Summary of preliminary feasibility assessment for drought response storages Babeldaob – Tabecheding River and Ngerderar River. (Based on a desktop study using available data).

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Background

Palau have identified construction of large water storage facilities in Aimeliik and Ngatpang States, as the focus under the Readiness for El Niño RENI project, to act as an emergency water supply in times of need. Palau has indicated that they are interested in using streamflow from Tabecheding River and Ngerderar River. The other potential source is groundwater for these water storage facilities, which would provide a secure water source during droughts if a productive bore could be drilled and constructed. This preliminary assessment restricts itself to investigate streamflow as a water source potential for the proposed storages and does not include consideration of the groundwater potential, which would require additional assessment.

Daily water demand is estimated by PPUC to be 3.8 MGD (14.4ML/d), although dry period water supply is more like 2 MGD (7.6ML/d) but can fall as low as 1 MGD (3.8ML/d) during drought periods (GWP pers comm July 2018). The proposal calls for the construction of a 50,000Gallon (200,000L) storage tank with sand filtration technology for water treatment to be constructed at two sites In Ngatpang State near Tabecheding River and in Aimeliik State near Ngerderar River, if supported by low flow conditions

The following assessment relies upon on reports by USGS including Der Brug, 1984; SOPAC Catalogue of Rivers, 2012; Dutch Risk Reduction Team Resilient water supply perspectives, de Bruijn et al 2016; and recent rainfall data provided by Palau Weather Service. It considers the available streamflow and rainfall data provided in the above reports and has not undertaken any detailed investigation from additional data sources.

Rainfall Data and Analysis

An assessment of the monthly rainfall (mm) for Koror from 1952 -2017 provides the following.

Table 1. Rainfall statistics for Koror, Palau 1947-2017

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean	279.2	224.7	209.8	233.8	323.3	414.6	438.4	365.8	325.4	324.9	285.6	309.7	3735.2
SD	148.5	141.1	109.5	127.7	111.0	132.3	173.2	126.7	135.7	100.5	101.5	108.4	547.7
CV	0.53	0.63	0.52	0.55	0.34	0.32	0.40	0.35	0.42	0.31	0.36	0.35	0.15

The monthly coefficient of variation would suggest that Jan to April are the driest months with most variability of rainfall. The DRR report by der Bruijn et al 2016 indicates that rainfall volumes are decreasing (average 6mm/year) and that impacts during El Nino years may becoming more extreme.

The Climate Variability, Extremes and Change in the Western Tropical Pacific: New Science and Updated Country Reports, (BOM and CSIRO; 2014) indicate that climate projections from global climate model (GCM) projections for Palau suggest

- El Niño and La Niña events will continue to occur in the future (very high confidence), but there is little consensus on whether these events will change in intensity or frequency;
- Annual mean temperatures and extremely high daily temperatures will continue to rise (very high confidence);
- Average rainfall is projected to increase, especially in the wet season (medium confidence), along with more extreme rain events (high confidence);
- Droughts are projected to decline in frequency (medium confidence);

An assessment of the monthly rainfall data for the entire record 1952-2017 using the Seasonal Climate Output for Pacific Island Countries SCOPIC provides insight into the historical meteorological droughts over the available rainfall record. The assessment of rainfall considers the 3 month (90 days) drought index as the most appropriate for stream flow. That is the cumulative rainfall in a 3 month period is compared against the cumulative rainfall for the same 3 months period across the entire rainfall record. The rainfall periods which are below the lowest 10 % of rainfall for the 3 months period are then ranked with regard to an integral of drought peak and drought duration providing insight into drought severity, in combination with the ENSO phase.

The three month drought index is considered useful as an indicator of the impact on the stream flow where low rainfall over a 3 month period will result in impact on stream flow. Based on the gauging stations from the USGS, der Brug, 1984, indicates that surface runoff accounts for up to 70% of the total annual rainfall, suggesting that only a small percentage of rainwater infiltrates the soil as groundwater, inferring that baseflow will be low during dry periods.

