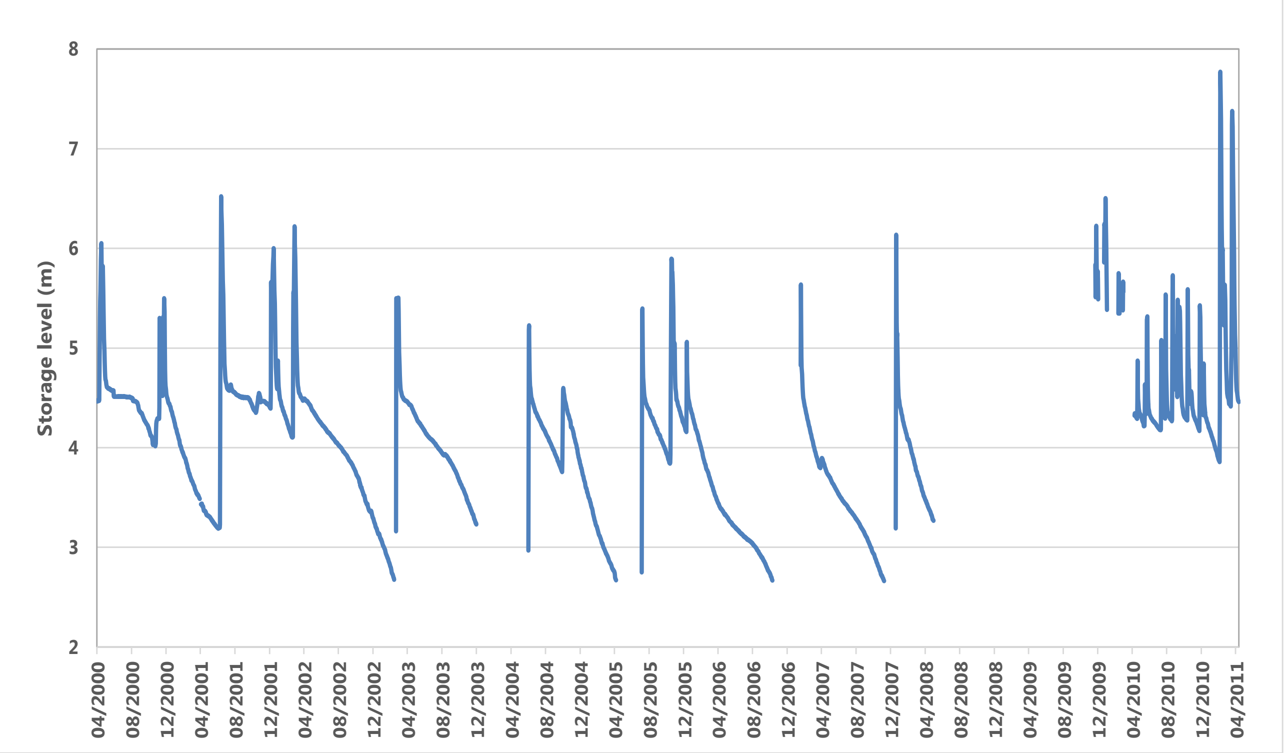


Figure 3.1 **Algebuckina Waterhole stage data**

3.2.2 Data analysis

Given the lack of data for the calibration process, flows generated from the model were converted into water levels in waterholes and compared with observed stage data. To undertake this, a water balance model is required to take the modelled inflows from a rainfall-runoff model as input and represent the water level in each water hole.

Each storage in the model requires a depth–area–volume relationship to allow the volume in storage to be converted into a depth (the key variable in the calibration process), as well as an area to allow the net effect of rainfall and evaporation from the water surface to be taken into account.

Apart from morphological data, loss rates (loss rates are driven by potential evapotranspiration plus loss to the unconfined aquifer) are required for each waterhole to characterize the waterhole behavior. Reliable measurements of CTFD in conjunction with vegetation surveys have enabled robust estimation of potential evapotranspiration (ET). Work by Russel (2009) has demonstrated that some waterholes in the catchment (South Stewart, Cramps Camp Waterholes) experience losses in excess of calculated evapotranspiration (ET). This suggests that some water is lost to the unconfined aquifer reducing the persistence of the waterhole between flow events. The same research showed that Algebuckina Waterhole largely loses water at the ET rate further enhancing its importance as the ark refugia in the region (McNeill et al., 2011).

Two types of loss rates (Figure 3.2) from a previous study (Costelloe, 2011a) were utilised in a simple water balance model for waterholes with the available stage data and were compared with drawdown rates to identify which loss rate type should be applied for each waterhole. For the rest of the waterholes where there is no stage data available, field observations (approximate timing from filling to drying states) were used to adopt one of those two loss rates. From these comparisons the uncertainty of the duration of drying period is likely to be less than two months.

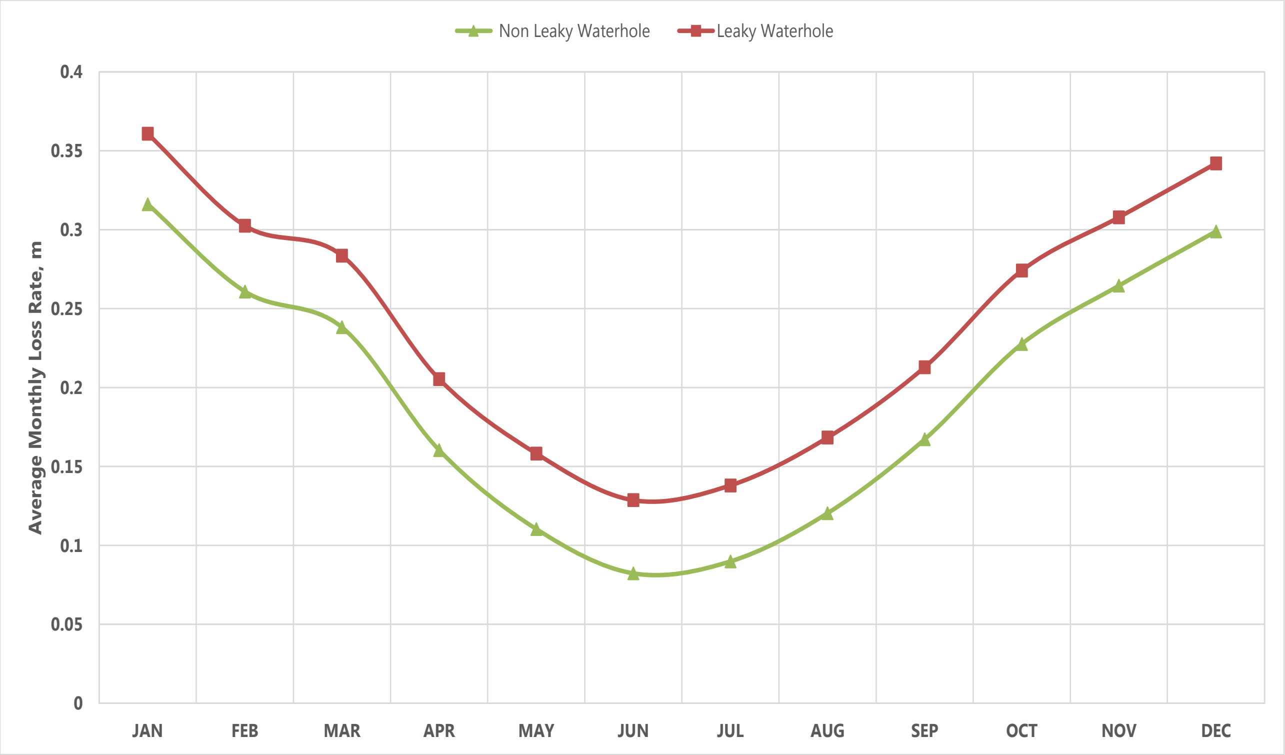


Figure 3.2 **Average monthly loss rate for Neales-Peake catchment waterholes**

Waterholes are categorised based on their loss rates in Table 3.1. The variability in loss rates across the region suggests that the waterholes located at the upper part of the catchment have higher loss rates than the waterholes in the downstream part which is consistent with the fact that the groundwater table is deeper in the upper part of the catchment than in the lower part. Storage dimensions and daily time series of total loss (Evaporation + Seepage) were imported into each storage node in the model using the storage editor's window, further details of which are presented in the next section.

Table 3.1 Waterhole types

No.	Name	Type	
1	Peake	Non Leaky	Ground water-fed
2	Tardetakarinna	Non Leaky	Ground water-fed
3	Warrawaroona	Non Leaky	Ground water-fed
4	Baltucoonda	Non Leaky	Ground water-fed
5	Fish Hole	Non Leaky	Surface water-fed
6	Hagan Hole	Non Leaky	Surface water-fed
7	Birribiana	Non Leaky	Surface water-fed
8	The Cliff	Non Leaky	Surface water-fed
9	South Cliff	Non Leaky	Surface water-fed
10	Algebuckina	Non Leaky	Surface water-fed
11	Cramps Camp	Non Leaky	Surface water-fed
12	Afghan	Leaky	Surface water-fed
13	Angle Pole	Leaky	Surface water-fed
14	Cootanoorina	Leaky	Surface water-fed
15	Shepherds	Leaky	Surface water-fed
16	Hookey	Leaky	Surface water-fed
17	Mathieson	Leaky	Surface water-fed
18	Stewart	Leaky	Surface water-fed
19	South Stewart	Leaky	Surface water-fed

4 Surface water modelling

4.1 Overview

Reliable estimates of arid zone streamflow are required to inform and support policy and decision makers in water planning and management. A variety of methods are available to determine or estimate routed streamflow through catchments. Observed data are best wherever possible, but alternatively, estimates can be provided by using empirical and statistical techniques, and more commonly using hydrological models (Vaze, et al., 2012, p. 5).

Hydrological modelling can be undertaken using a range of approaches, such as, simple empirical methods, large scale energy-water balance equations, conceptual hydrological models, landscape hydrological models and fully distributed physically based hydrological models. The choice of modelling approach is driven by various factors, with problem definition (purpose of the modelling exercise) and data availability being two key factors. Conceptual hydrological modelling is the commonly used category for investigations of this type. Description of other hydrological modelling categories and their applications are provided in 'Guidelines for rainfall-runoff modelling: Towards best practice model application' (Vaze, et al., 2012).

Conceptual hydrological models are simplified conceptual representations of different components of the hydrological cycle and the interactions between them (e.g. rainfall, evaporation, interception, storage, infiltration, surface runoff, groundwater recharge and base flow). These components and their interactions are described mathematically by equations that form the basis of the model.

4.2 Modelling objective

The objective of this modelling was to deliver a tool that will (i) aid in assessing the impacts on the flow regime if mining operations were to within the Neales-Peake catchment and (ii) aid in ecohydrological assessment of the region. To address this objective a hydrological model was built and calibrated to observed stage data in the region.

4.3 Methodology

The hydrological modelling platform used for this study was Source (Carr, R, Podger, G., 2012). Source is a nationally recognised hydrological modelling platform that has been developed as part of an Australia-wide collaboration and which has been endorsed by the Australian Government. Source is a PC-based rainfall-runoff and flow routing water balance modelling platform.

Within Source, a model is constructed as a series of nodes and links which are connected based on the drainage direction of the catchment being modelled. Each node/link can represent different components of the water balance, such as:

- confluences (the meeting of two or more streamlines)
- splitters (locations where the channel branches into two or more drainage lines)
- storages (lakes, waterholes, etc.)
- inflow nodes (locations where flow is added to the system).

A hydrological model has been constructed and calibrated in Source for the Neales-Peake Catchment using delineated sub-catchments, observed daily rainfall data, evaporation data, stage data, waterhole properties (e.g. volume and surface area), and estimated catchment parameters.

4.4 Model construction

Model construction is the process of:

- delineating the catchment into sub-catchments (described in Section 2.3)
- creating and parameterising nodes and links to represent the hydrological components, behaviour and characteristics of the catchment
- defining the interactions between the various processes of the hydrological cycle included in the model.

4.4.1 Nodes

4.4.1.1 Confluences

Confluences or catchment nodes incorporate information about the inflows from the sub-catchment area they are assigned to, such as:

- sub-catchment area
- rainfall and evaporation data for the station associated with the sub-catchment
- model catchment parameters for the functional units within the sub-catchment
- spatial location.

4.4.1.2 Storage nodes

Storage nodes are used to simulate the water balance model for each individual waterhole. Input data required for a waterhole water balance model include:

- depth-area-volume relationship
- initial volume (assumed to be empty)
- rainfall data for the waterhole location
- loss rate from the waterhole (evaporation + leakage to groundwater)
- spillway information.

Assumptions and information regarding waterholes are given in Section 3.2.

4.4.1.3 Controlled splitter nodes

Controlled splitter nodes are used to split the sub-catchment flow according to the ‘free-to-flow’ area (as a proportion of the total sub-catchment area), allowing floods to flow to two parallel waterholes. These nodes distribute flow down a main and an effluent branch according to a fixed percentage that can be a function of flow. There are two splitter nodes in the source model for Neales-Peake catchment and it is assumed that flow is equally distributed between main and effluent branches since no evidence suggested that one branch was preferred over another.

4.4.1.4 Gauge nodes

Streamflow gauges nodes represent the location of a site with streamflow records. This is only used in model validation, since there is no cross sectional information at the location of the stage loggers to convert stage data to flow. However, data at these points can be used to validate the timing of floods across the whole catchment.

Figure 4.1 is a schematic of the hydrological model built in Source for the Neales-Peake catchment.

