FutureWater

TECHNICAL REPORT IN SUPPORT OF TRANSBOUNDARY WATER MANAGEMENT BETWEEN THAILAND AND CAMBODIA (GIZ PROJECT NO. 2019.2207.9.001)

The impact of enhancing storage capacity on water shortages in North-western Cambodia under a changing climate

REPORT 216

CLIENT JBA Consulting

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1 Introduction

GIZ has hired a consortium of JBA Consulting, FutureWater, Stockholm Environment Institute, and Mekong Modelling Associates, to implement the project *Transboundary water management between Thailand and Cambodia as part of the adaptation of the agricultural sector in North- Western Cambodia to Climate Change* (GIZ project no. 2019.2207.9.001). This project takes an integrated approach to support water resources management planning for a transboundary rural region in Northwestern Cambodia and Thailand. The project involves extensive data collection and analysis related to agriculture, floods and droughts, and socio-economics, as well as scenario simulations using the Water Evaluation And Planning (WEAP) tool.

This document serves as a technical report supporting the Provincial Water Resources Management Report for Oddar Meanchey, a key output of the project. In particular, this technical report describes the methods (Chapter 2), results (Chapter 3) and main conclusions (Chapter 4) associated with the WEAP scenario simulations implemented by FutureWater. The objective of these analyses is to support an assessment of the scope for alleviating water shortages by developing additional storage capacity in Oddar Meanchey province.

2 Data and methods

2.1 WEAP model

2.1.1 General

The basis for the water resources simulation modelling is the WEAP model of Tonle Sap River Basin Group that was previously developed by the consultant team, under assignment of Asian Development Bank[1]. The WEAP model is set up covering a total of 20 years (1999 - 2018) to ensure that most recent conditions are incorporated and also to have a sufficient number of years to cover average, wet and dry conditions. Initialization of the model was accomplished by running an initial 2 years of model warm-up (1997-1998) which were ignored in the output analysis. The timestep of the model is 7 days, to allow for a good balance between accuracy and calculation time. Model performance was assessed with available streamflow data and found to be satisfactory (Droogers et al., 2019).

2.1.2 Model schematization

The model is subdivided into catchments and subcatchments. An objective of the current project is to support water management plans on a regional scale defined by administrative boundaries rather than physical watersheds. For this reason, the subcatchments intersecting with Oddar Meanchey and Banteay Meanchey provincial boundaries were extracted from the original model, as well as their upstream areas to be consistent with hydrological reality. Figure 1 shows the provincial and hydrological boundaries. In line with this map, the following categorization was maintained in interpreting the WEAP results on supply and demand:

- Oddar Meanchey
  - TON.SRE.1
  - TON.SRE.2
- Banteay Meanchey
  - TON.SIS.3
  - TON.SIS.4
  - TON.SIS.5
  - TON.SIS.6

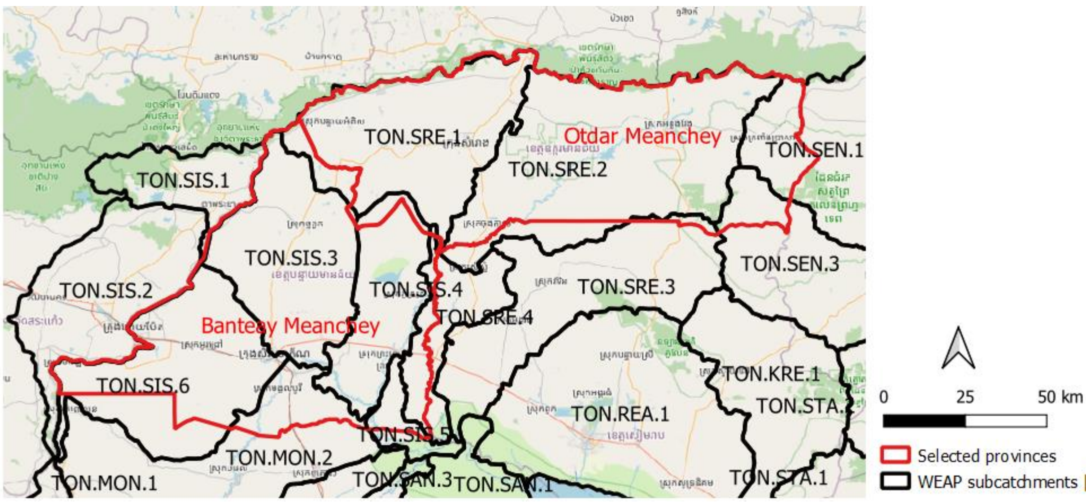

Figure 1. Provincial boundaries and WEAP subcatchments.