Of the 29 meteorological droughts identified (lowest 10% of rainfall) the most severe droughts are associated with El Nino and Neutral ENSO status. The worst drought on record for the 3 month aggregate drought index occurred from Jul 1997 – Oct 1998. Drought lengths under the 3 month index can range in duration from 2 months to 19 months with the average drought length of 6.4 months. Droughts that commenced during a La Nina ENSO phase are generally shorter. On average a meteorological drought can be expected every 23 months, or approximately once every 2 years.

The following table identifies the 10 most severe droughts between 1947-2017. Annex 1 indicates the output on drought history and drought statistics available from SCOPIC for the 1947-2017 rainfall record period.

Table 2: Ranking of ten most severe meteorological droughts for Koror rainfall using a 3 month rainfall index (after SCOPIC output)

Rank	Drought period	Drought length	Drought ENSO state	Rainfall during drought (mm)
1	Jul 1997 to Oct 1998	16mths	El Nino	3419.9
2	Dec 2014 to Jun 2016	19mths	El Nino	3993.3
3	Dec 1969 to Dec 1970	13mths	Neutral	3072.0
4	Oct 1982 to Jul 1983	10mths	El Nino	2205.7
5	Mar 2010 to Jan 2011	11mths	El Nino	2915.0
6	Sep 2004 to May 2005	9mths	Neutral	1990.9
7	Jan 1973 to Oct 1973	10mths	Neutral	2464.7
8	Jul 1976 to Dec 1976	6mths	Neutral	1721.7
9	Oct 1993 to Mar 1994	6mths	El Nino	1354.7
10	Jun 1968 to Dec 1968	7mths	La Nina	2089.9

Stream flow data

This analysis draws on flow information from available sources, specifically including Der Brug, 1984; SOPAC Catalogue of Rivers, 2012; De Bruijn, 2016. The focus is on identifying the period of low flow for the Tabecheding and Ngerderar rivers and their catchments from the available data to indicate daily low flows during periods of low rainfall which would represent stream baseflow. Where limited flow data is available such as in the Ngerderar river, an interpolation of flow from a similar sized catchment where stream flow data is available is made.

Table 3: Minimum flow estimates Babeldaob catchments

Station no.	Drainage area km^2	Data Source	Period of record	Minimum flow discharge m^3/s
16890900 Tabecheding (below falls)	15.7	Der Brug, 1984	1971-1982 (23-24 March 1973)	0.023 0.031#
		SOPAC, 2012	1989 -2005	0.052
		De Bruijn et al, 2016	1970 - 1994, 1997-1999, 2000-2003,2004-2005	0.030*
Ngerdarar river	4.46	De Bruijn et al, 2016 (after ADP 2008)		0.011*
Kmekumer 16891310	4.1	SOPAC, 2012	1990 -2005	0.035 0.048#
		De Bruijn et al, 2016	1978 - 1991, 1992-1993, 1997-1998, 1999-2000 2000-2001 2002-2003, 2004-2005	0.0096*
Ngardok South Fork 16891400	6.32	Der Brug, 1984	1971-1982 (9 March 1973)	0.016 0.018#
		SOPAC, 2012	NA	0.028
		De Bruijn et al, 2016	1971 - 1991, 1991-1992	0.018*
Diongradid 16890600	11.5	Der Brug, 1984	1970-1982 (24,25,31 March; 1 April 1973; 28,29 April 1977)	0.076 0.071#
		SOPAC, 2012	NA	0.118
Edeng River 16891300	11.0	Der Brug, 1984	1972-1982 (23-24 March 1973)	0.045 0.045#
		De Bruijn et al, 2016	1969 - 1982,	0.028*

*Calculated minimum discharges with a return period of 25 years (T25); #minimum discharge with 20 year return period.

The minimum flows recorded are considered against the monthly rainfall and the drought ranking in which the low flow was experienced to assess the severity of the rainfall deficiency and consider its impact on the stream flow.