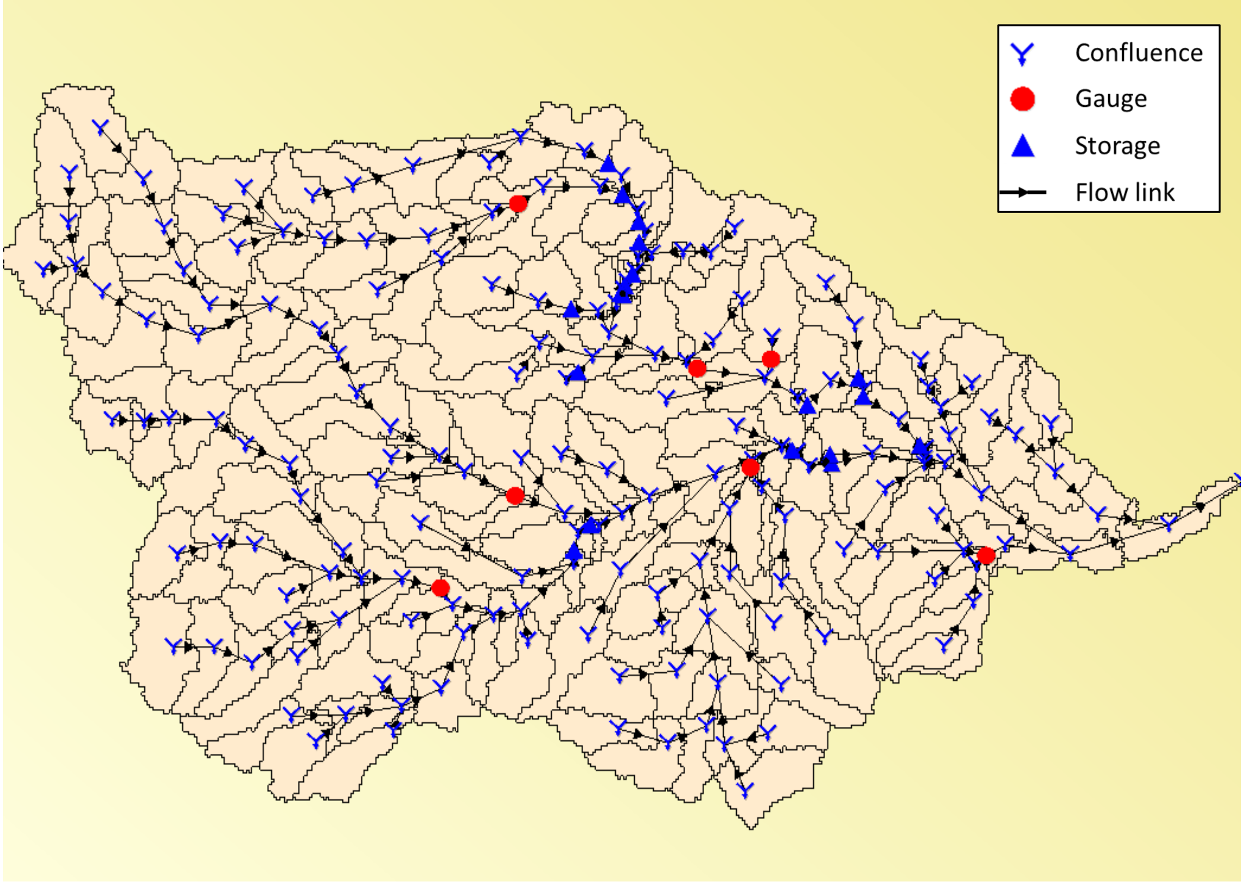


**Figure 4.1	Node-link model schematic of Neale-Peake catchment**

### 4.4.2	Rainfall-runoff model

In this study AWBM (Boughton, 2004) was used, which is a commonly used and one of the many available rainfall–runoff models within Source. The AWBM rainfall–runoff model (Figure 4.2) uses rainfall and evaporation data inputs to calculate the net rainfall input for a sub-catchment. This rainfall then fills a number of soil stores (C1 to C3) of variable areal extent (A1 to A3) which are subject to evaporation before the excess becomes runoff. The total runoff is partitioned into surface runoff and sub-surface storage by the use of the base flow recharge parameter, before the release of the sub surface flow (base flow). The surface runoff storages are routed by recession coefficients to delay the timing of flows to the downstream node. The process is repeated for each sub-catchment in the system.

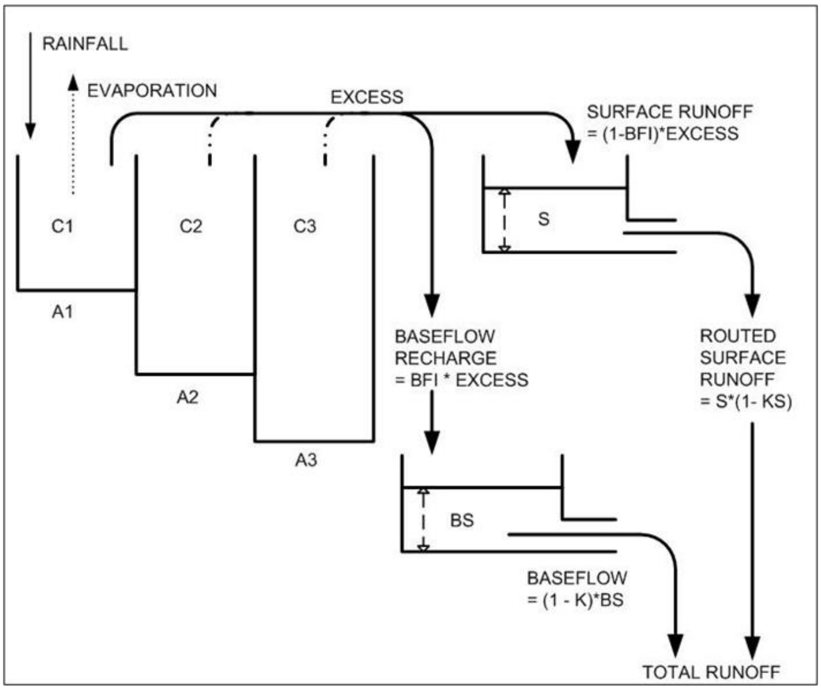


Figure 4.2 Schematic of the AWBM rainfall-runoff model (Boughton, 2004)

4.4.3 Flow routing and transmission loss model

The routing model is required to be implemented in links in Source to represent transmission losses and for routing of discharge along the reach (reaches are represented by links in Source). There are several methodologies available to perform routing and transmission losses within Source. Transmission losses in arid land rivers are mostly due to evapotranspiration, infiltration and ponding in ephemeral pools. Parameters such as width and length of the channel, soil type and stream gradient have relative importance in estimating the losses. However, given the large range of uncertainties in estimating any of these parameters, a simpler approach was incorporated that assumes all channels (links) between sub-catchments are of equal length and also the soil type is fixed across the whole catchment. The routing formula incorporated in each link in Source is:

$$S = KQ^m + L_T \text{ , where}$$
$$L_T = min[Q_{UPSTREAM}, a \cdot Q_{UPSTREAM} + b]$$

Where: S is the storage volume in the reach (ML)
K is the storage constant (Seconds)
Q is the discharge or outflow rate (ML/day)
m is a dimensional empirical exponent, a measure of the non-linearity of the model
a is a dimensionless ratio
b is an initial loss in the reach (ML/day)

The value of m was set to m = 0.8, which is the recommended starting value for non-linear routing (eWater Ltd., 2013). The remaining parameters, *K*, *a* and *b* were derived from the rainfall-runoff model calibration process to match the peaks between the modelled and observed water levels at the waterholes.

4.5 Model calibration and validation

Model calibration is a process of optimising model parameter values to get a set of parameters which provides the best estimate of the observed streamflow (Vaze, 2012). By comparing modelled data against observed records, the degree of correlation between the two datasets can be assessed. The iterative process of varying catchment input parameters is undertaken until a 'good correlation' is achieved between the simulated and observed datasets. The purpose of calibration is to ensure the model is able to adequately represent the hydrological behaviour of the catchment.

Model validation is usually a process of using the calibrated model parameters to simulate runoff over an independent period outside the calibration period (Vaze, 2012). This is undertaken to evaluate the suitability of the calibrated model for predicting runoff over a period outside the calibration period. Validation is considered an important step in the modelling process as it increases the confidence in the ability of the model to undertake prediction. However, in this study different characteristics of the catchment were studied as validation process. For example, there are some waterholes with no stage data available to be used for calibration, but there are some field observations that indicate when those waterholes dried. These observations were then used to validate the calibrated parameters.

AWBM, which is one of the catchment rainfall-runoff models in the Source platform, was used in this study. A description of the model is provided in Section 4.4.2. The input parameters that were varied during calibration were the parameters of the AWBM rainfall-runoff model and the input parameters of the routing and transmission loss model across the catchment. These parameters are listed in Appendix B.

For the purposes of this study, 'good correlation' involved visual and statistical comparison of observed and simulated storage level data at daily timescale. This is further discussed in Section 4.5.2.

4.5.1 Calibration method

The inbuilt Source 'Calibration Wizard' was considered not appropriate for use in this study, as it requires adequate flow data to perform a calibration analysis. As discussed in Section 3.2.1, since adequate flow data are not available for this region, water level records were instead used for calibration. The water level records for the following waterholes were used for calibration:

- Algebuckina
- Afghan
- South Stewart
- Peake

Manual calibration was performed to produce one optimum set of inputs (Appendix B) and assist the process of predicting flow data that accord with daily stage data. To undertake this, input parameter sets for the AWBM rainfall-runoff model were populated with pre-calibrated model parameters provided through Ryu et al., 2014 with the model then run iteratively and selected statistical measures checked to achieve the best calibration possible. Visual comparison of the two datasets at daily timescales was also used.

4.5.2 Calibration results

The following statistical measures were used to verify the effectiveness of calibration:

- Percentage difference from mean
- Coefficient of determination (R2)
- Nash-Sutcliffe coefficient of efficiency (NSE).

Using the statistical measures listed above, observed and modelled storage levels in waterholes were compared at a daily timescale. The two datasets at a daily timescale for each studied waterhole are shown in Figure 4.3 to Figure 4.6.

A summary of daily calibration statistics is provided in Table 4.1.

Table 4.1 Daily calibration statistics

Measures	Afghan WH		Sth Stewart WH		Algebuckina WH		Peake WH	
	Observed	*Modelled*	*Observed*	*Modelled*	*Observed*	*Modelled*	*Observed*	*Modelled*
Mean (m)	1.12	1.23	2.31	1.95	4.04	4.09	1.74	1.61
Median (m)	1.06	1.17	2.35	2.1	4.13	4.32	1.69	1.72
R^2	0.64		0.57		0.65		0.31	
NSE	0.21		0.09		0.19		-1.29	
% Difference from mean	9.48%		18.41%		1.23%		-7.27%	

R^2 describes the proportion of the variance in these data that can be explained by the model. R^2 can range between 0 and 1.0, with higher values (i.e. closer to one) describing a better fit.

NSE defined by Nash and Sutcliffe (1970) is the ratio of the mean square error to the variance subtracted from one. It can range between -∞ (negative infinity) and 1.0. A value of one describes a perfect fit, a value of zero indicates that the mean value for the time step is an equally good predictor than the model, and a value of less than one indicates that the mean would be a better predictor than the model.

The R^2 and NSE values (Table 4.1) for the each of the waterholes used for calibration indicate a good correlation between observed and modelled data. Investigation of the daily hydrographs indicate, that in general, the model is able to simulate most of the flow events and their duration quite close to the observed events. However, the difficulty appears to be in the simulation of the magnitude of those events as shown in Figure 4.3 to Figure 4.6.