[1] https://www.futurewater.eu/projects/water-resources-and-eco-hydrological-assessments-of-tonle-sap-and-mekong-delta-basins/

The WEAP model makes use of a rainfall-runoff module. Each subcatchment is schematized as consisting of a “Catchment” node, which contains rainfall-runoff characteristics as well as agricultural water requirements to ensure that demand follows water availability. The Catchment Nodes are the core of the WEAP model. Different from the more traditional rainfall-runoff models (such as SWAT, IQQM, HEC-HMS, amongst others), the Catchment Nodes also calculate water demands by the various crops. Moreover, the Catchment Nodes include also advanced options for re-use of water within a catchment, recoverable and non-recoverable flows and beneficial and non-beneficial water consumptions. Figure 2 shows the core processes as calculated by WEAP.

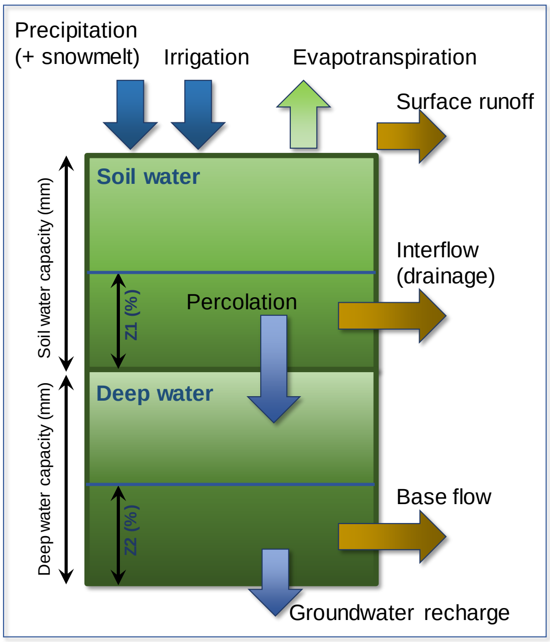

Figure 2. Schematic overview of the core processes in the WEAP catchments’ calculations.

Next to the Catchment nodes, “Demand Sites” with domestic water requirements are explicitly included for each subcatchment. Each demand site has two specific water users: urban and rural water supply. Following data gathered in the ADB TA7610 project, the following domestic water requirements were used: (i) urban - 160 liter per person per day and (ii) rural - 90 liters per person per day. Within each subcatchment, a storage “Reservoir” node is defined. Runoff from a “Catchment” node can enter a river and/or reservoir, and infiltration can occur to a groundwater element that is defined at basin scale (Sreng and Sisophon). For each Groundwater Node recharge is calculated by WEAP and abstractions are based on the domestic demands and the actual groundwater storage. Finally, downstream in every subcatchment an environmental flow requirement is defined. The environmental requirement is set at 30% of the mean annual flow during the wet season, and 0.2 m^3 s^{-1} per 100 km2 of catchment area during the dry season. Mean annual flow was simulated by WEAP based on a scenario with no minimum flow requirements.

A full overview of the model schematization is shown in Figure 3.