Table 4 Summary of minimum flow and rainfall ranking for 3 month rainfall index

Catchment	Minimum daily flow and period m^3/sec	Ranking of 3 month rainfall ranking relative to minimum flow period
Tabecheding	0.023 (March 1973)	7th ranked (Jan 1973 – Oct 1973)
Ngerdarar	0.011 (similar sized catchments indicate similar flow)	NA

The minimum daily flows identified are considered indicative of the likely base flow during an extended dry period, with the flows corresponding with the end of a 3 month rainfall deficit period. It should be noted that the measured flows are considered to be the lowest measured flows from available records. The available reports indicate these minimum flows are limited to less than 5 consecutive days. Over the course of a 3 month period, flows above the minimum can be expected however the range of these flows has not be quantified. For the purposes of planning for a water supply system a minimum flow discharge is used.

Minimum flows in streams are important for the environment, where it is important to ensure that sufficient flow is available to sustain the aquatic river environment. In lieu of specific studies on the stream flow requirements for Tabecheding and Ngerderar Rivers to sustain the freshwater ecosystem general guidance is taken from available literature, (Pastor et al, 2014). Pastor et al (2014) review of five methods for calculating environmental flows suggests that methodologies differ in their assignment of how much water is required from a low flow river to maintain freshwater ecosystems in reasonable ecological condition, and ranges from allocation of all water to environmental flow requirements in low-flow periods while an alternate method allocates 60% of the flow in low-flow periods.

The range of water that could be withdrawn from a low flow to support other water needs than the environmental flow ranges from 0% to 40% of flow in the low flow period. Given the uncertainty and the large range associated with allocation of environmental flows it is considered prudent that a minimum of 80% of the flow in a low flow period is allocated as an environmental flow and that up to 20% of low flow could be made available for other water needs in the absence of any specific study on the requirements of the freshwater ecosystem, especially during periods of low-flow.

An assessment of the maximum withdrawal of 20% of the measured low flow from each river station for two different pumping scenarios is provided for consideration in the assessment of the feasibility of abstraction from the Tabecheding and Ngerderar Rivers as a drought water supply.

Pumping scenarios with withdrawal limited to 20% of flow in the low flow period

a) Abstraction from the river is limited to an estimated 8 hours a day at 20% of the flow for low- flow, to accommodate a solar pump setup
b) Abstraction from the river is up to 24 hours a day at 20% of the flow for low- flow, where 24hr electricity is available.

Table 5. Maximum volume available from low-flow under two pumping scenarios for Tabecheding and Ngerderar Rivers assuming abstraction at 20% of low-flow conditions

Catchment	Maximum allowable flow rate for low-flow conditions (L/s) (20% of minimum measured flow)	Maximum volume abstracted in 8 hour pumping (L)	Maximum volume abstracted in 24 hour pumping (L)	Number of hours required to fill a 200,000L storage tank (20% of minimum measured flow)
Tabecheding	4.6	132,480	397,440	12.1
Ngerderar	2.2	63,360	190,080	25.3

It should be noted that the establishment of an abstraction point will require containment of flow with sufficient depth to allow the setup of a pump. Further the pump should be protected from the high flows and debris with consideration to minimising sediment inflow, when considering the establishment of a pumping station for the emergency water supply.

Annex 1

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scopic Drought Statistics

Koror (Jul 1947 to Sep 2017)

3mth Percentile Drought method - *"3 month aggregate drought index using percentile method"*

ENSO States defined using 3 Phase SOI Values (Assigned at Drought Start)

DroughtStatistics

In-Drought Durations	All Events	El Nino	La Nina	Neutral
Number of Droughts	29	10	7	12
Total Months In Drought	186 mths	87 mths	31 mths	68 mths
Drought Lengths	2 to 19 mths	3 to 19 mths	3 to 7 mths	2 to 13 mths
Average Drought Lengths	6.4 mths	8.7 mths	4.4 mths	5.7 mths
In-Drought Rainfall	**All Events**	**El Nino**	**La Nina**	**Neutral**
Lowest In-Drought Rainfall	587.9 mm	999.4 mm	820.9 mm	587.9 mm
Highest In-Drought Rainfall	3993.3 mm	3993.3 mm	2089.9 mm	3072.0 mm
Mean In-Drought Rainfall	1648.7 mm	2037.1 mm	1314.9 mm	1519.8 mm
Between-Drought Lengths	**All Events**	**El Nino**	**La Nina**	**Neutral**
Between-drought lengths	2 to 78 mths	5 to 32 mths	12 to 75 mths	2 to 78 mths
Average between-drought length	22.8 mths	15.5 mths	33.5 mths	23.5 mths