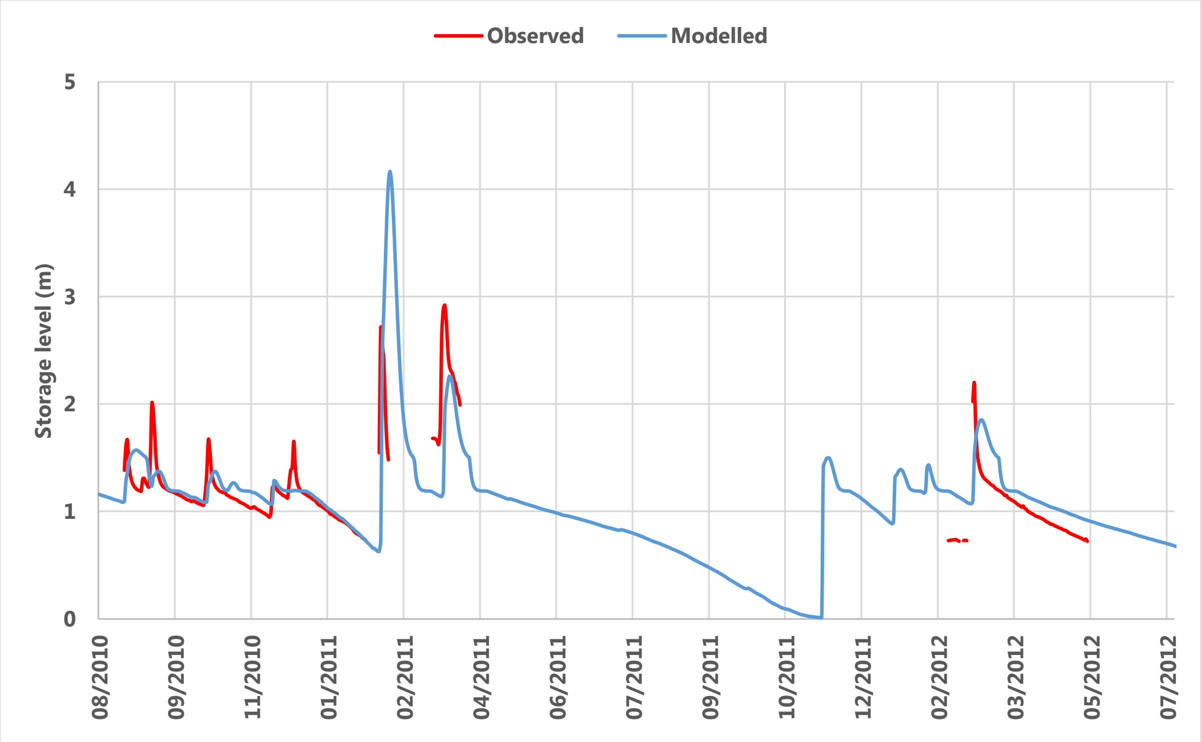


Figure 4.3 Observed and modelled water levels for Afghan Waterhole

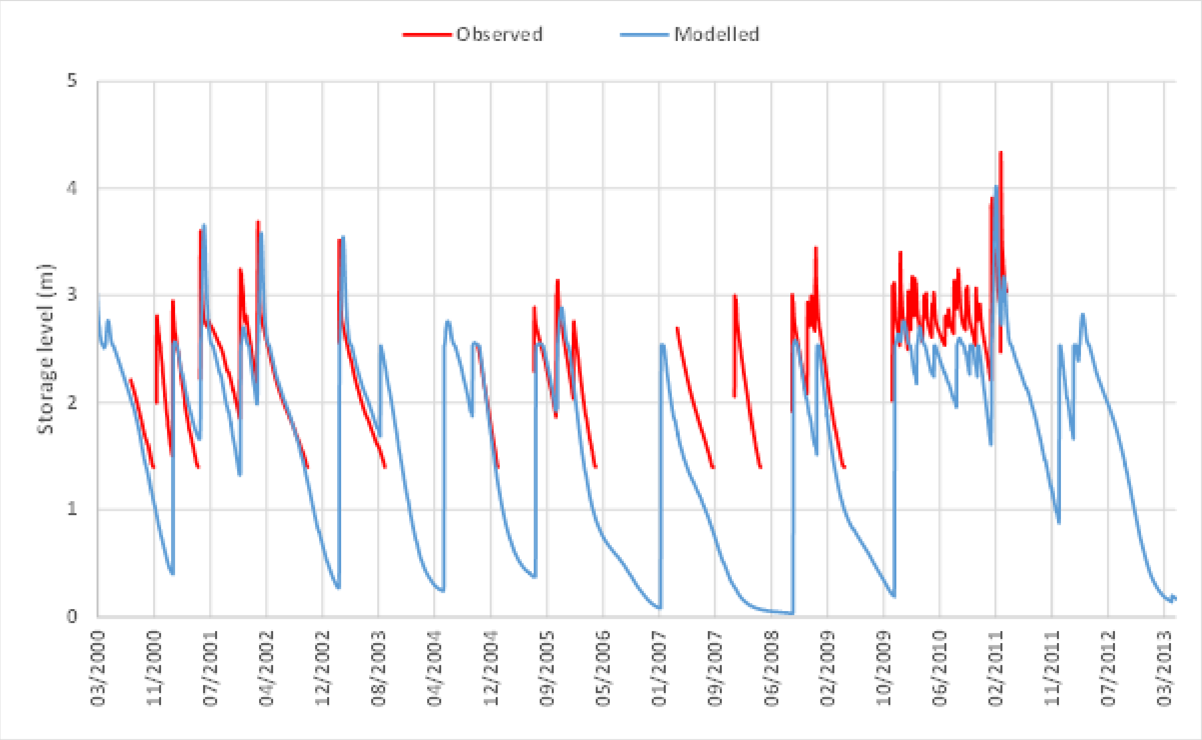


Figure 4.4 Observed and modelled water levels for South Stewart Waterhole

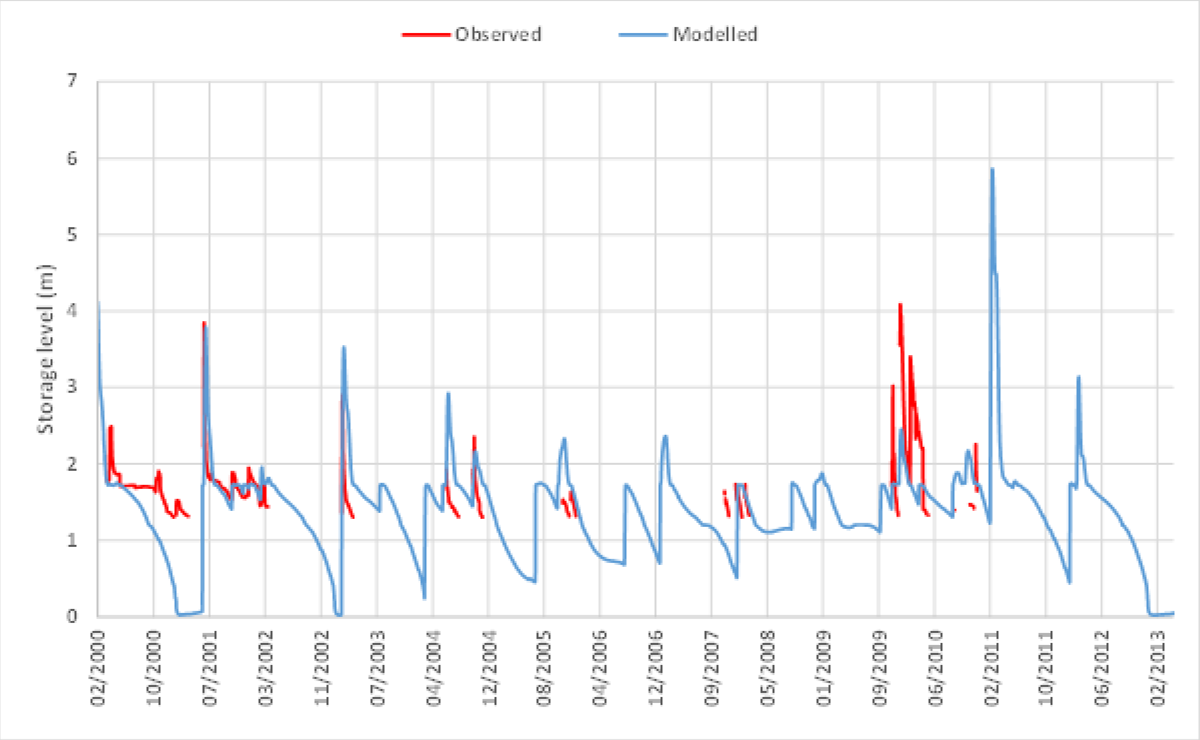


Figure 4.5 Observed and modelled water levels for Peake Waterhole

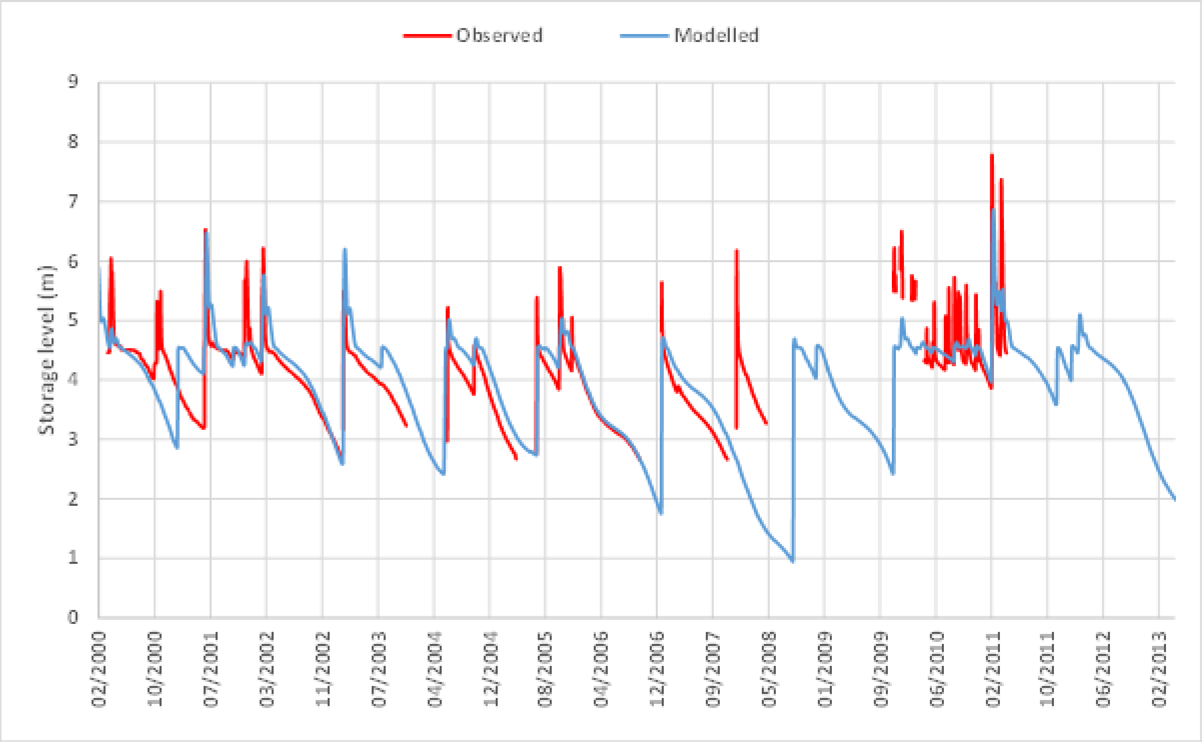


Figure 4.6 **Observed and modelled water levels for Algebuckina Waterhole**

4.5.3 Validation

Due to the limited available data, the complete datasets were used for calibration, leaving no independent data available for validation. For this reason, field observations regarding the timing between filling and drying of waterholes were used where available to validate model parameters. Available field observations are shown in Table 4.2, modelled water level data were compared with field observations in five waterholes to determine the level of confidence. From Figure 4.8 to Figure 4.12 it can be seen that the model is able to reproduce the timing between filling and drying of the waterholes very well.

Table 4.2 **Field observation**

No.	**Waterhole**	*Time when observed Full*	*Time when observed empty*
1	Shepherds	March 2012	May 2013
2	Hookey	March 2012	May 2013
3	Mathieson	March 2012	May 2013
4	Stewart	March 2012	June 2013
5	Cramps Camp	March 2012	October 2013[1]

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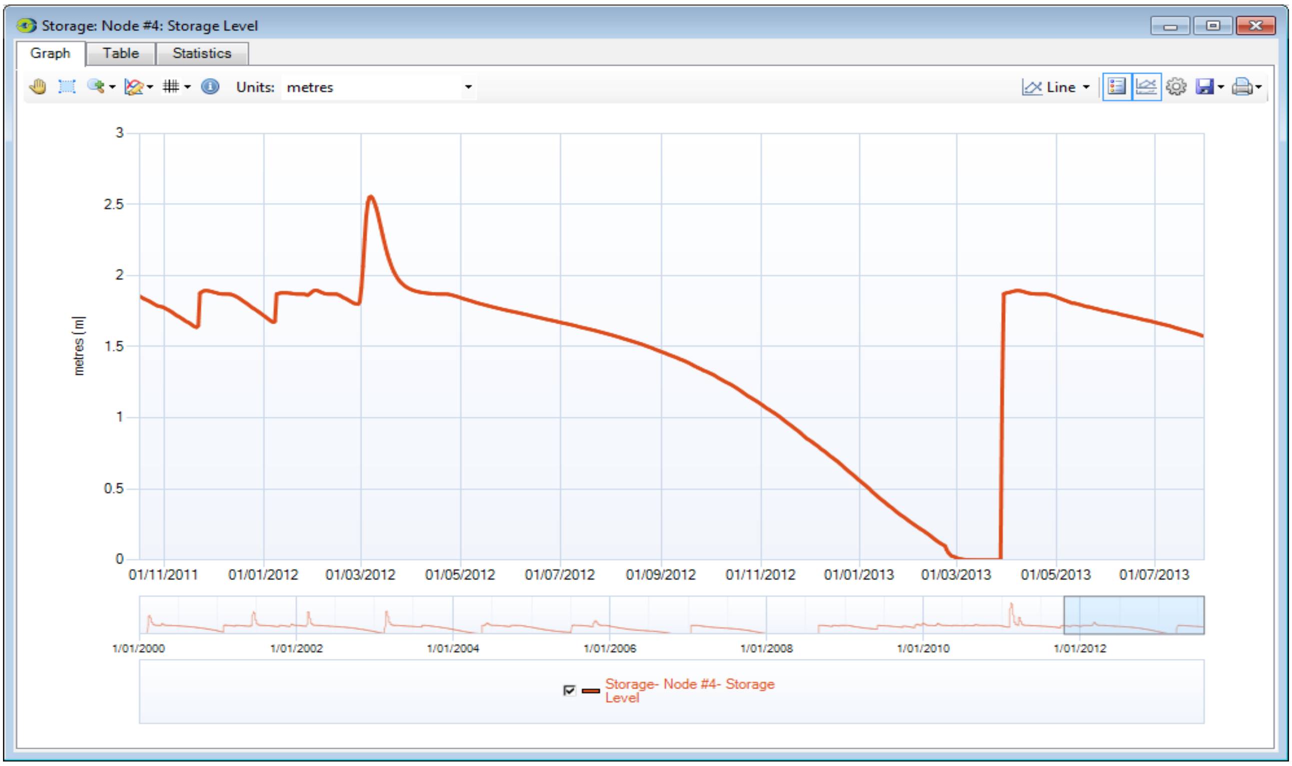
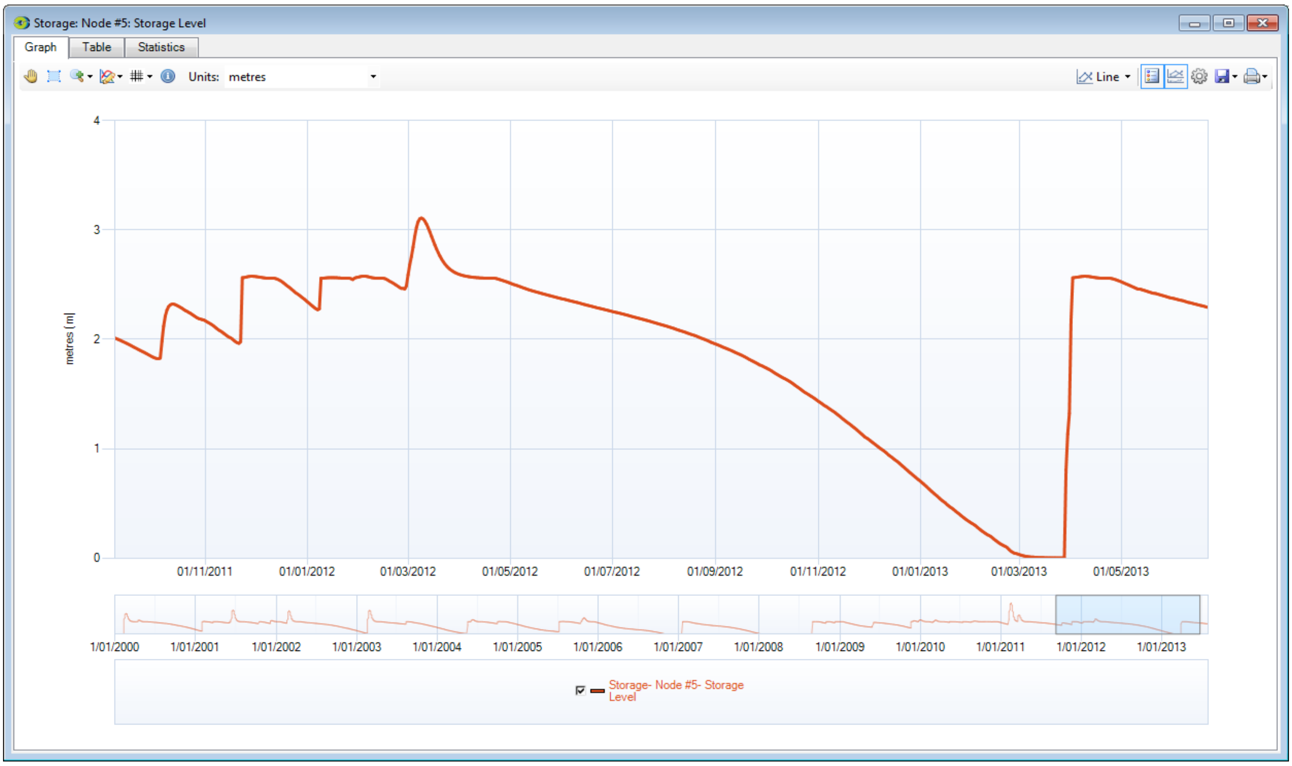
[1] The study period ends on 30 July 2013, however from Figure 4.12 it is expected that the waterhole dries up around October 2013