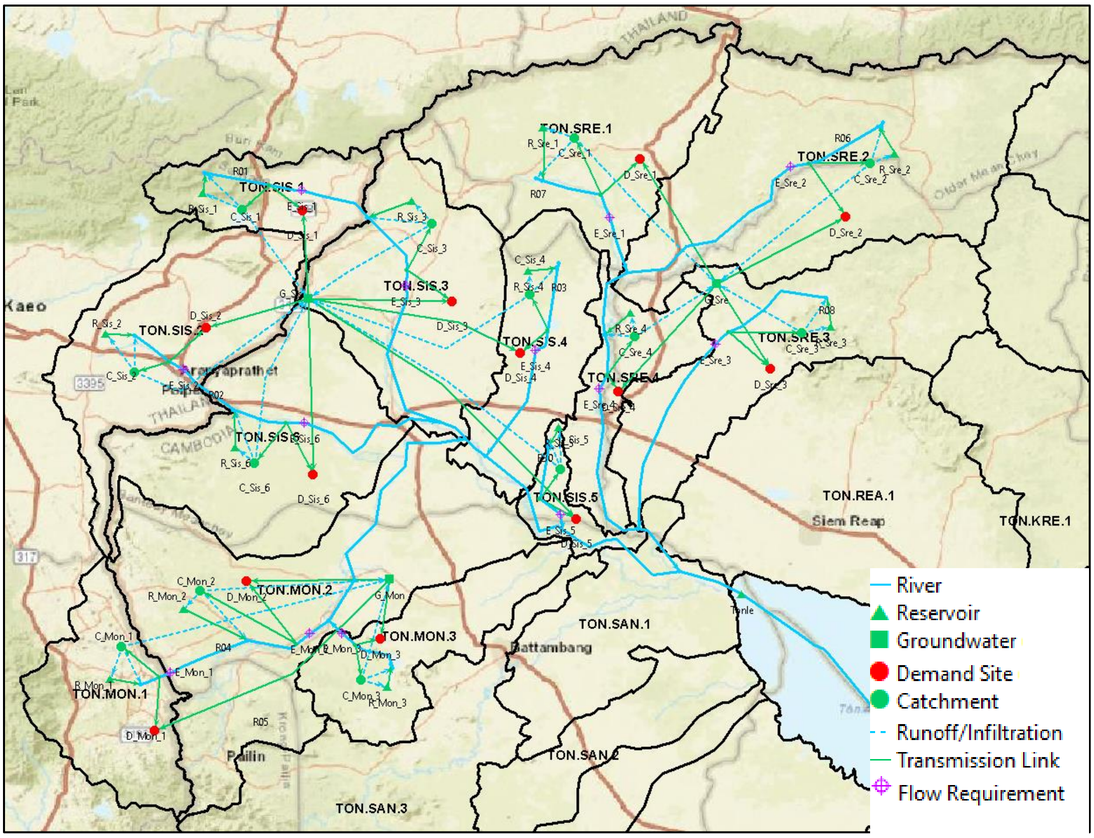

Figure 3. Schematization of the WEAP model for Oddar Meanchey and Banteay Meanchey.

2.1.3 Land use and irrigation

Each Catchment Node is divided into twelve land use classes, making a total of 156 (13*12) calculation units within the entire model. The distribution of eight of those classes is shown in Figure 4 (data source: MRC land cover mapping, 2016). An obvious difference between the two provinces is the relatively large stretch of forest that is still present in Oddar Meanchey.

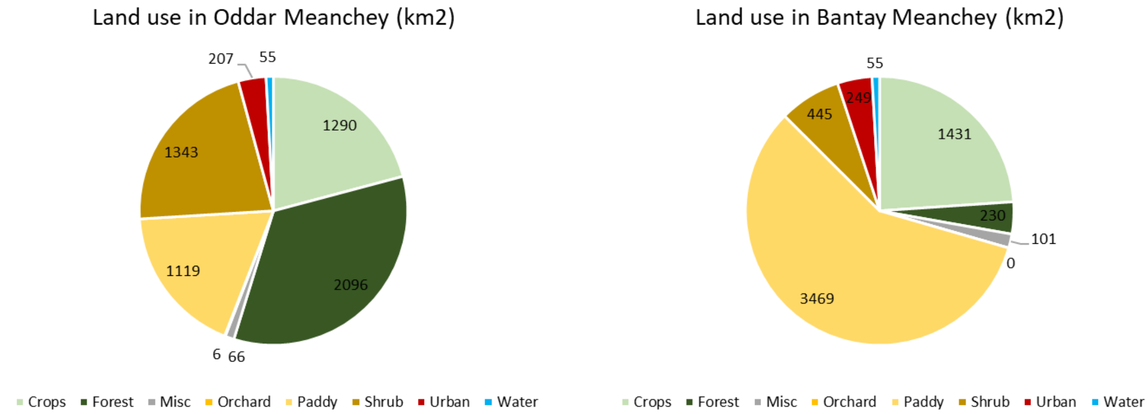

Figure 4. Land use in Oddar Meanchey and Banteay Meanchey as incorporated in WEAP (values indicate areas in km^2).