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scopic *Drought History*

Koror (Jul 1947 to Sep 2017)

3mth Percentile Drought method

ENSO States defined using 3 Phase SOI Values (Assigned at Drought Start)

Rank*	Drought Period	Drought Length	Warning Start	Warning Length	Watch Length	Warning ENSO State**	Drought ENSO State**	Rainfall During Drought
1	Jul 1997 to Oct 1998	16mths	May 1997	2mths		El Nino	El Nino	3419.9
2	Dec 2014 to Jun 2016	19mths	Oct 2014	2mths	4mths	El Nino	El Nino	3993.3
3	Dec 1969 to Dec 1970	13mths	Dec 1969	0mths	2mths	Neutral	Neutral	3072.0
4	Oct 1982 to Jul 1983	10mths	Sep 1982	1mth		El Nino	El Nino	2205.7
5	Mar 2010 to Jan 2011	11mths	Mar 2010	0mths	1mth	El Nino	El Nino	2915.0
6	Sep 2004 to May 2005	9mths	Sep 2004	0mths	4mths	Neutral	Neutral	1990.9
7	Jan 1973 to Oct 1973	10mths	Dec 1972	1mth		El Nino	Neutral	2464.7
8	Jul 1976 to Dec 1976	6mths	Jul 1976	0mths	4mths	Neutral	Neutral	1721.7
9	Oct 1993 to Mar 1994	6mths	Jul 1993	3mths		El Nino	El Nino	1354.7
10	Jun 1968 to Dec 1968	7mths	Jun 1968	0mths	1mth	La Nina	La Nina	2089.9
11	Jan 1958 to May 1958	5mths	Jan 1958	0mths	1mth	El Nino	El Nino	999.4
12	Sep 2002 to Mar 2003	7mths		0mths			El Nino	1690.3
13	Oct 1994 to Feb 1995	5mths	Sep 1994	1mth		El Nino	El Nino	1228.6
14	Aug 1964 to Dec 1964	5mths	Jul 1964	1mth		Neutral	La Nina	1478.2
15	Apr 1992 to Aug 1992	5mths	Dec 1991	4mths		El Nino	El Nino	1533.0
16	Apr 1977 to Jul 1977	4mths	Mar 1977	1mth	2mths	Neutral	Neutral	1212.2

17	Jan 1990 to May 1990	5mths	Nov 1989	2mths	1mth	Neutral	Neutral	1000.8
18	Jun 2007 to Sep 2007	4mths	Apr 2007	2mths		Neutral	Neutral	1374.3
19	Sep 1955 to Jan 1956	5mths	May 1955	4mths		Neutral	La Nina	1668.2
20	Aug 2016 to Oct 2016	3mths	Jul 2016	1mth		Neutral	Neutral	1006.9
21	Aug 1996 to Nov 1996	4mths		0mths			La Nina	1103.3
22	Dec 1977 to Feb 1978	3mths	Nov 1977	1mth		El Nino	El Nino	1031.0
23	Oct 2013 to Jan 2014	4mths	Nov 2012	11mths	1mth	Neutral	Neutral	1213.1
24	Nov 1951 to Apr 1952	6mths	Oct 1951	1mth	1mth	Neutral	Neutral	1607.5
25	Jul 1950 to Sep 1950	3mths		0mths			La Nina	1052.5
26	Jan 2012 to Apr 2012	4mths	Jan 2012	0mths	1mth	La Nina	La Nina	820.9
27	Nov 1999 to Jan 2000	3mths		0mths			La Nina	991.6
28	Mar 1957 to Apr 1957	2mths	Feb 1957	1mth		Neutral	Neutral	587.9
29	May 1981 to Jun 1981	2mths	May 1981	0mths	1mth	Neutral	Neutral	986.2

* NB: Ranking is based upon the Integral Area method. Equal ranks are ordered by integral (descending) then Period (ascending).

** ENSO state at the start of Warning or Drought event (ie. ENSO state at month 1 of the event)