Storage: Node #4: Storage Level

Units: metres

Figure 4.8 **Storage level for Shepherds waterhole**



Storage: Node #5: Storage Level

Units: metres

Figure 4.9 **Storage level for Hookey waterhole**

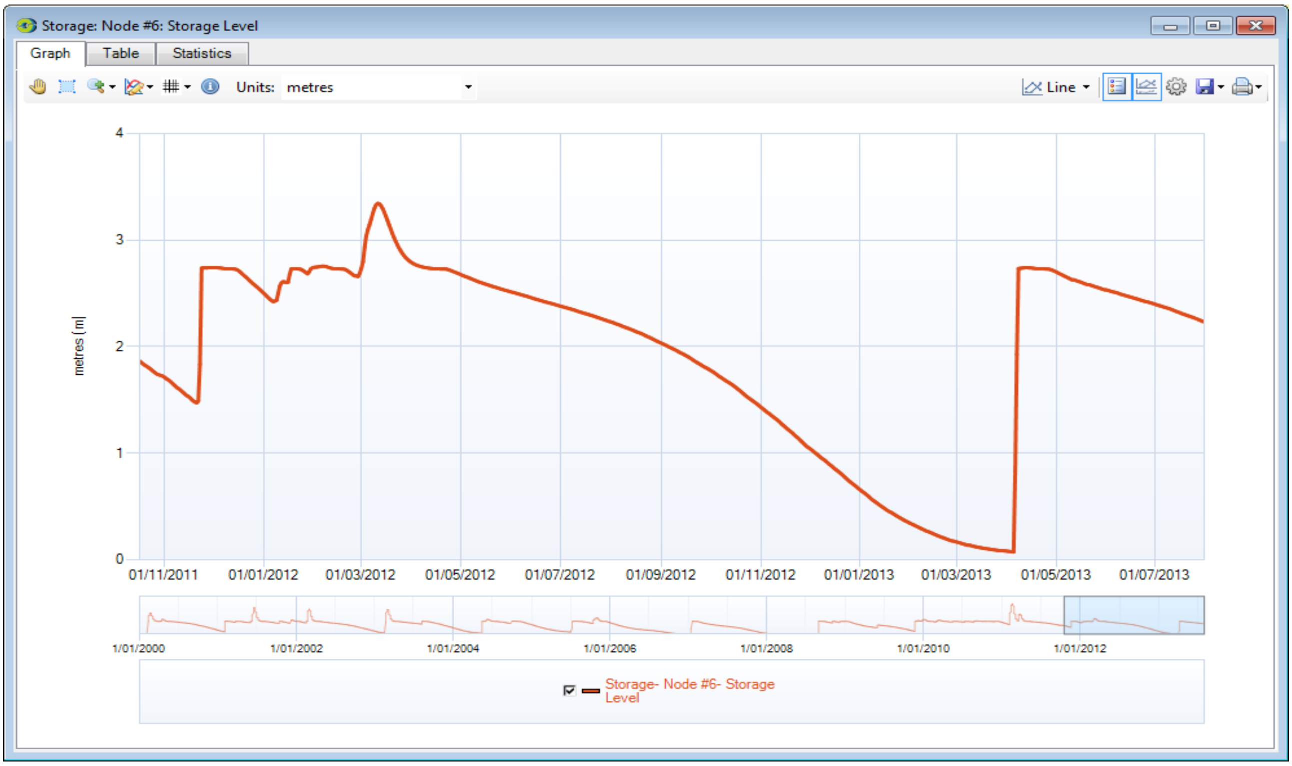


Figure 4.10 Storage level for Mathieson waterhole

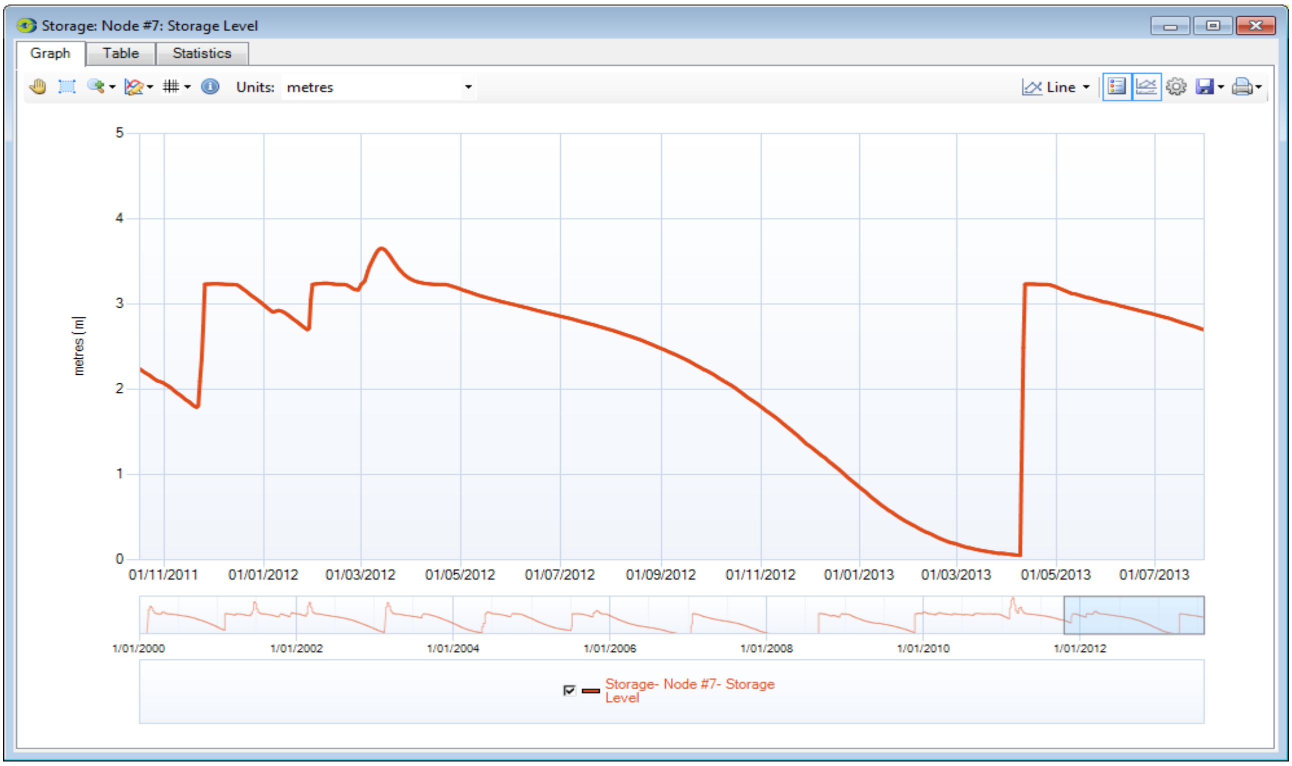
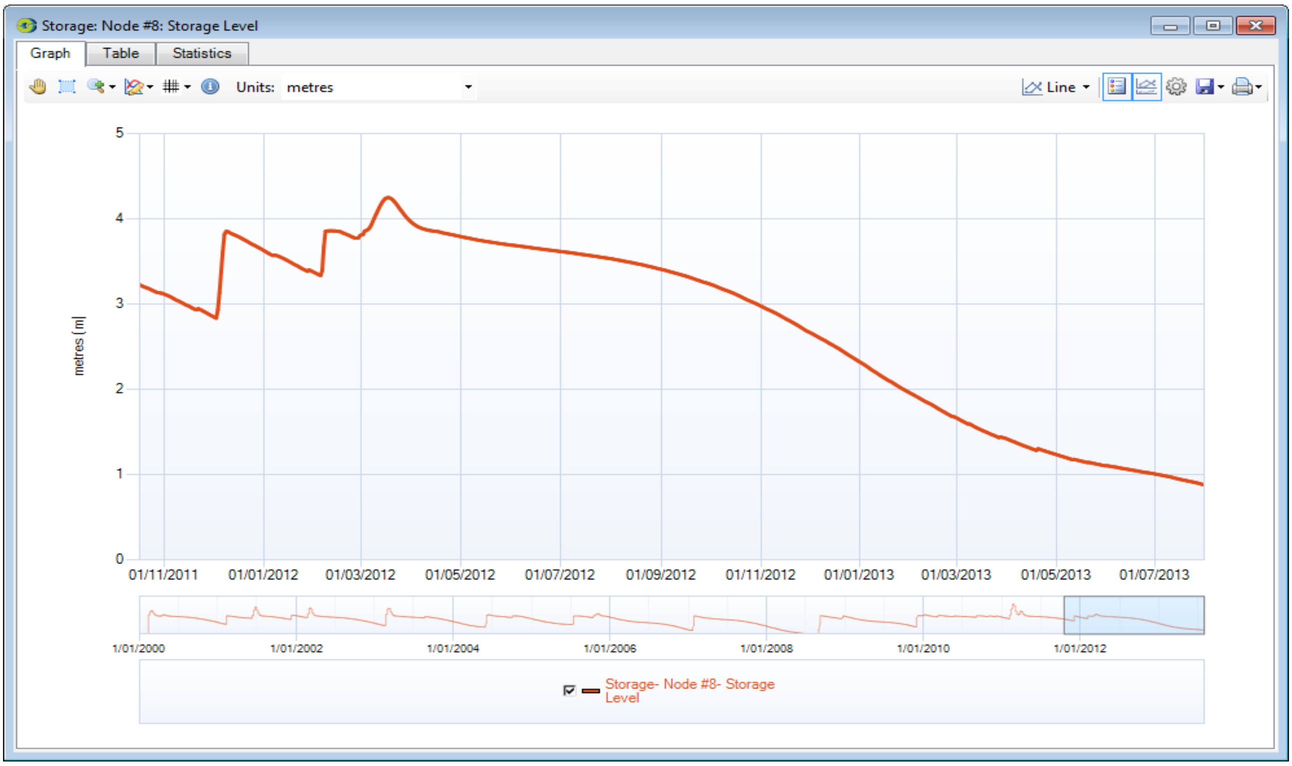


Figure 4.11 Storage level for Stewart waterhole


Storage: Node #8: Storage Level

Units: metres

Figure 4.12 **Storage level for Cramps Camp waterhole**

The model should be considered limited in its ability to estimate flow data and the measurement of flow out of key waterholes can definitely improve the model in replicating the volumetric data. In addition, a detailed analysis of enhanced satellite imagery could lead to a better understanding of the hydrograph and a more complete hydrological understanding of the complex system.

Finally, the use of two classes of routing and transmission loss parameters should be revisited. Although modelling the system in all its complexity is beyond the scope of this current work, additional hydrologic data would enable construction of a slightly more complex routing model. Through cross-comparison with satellite imagery it would be possible to determine at what volume floodwaters overtop channels in the channelized country and access portions of the outer floodplain in the lagoon, registering higher losses in both cases, providing requisite information for a switching model in terms of routing and losses for both sections.

5 Summary and recommendations for future work

This report details the construction of a rainfall-runoff and flow routing model for the Neales-Peake catchment in the Source modelling platform. The model uses the Australian Water Balance rainfall/runoff Model (AWBM) to generate runoff for 177 sub-catchments and routes this flow through the system to discharge at Lake Eyre North, accounting for 20 waterhole storages. Detailed bathymetry of the waterholes in the system, in addition to observations regarding surface-water/groundwater interactions at the waterholes, was incorporated into the model, ensuring that waterhole dynamics were accurately represented by the model.

The model was calibrated by comparing modelled stage heights with those heights observed at four key waterholes. The limited and patchy nature of the data coverage over the study region means that traditional calibration statistics may be misleading. This being said, the model was able to reproduce observed stage, with an average difference of 6.5% between modelled and observed median stage height across the waterholes. This translated to an average difference of approximately 9% in average storage volume. Additionally, it was shown visually that the model tended to replicate the timing of events very well. At each waterhole the model struggled to identify some smaller flow events, in particular multiple flow events, however it did not register any false positives and as such was considered fit for purpose.

To assist in validating the model, the wetting and drying cycles at waterholes were compared with field observations. The model was also able to reproduce these observations, within one month of what was observed. Given the vagaries surrounding the timing of field observations, this can be regarded as a reasonable result which indicates that the flow routing models are consistent with observations.

Although the model is able to reproduce the timing of observed events in the system very well, the model should be considered limited in its ability to estimate the magnitude of the events. The lack of volumetric information to calibrate the model means that it is not possible to estimate confidence surrounding simulated discharge volumes.

Recommendations for future work fall into two complementary categories, data collection and model refinement. By conducting flow gaugings at strategic locations throughout the system a measure of confidence in simulated flow volumes could be gained. Additionally, more detailed information regarding the surface-water/groundwater interactions at waterholes and throughout the system would enable a more complete representation of the hydrological dynamics of the catchment. Data that have been collected are often inconsistent owing to malfunctioning loggers, disturbance from local fauna, theft and varying installation and removal dates. Establishment of a more permanent monitoring network and the collection of data that come from such a network would enable continuous refinement of model parameters and deliver a better understanding of the hydrology of the system.

The Neales-Peake Catchment has a varied geography, containing a diverse range of country – from the red sands of the Pedirka Desert to the hard packed clays of the gibber pans. Furthermore, the watercourses of the Neales-Peake are equally varied, ranging from well-defined incised channels to poorly channelized floodplains. As such, it is unlikely that the rainfall-runoff response and transmission losses will be consistent throughout the catchment as considered in the model. More comprehensive data on land type, supplemented by hydrological observations, would allow the calibration of discrete rainfall-runoff and transmission loss models within sub-regions of the catchment that share similar geography and hydrology.

6 References

1 Boughton, W. C. (2004) The Australian water balance model, Environmental Modelling and Software, 19,943-956.

2 Costelloe J. F., Hudson P. J., Pritchard J. C., Puckridge J. T. and Reid J. R. W. (2004) ARIDFLO Scientific Report: Environmental Flow Requirements of Arid Zone Rivers with Particular Reference to the Lake Eyre Drainage Basin.Final Report to South Australian Department of Water, Land and Biodiversity Conservation and Commonwealth Department of Environment and Heritage. School of Earth and Environmental Sciences, University of Adelaide, Adelaide.

3 Carr, R., Podger, G., 2012. eWater Source - Australia's next generation IWRM modelling platform, 34th Hydrology and Water Resources Symposium December 2012.

4 Costelloe J. F., Grayson R. B. and McMahon T. A. (2005a) Modelling streamflow in a large ungauged arid zone river, central Australia, for use in ecological studies. Hydrological Processes 19: 1165-1183.

5 Costelloe J. F., Shields A., Grayson R. B., and McMahon T. A. (2007a) Determining loss characteristics of arid zone river waterbodies. River Res. Appl. 23: 715-731, doi: 10.1002/rra.991

6 Costelloe J. F. (2011a) Hydrological assessment and analysis of the Neales Catchment, Report to the South Australian Arid Lands Natural Resources Management Board, Port Augusta.

7 eWater Ltd (2013). Source User Guide (v3.5.0).
[https://ewater.atlassian.net/wiki/display/SD35/Source+User+Guide]

8 Jeffrey, S.J., Carter, J.O., Moodie, K.B. and Beswick, A.R. (2001). Using spatial interpolation to construct a comprehensive archive of Australian climate data External link icon, Environmental Modelling and Software, Vol 16/4, pp 309-330.

8 McNeil D., Schmarr D. and Rosenberger A. (2011) Climatic variability, fish and the role of refuge waterholes in the Neales River catchment: Lake Eyre Basin, South Australia, Report to the South Australian Arid Lands Natural Resources Management Board.

9 Russell K. (2009) Determining loss characteristics of arid zone river waterbodies – final report. 4th year undergraduate research report, University of Melbourne.

10 Ryu, D., J. Costelloe, R. Pipunic, and C.-H. Su, (2014) Rainfall-runoff modelling of the Neales River catchment. Report to the South Australian Department of Environment, Water and Natural Resources.

11 The State of Queensland, (2013) SILO Climate Data, Department of Science, Information Technology, Innovation and the Arts, viewed 27 May 2013, <http://www.longpaddock.qld.gov.au/silo/about.html>

12 Vaze, J., Jordan, P., Beecham, R., Frost, A., Summerell, G. (2012) Guidelines for rainfall-runoff modelling: Towards best practise model application'. eWater Ltd.

13 Wakelin-King, G.A., (2011) Geomorphological assessment and analysis of the Neales Catchment: A report to the South Australian Arid Lands Natural Resources Management Board. Wakelin Associates, Melbourne.

Appendix A: Waterholes bathymetry relationships

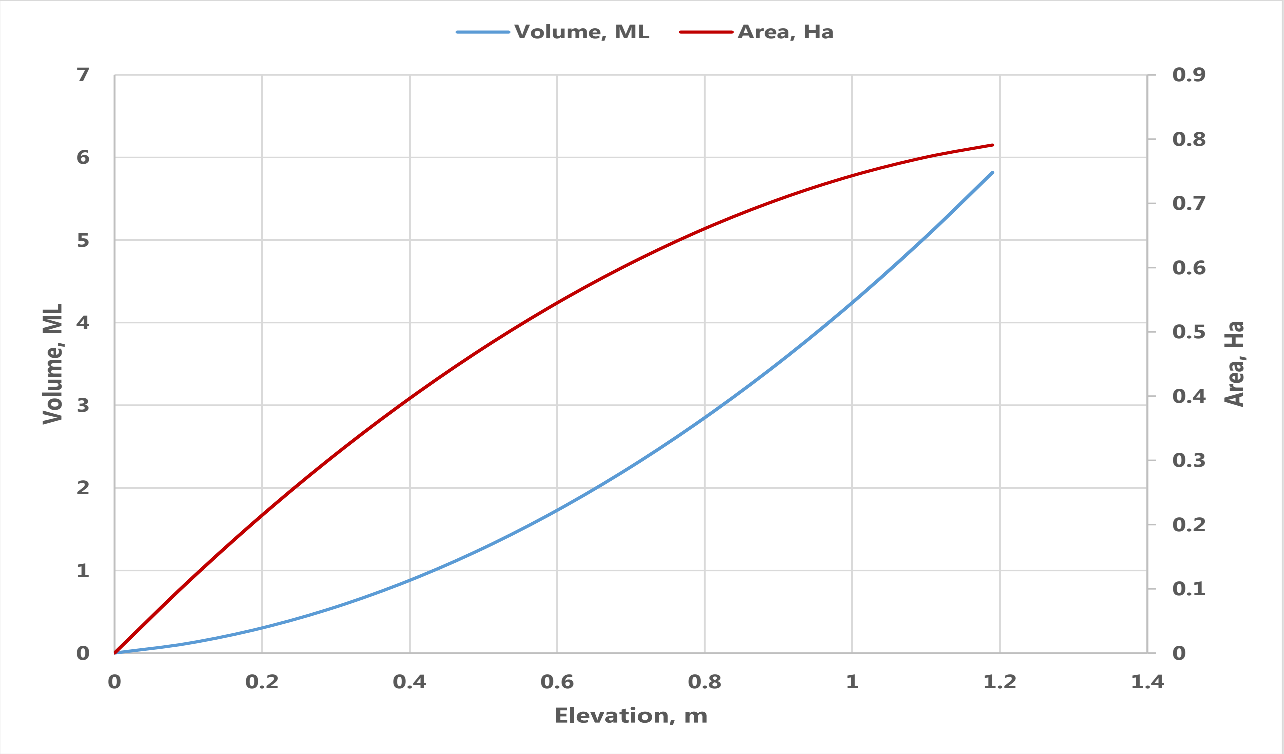


Figure 1 **Bathymetry relationship for Afghan Waterhole**

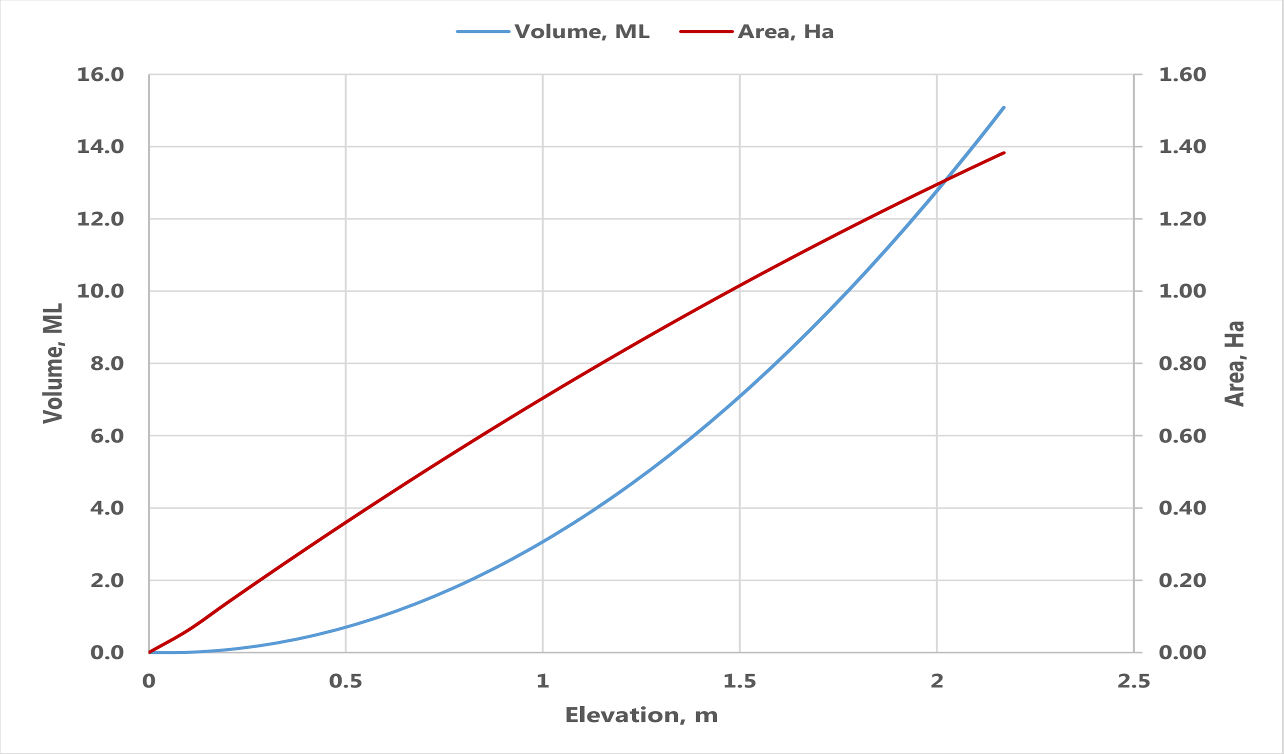


Figure 2 **Bathymetry relationship for Angle Pole Waterhole**

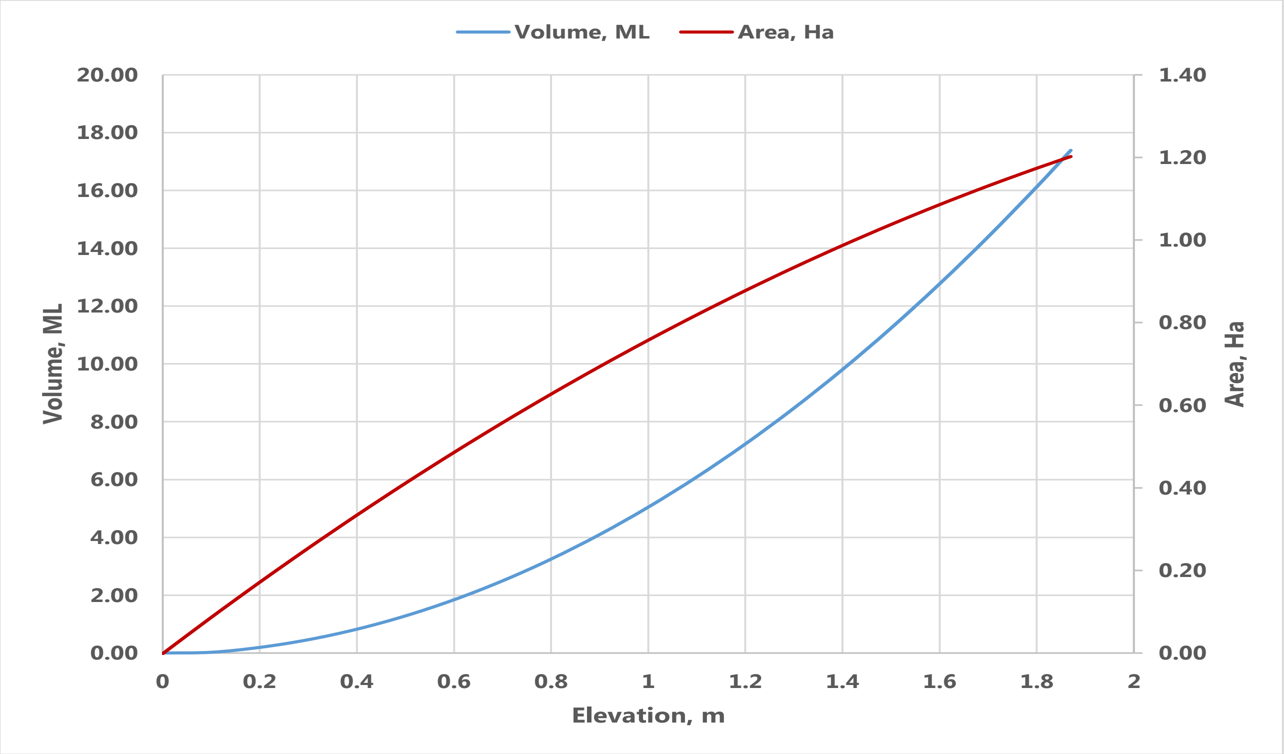


Figure 3 Bathymetry relationship for Shepherds Waterhole

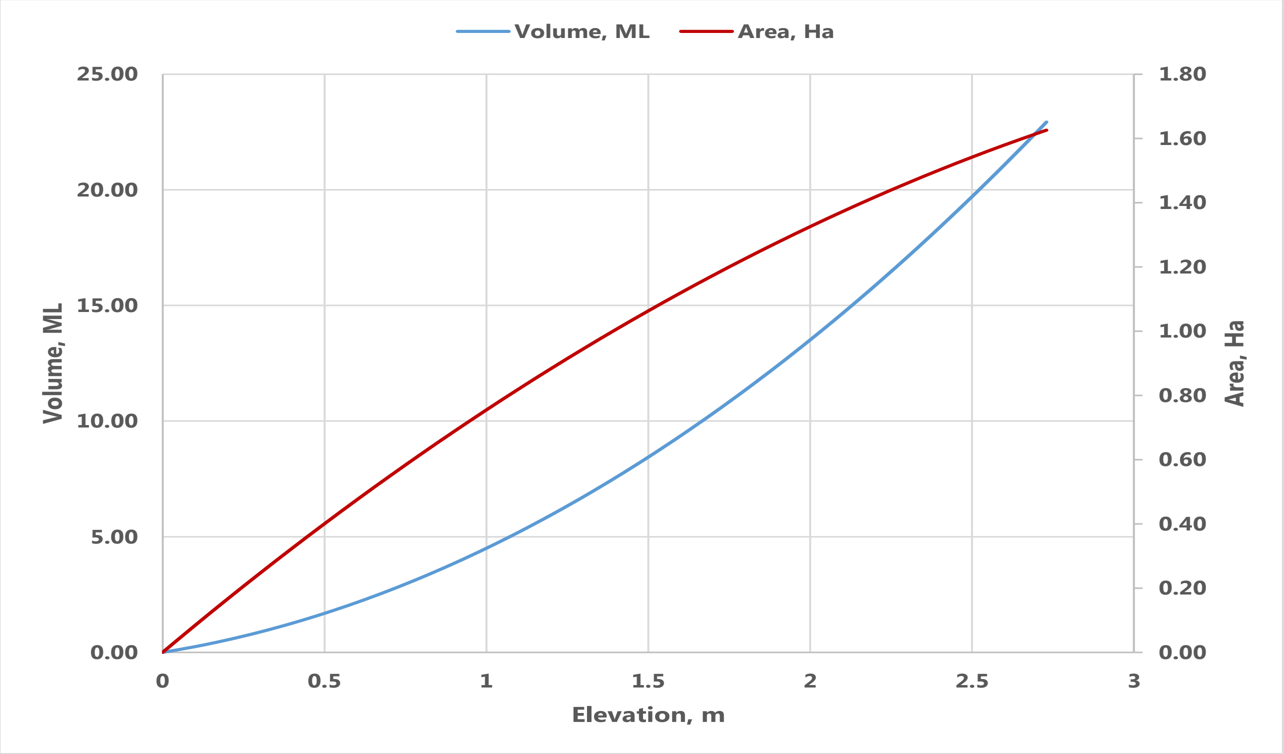


Figure 4 Bathymetry relationship for Mathieson Waterhole

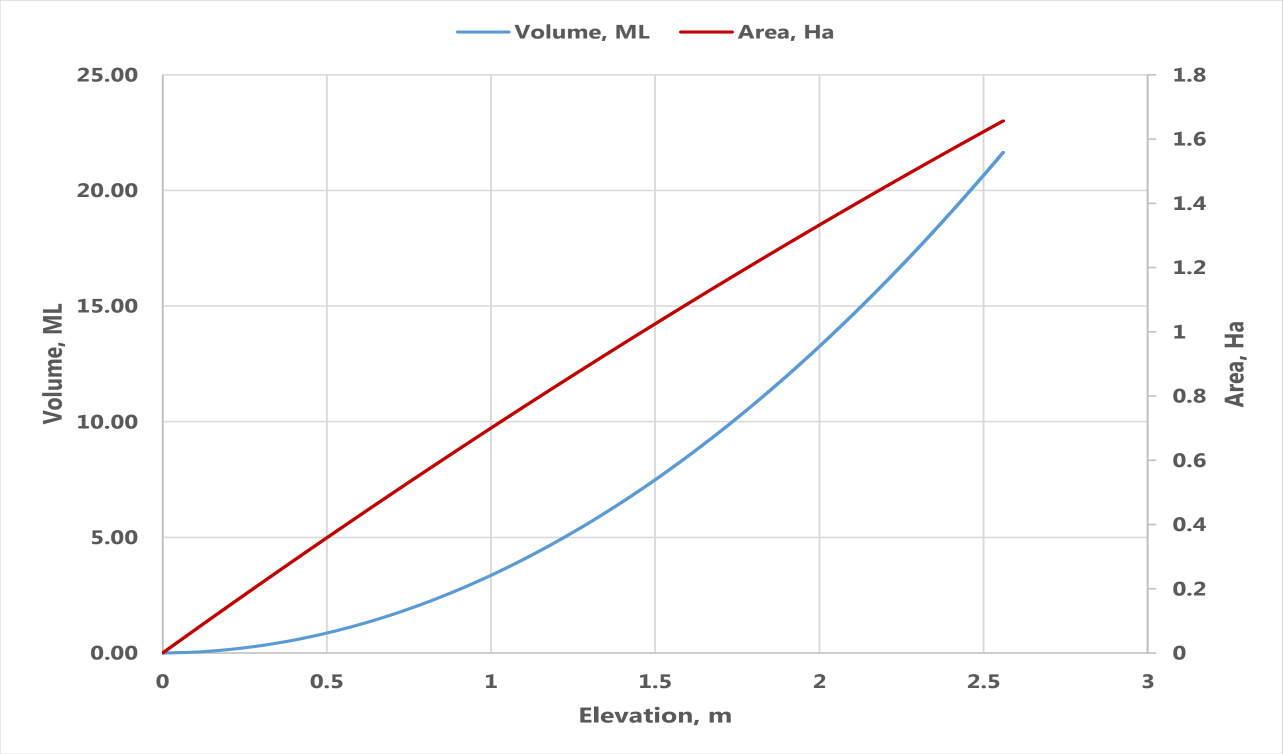


Figure 5 Bathymetry relationship for Hookey Waterhole

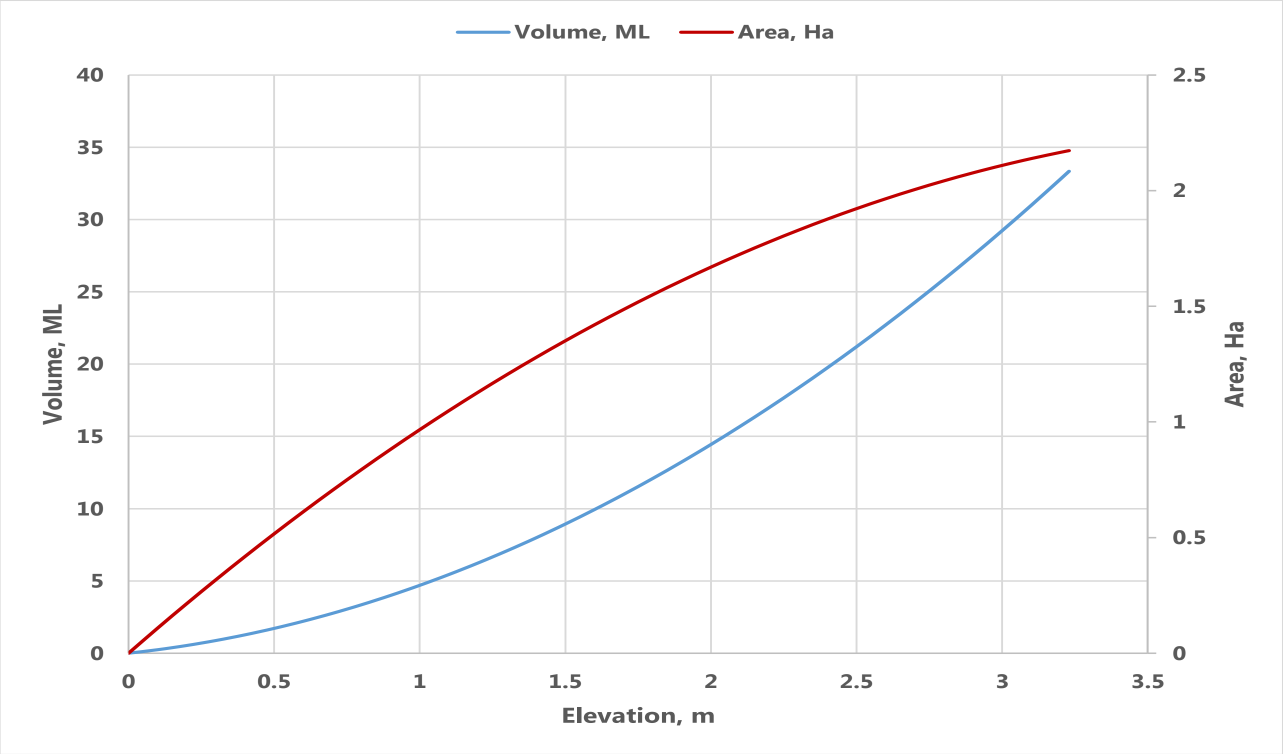


Figure 6 Bathymetry relationship for Stewart Waterhole

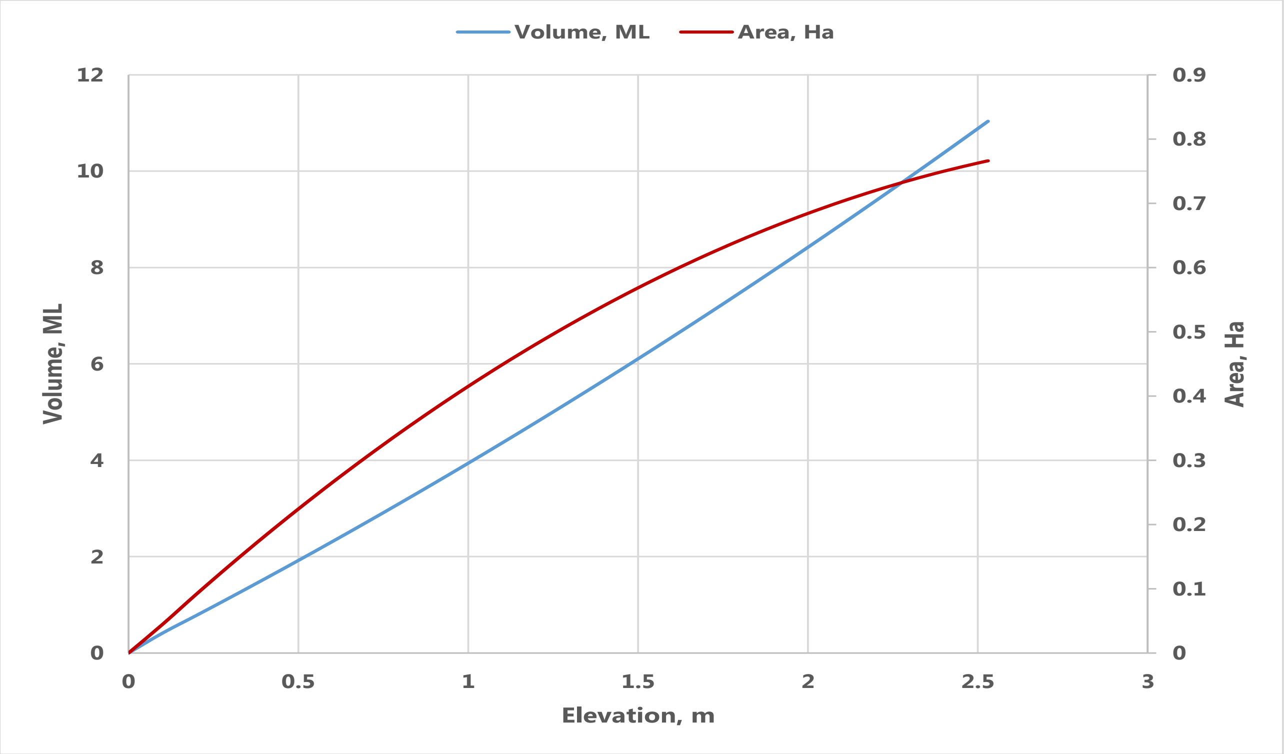


Figure 7 Bathymetry relationship for South Stewart Waterhole

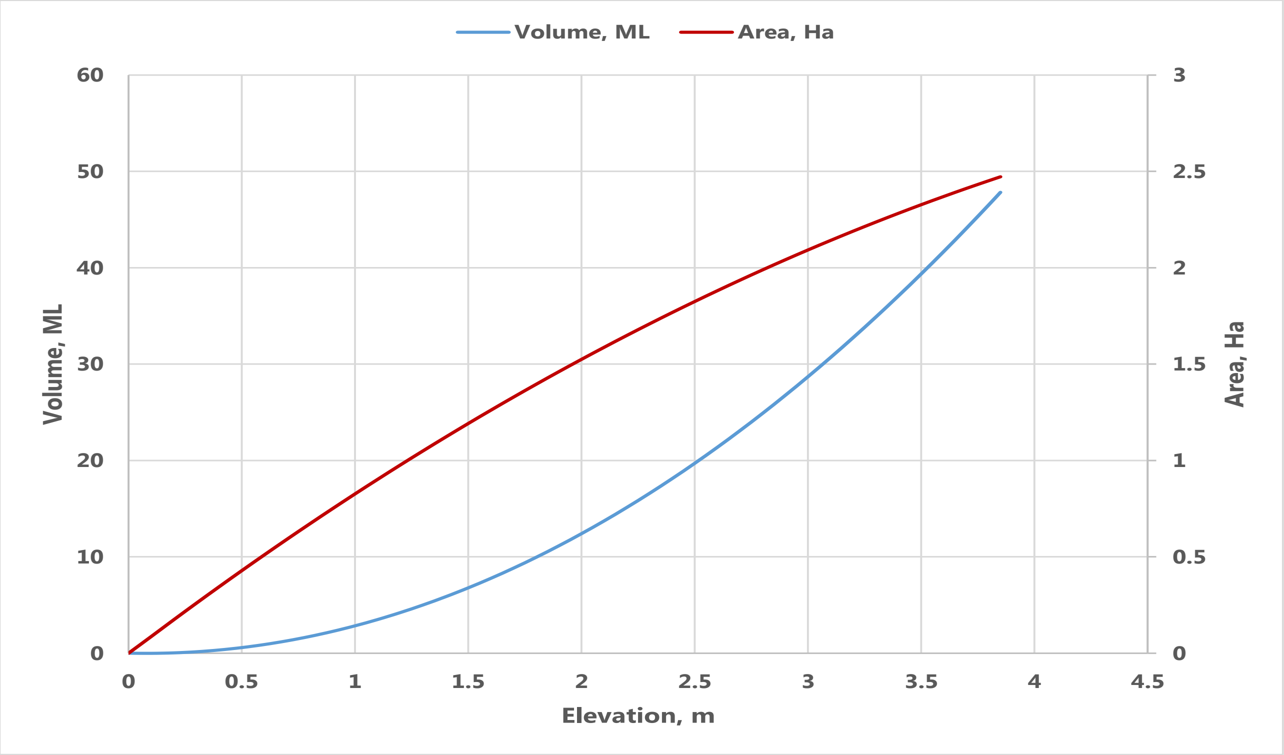


Figure 8 Bathymetry relationship for Cramps Camp Waterhole

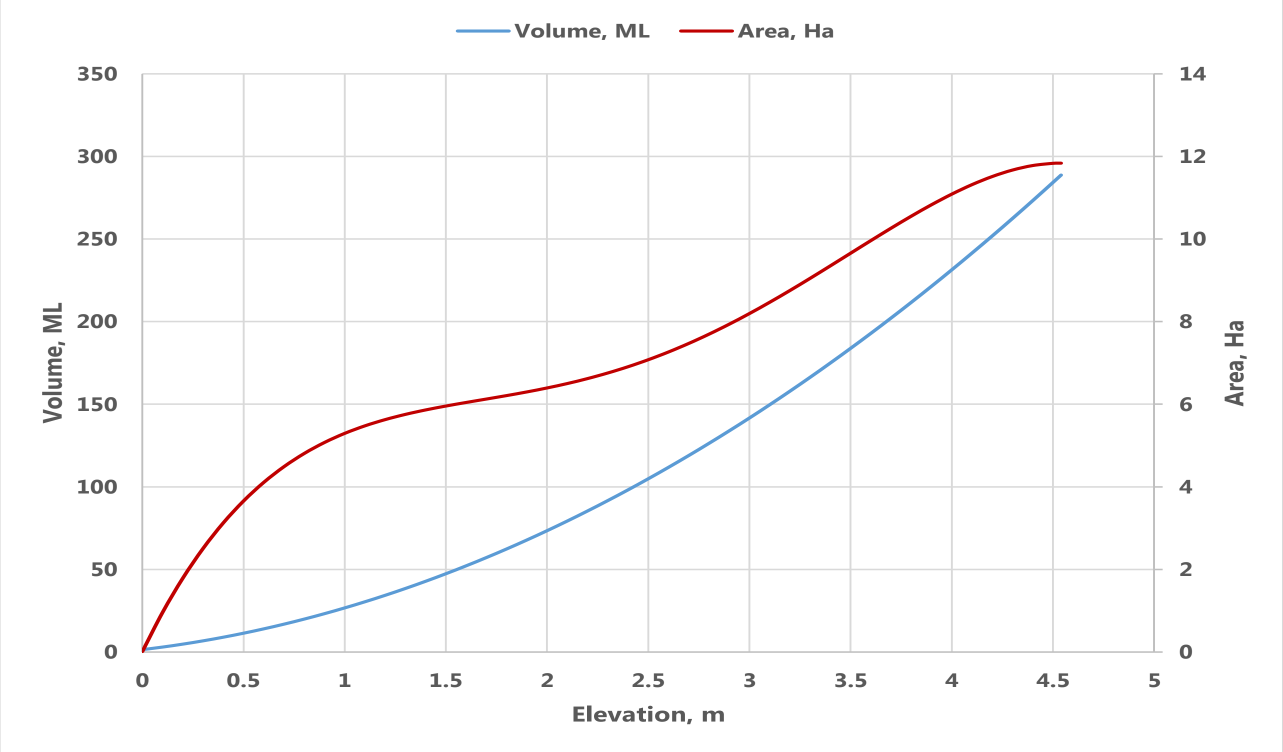


Figure 9 Bathymetry relationship for Algebuckina Waterhole

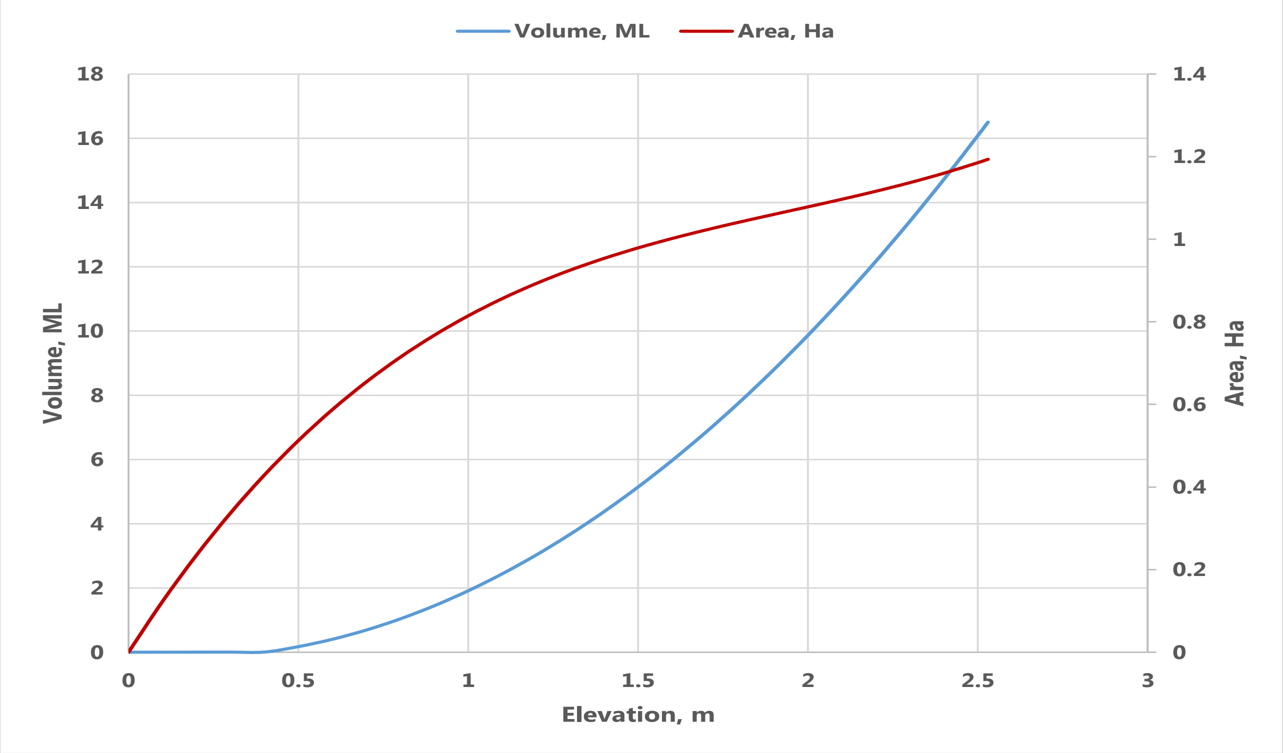


Figure 10 Bathymetry relationship for South Cliff Waterhole

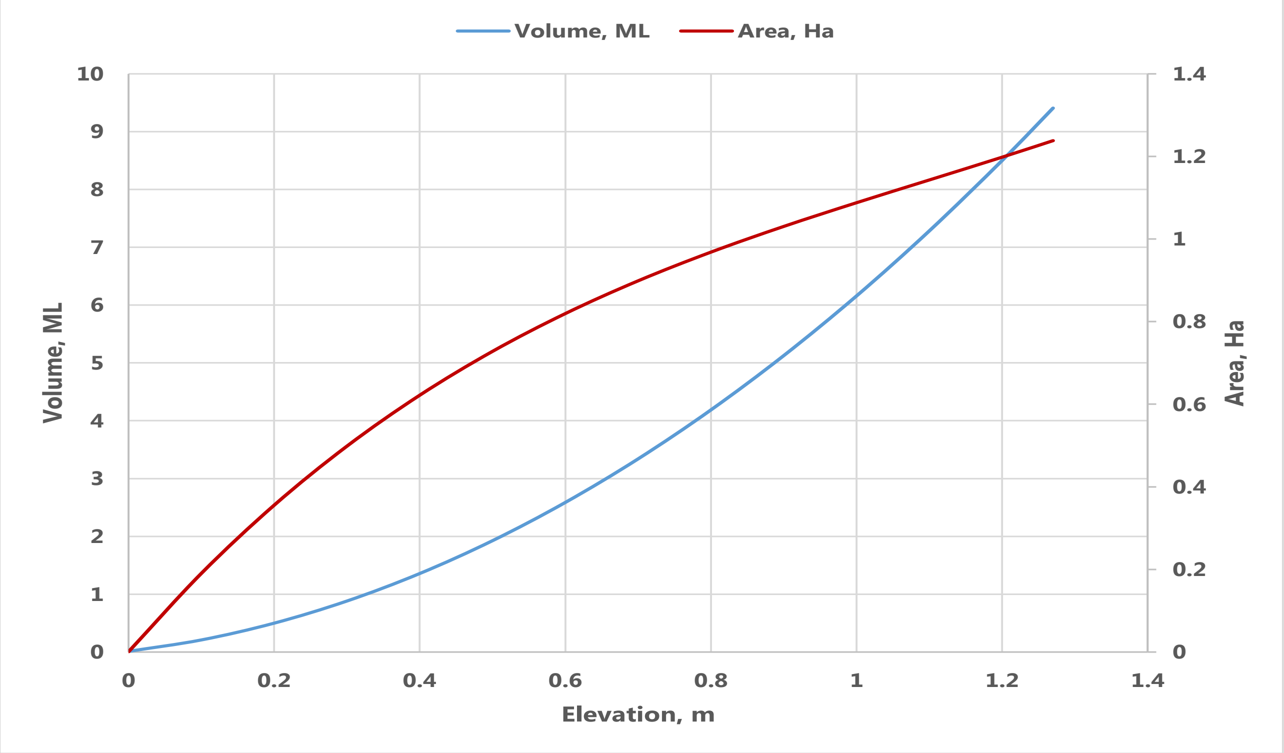


Figure 11 Bathymetry relationship for The Cliff Waterhole

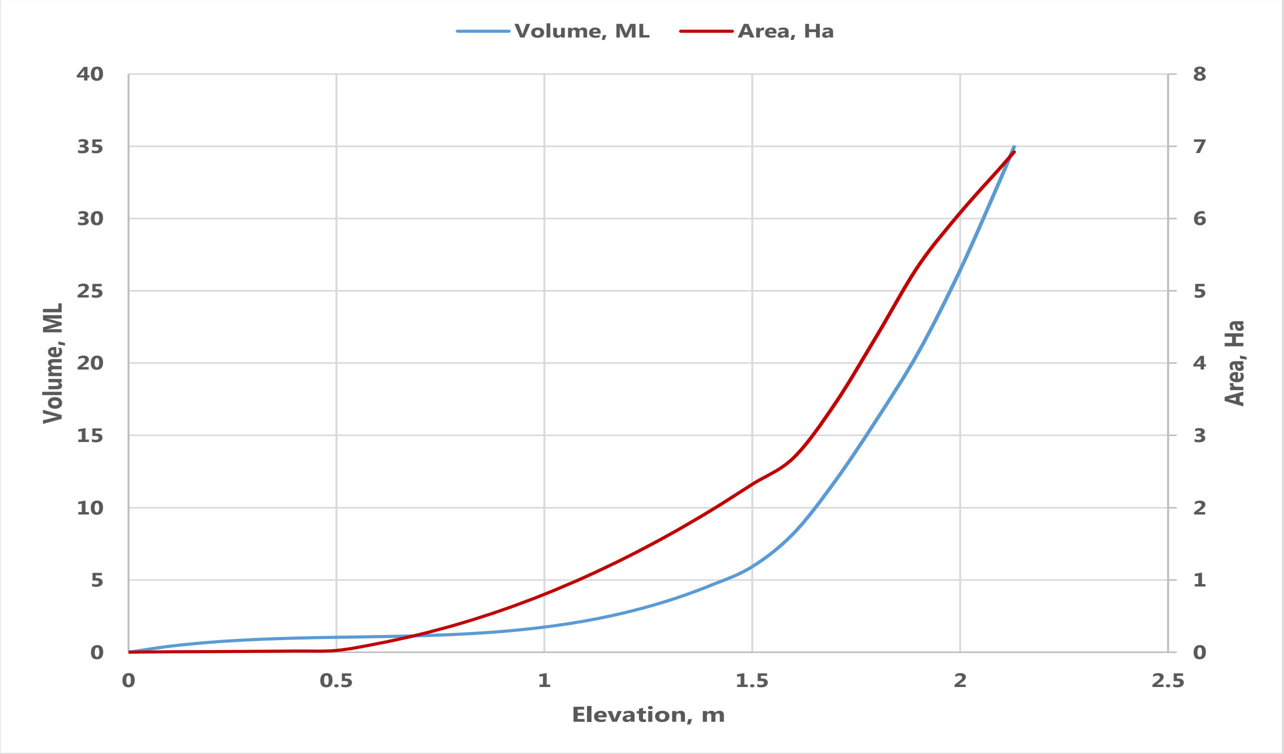


Figure 12 Bathymetry relationship for Tardetakarinna Waterhole

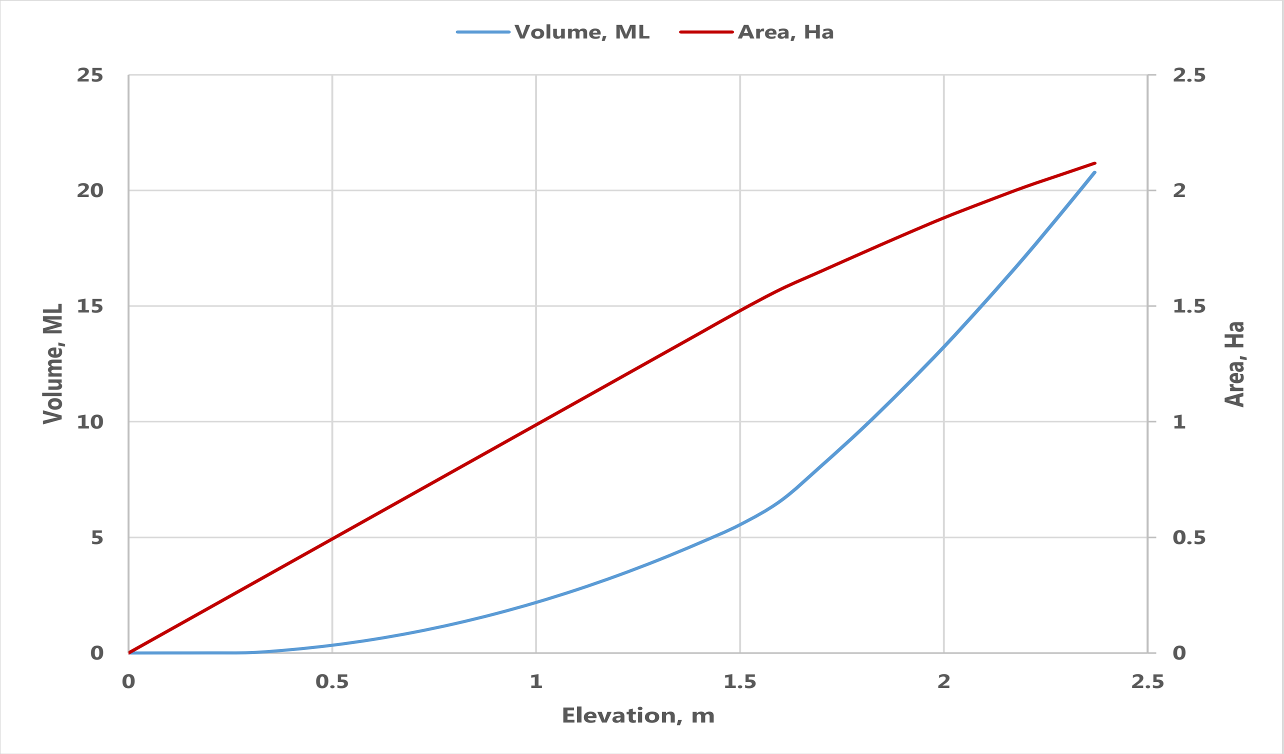


Figure 13 Bathymetry relationship for Baltucoodna Waterhole

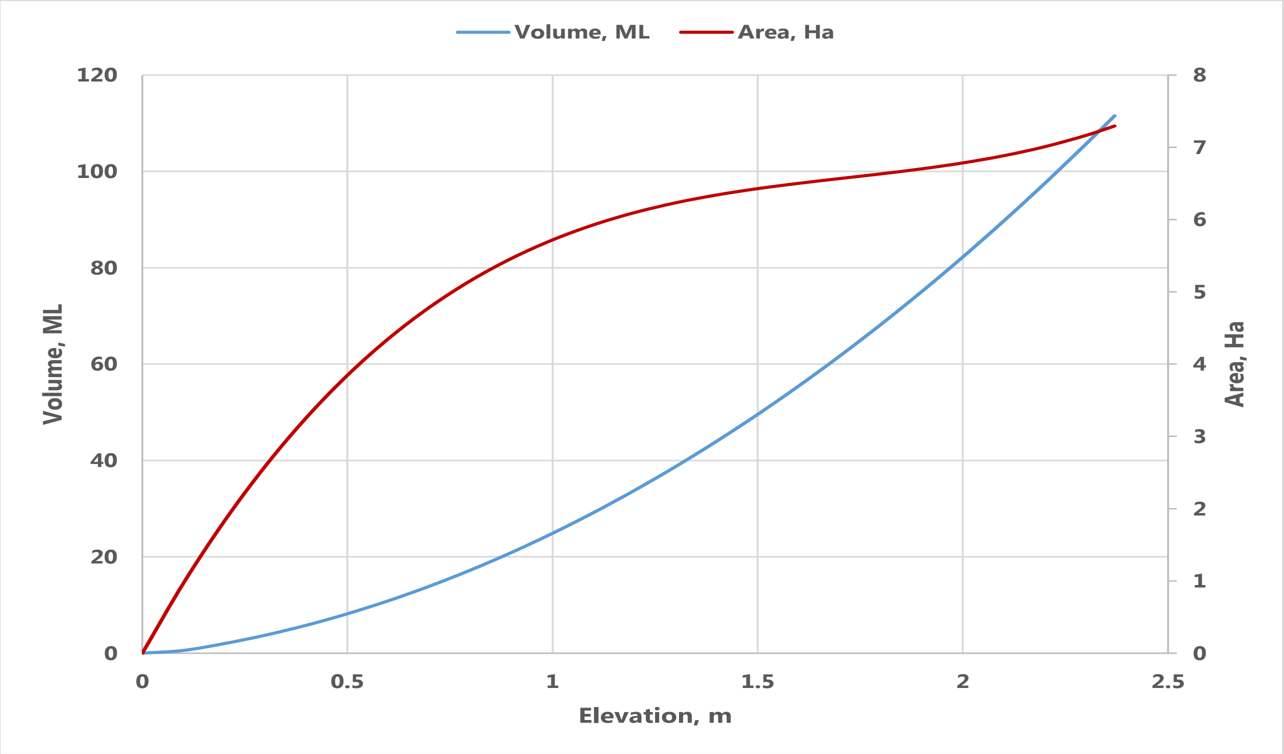


Figure 14 Bathymetry relationship for Warrawaroona Waterhole

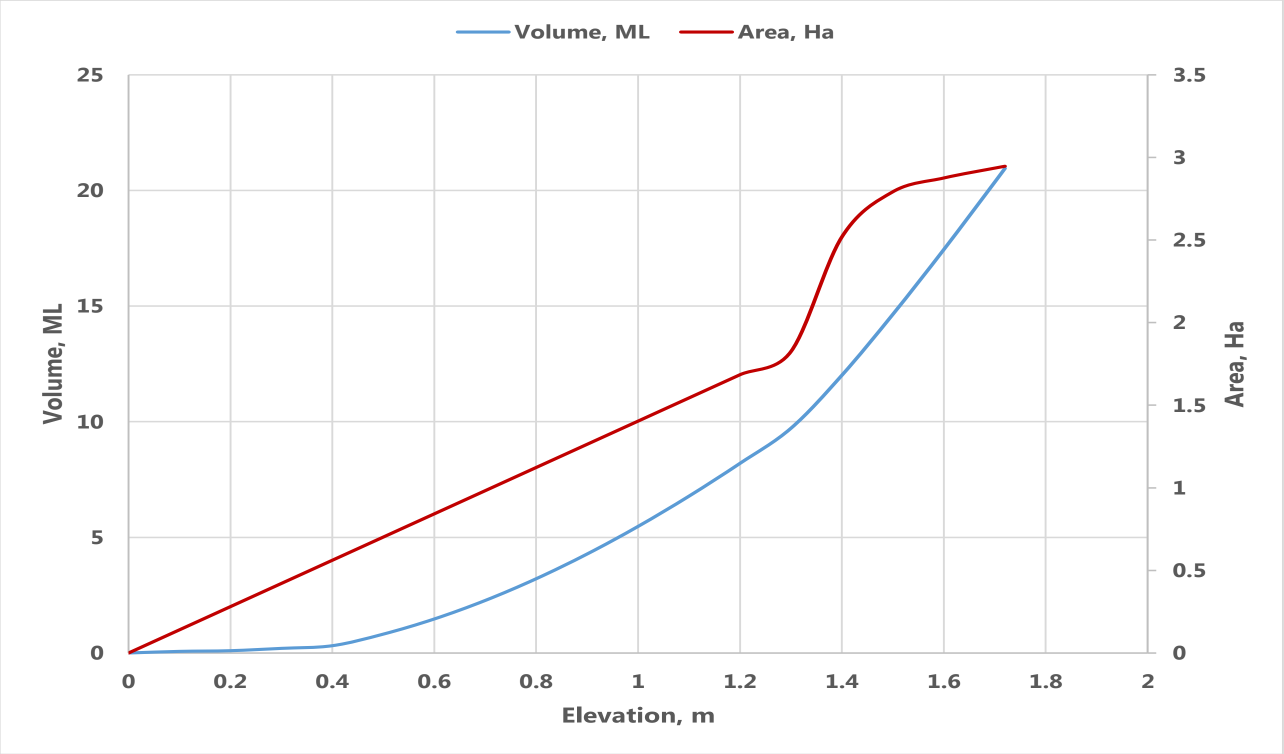


Figure 15 Bathymetry relationship for Peake Waterhole

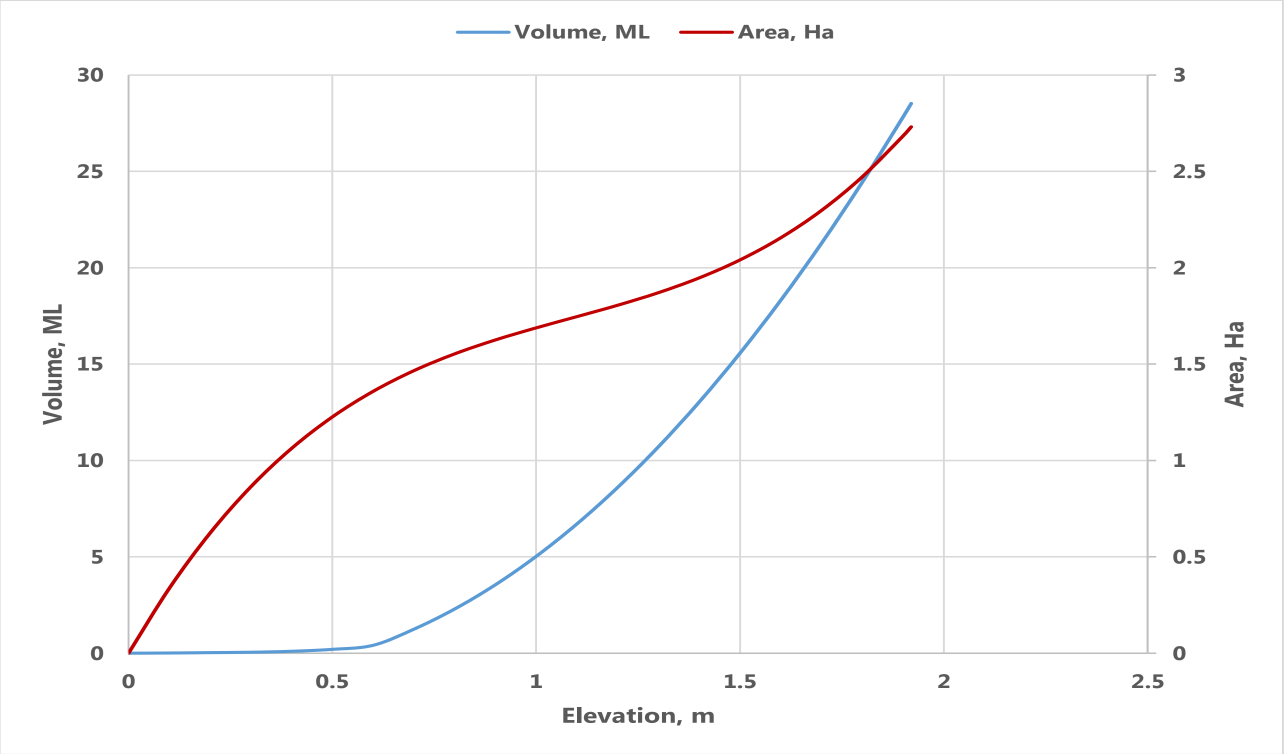


Figure 16 Bathymetry relationship for Cootanoorina Waterhole

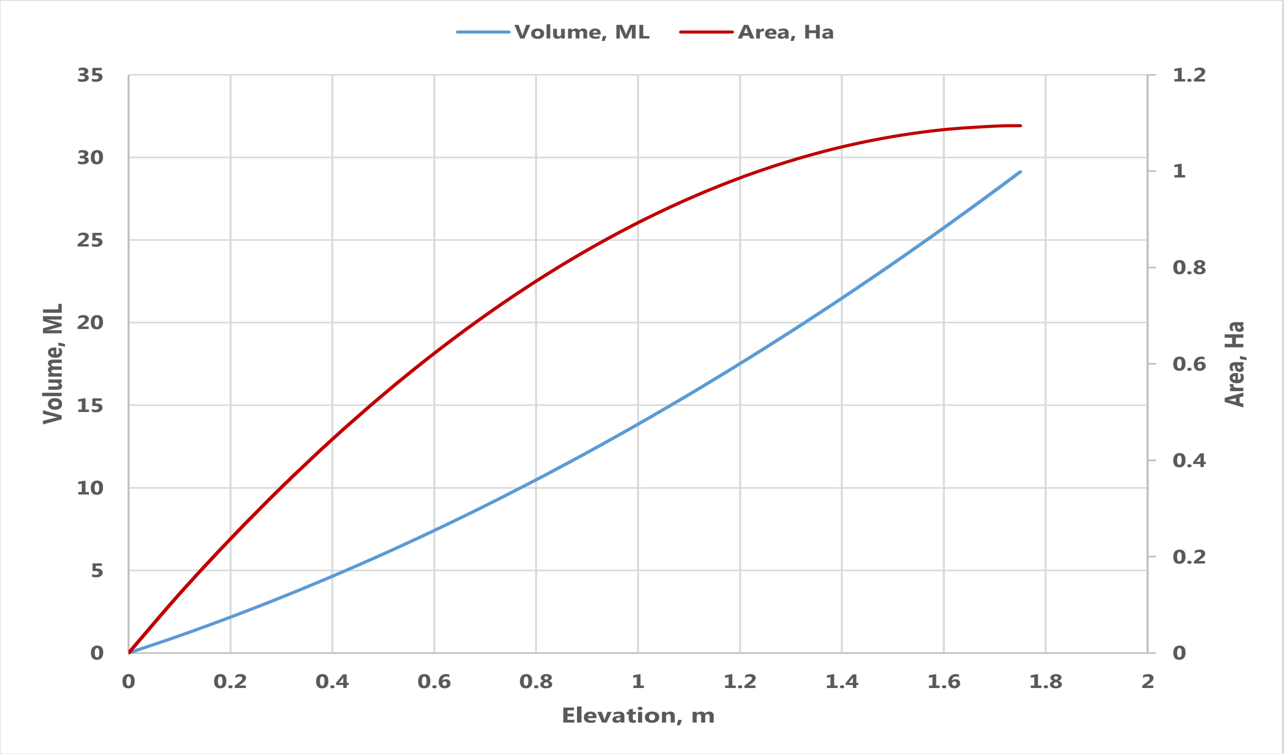


Figure 17 Bathymetry relationship for Birribiana Waterhole

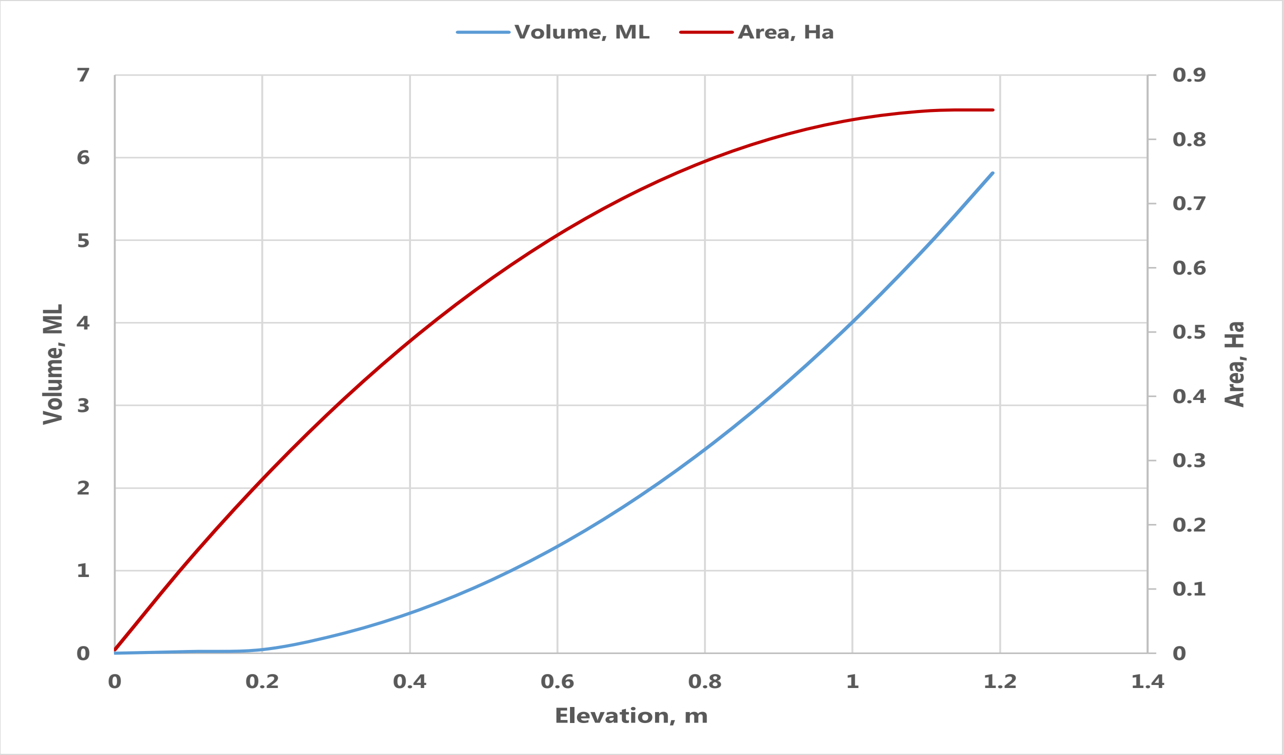


Figure 18 Bathymetry relationship for Hagan Waterhole

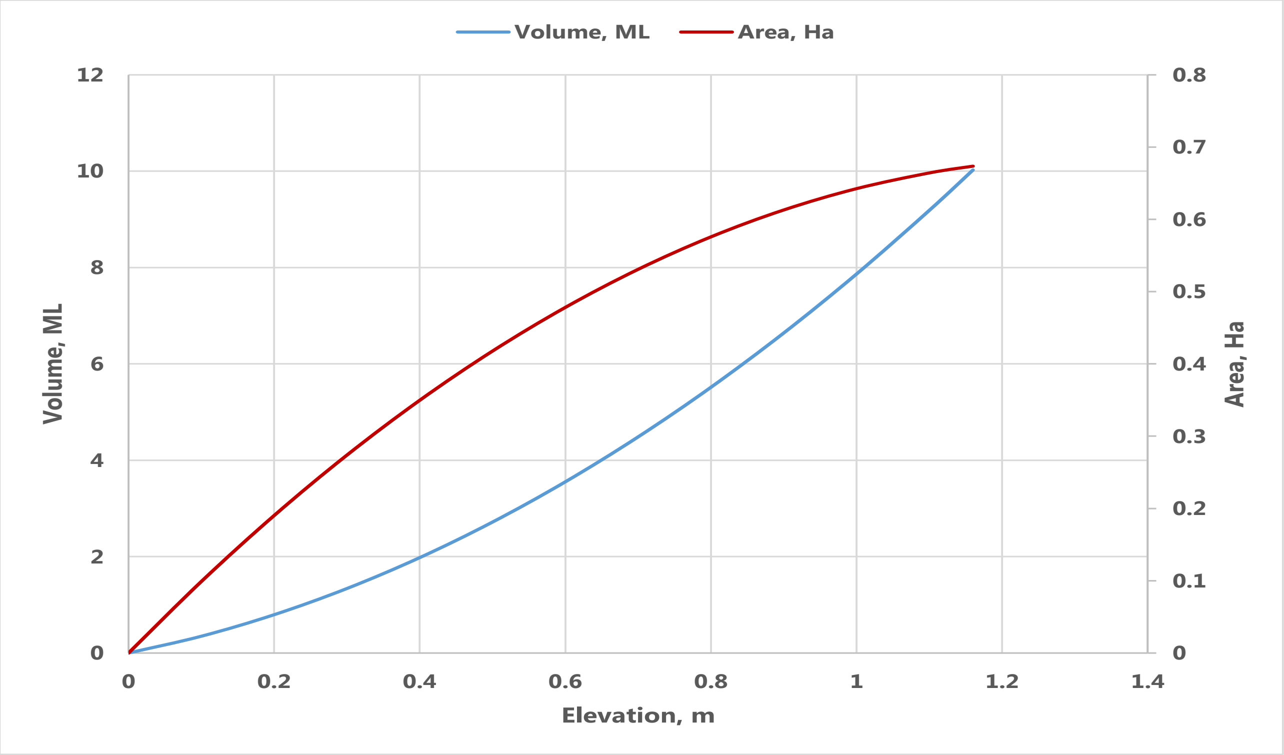


Figure 19 Bathymetry relationship for Fish Hole Waterhole

Appendix B: Calibrated parameters

AWBM Parameters;

A1 (Partial area of smallest store)	0.094
A2 (Partial area of middle store)	0.861
BFI (Baseflow index	0.954
C1 (Capacity of smallest store)	8.3
C2 (Capacity of middle store)	25
C3 (Capacity of largest store)	50
K base (Baseflow recession constant)	0.5
K surf (Surface runoff recession constant)	0.1

Routing and transmission loss parameters;

K (storage constant) = 1000,000 Seconds

A (dimensionless ratio) = 9 %

B (Initial Loss in the reach) = 10 ML/d

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