The other four land use classes are representative of different irrigation practices. Actual water demand by the paddy cultivation is not well known and is calculated by the WEAP model using the Penman-Monteith equation. Additional irrigation requirement is calculated based on the actual available soil water, This irrigation water requirement is abstracted from the streams and rivers in the sub-catchment. In case insufficient water is available, WEAP calculates the water shortage ("unmet demand"). There are three main paddy growing practices in the area (Figure 5):

- Wet Season
    - Land preparation: 1-Jun / 15 Jun
    - Planting: 15-Jun / 30-Jun
    - Harvesting: 1-Nov / 15 Nov
- Dry in Wet (Early Dry Season Short Duration variety)
    - Land preparation: 15-Apr / 30-Apr
    - Planting: 1-May / 15-May
    - Harvesting: 15-Jul / 31-Jul
- Dry Season
    - Land preparation: 1-Dec / 15-Dec
    - Planting: 15-Dec / 30-Dec
    - Harvesting: 1-Mar / 15-Mar

For each of the sub-catchments, acreages of the MoWRAM CISIS database have been used in the model.

	01-Jan / 15-Jan	15-Jan / 01-Feb	01-Feb / 15-Feb	15-Feb / 01-Mar	01-Mar / 15-Mar	15-Mar / 01-Apr	01-Apr / 15-Apr	15-Apr / 01-May	01-May / 15-May	15-May / 01-Jun	01-Jun / 15-Jun	15-Jun / 01-Jul	01-Jul / 15-Jul	15-Jul / 01-Aug	01-Aug / 15-Aug	15-Aug / 01-Sep	01-Sep / 15-Sep	15-Sep / 01-Oct	01-Oct / 15-Oct	15-Oct / 01-Nov	01-Nov / 15-Nov	15-Nov / 01-Dec	01-Dec / 15-Dec	15-Dec / 31-Dec
Wet Season											1	2	3	3	3	3	3	3	3	3	4			
Recession	3	3	3	3	4																1	2	3	3
Dry in Wet								1	2	3	3	3	3	4										
Dry Season	3	3	3	3	4																		1	2

Figure 5. Cropping calendar for four paddy seasons. 1 = land preparation, 2 = planting, 3 = growing, 4 = harvesting. Note: in reality, quite some variation in paddy cultivation periods exists in the region.

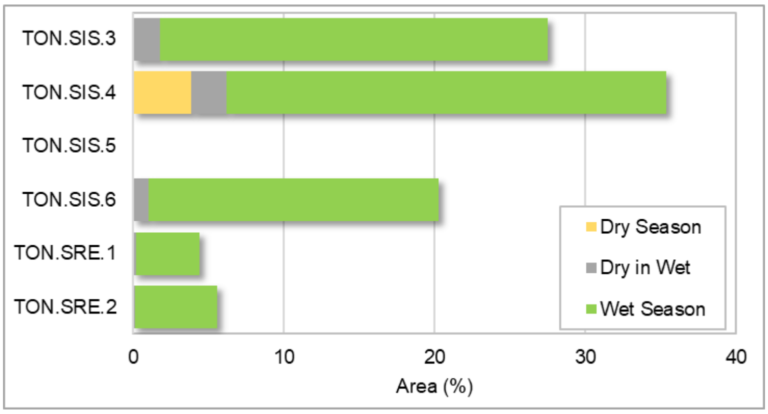

Figure 6. Area of irrigation crop calendar season for each sub-catchment presented as total area of the sub-catchment.

2.2 Storage data

It is essential for the model to simulate well the carrying over of water from wet to dry seasons by making use of the available storage capacity in the subcatchments. To quantiffy the capacity of the Reservoir nodes in WEAP, two main data sources are available: (i) the CISIS database, and (ii) the ESA EO Clinic report *Mitigation of Climate Change Risks in the Agricultural Sector of Cambodia* (ESA, 2020) and the accompanying satellite-derived data. Reservoirs included in the CISIS database for Oddar Meanchey and Banteay Meanchey are listed in the Annex to this document. Where capacities where not included, these were computed based on listed reservoir surfaces and an average depth of 2.2 m derived from other reservoirs having all data available. The ESA EO Clinic data consist of set of 10m rasters of surface water extent in 2017-2019 in Oddar Meanchey.

Table 1 provides an overview of both datasets for Oddar Meanchey. ESA data listed here are the maximum extents for the 2019 wet season, which has the greatest surface water coverage in the period of analysis. Although the spatial distribution of included reservoirs generally is similar (Figure 7), it is clear from the table that the two datasests are somewhat difficult to reconcile. Likely reasons for this are that (i) the reservoirs, particularly the large ones, were not filled to their maximum capacity at the time of monitoring, and (ii) CISIS particularly misses data on storage sites in communes with small reservoirs and ponds.

Table 1. Overview of storage in Oddar Meanchey districts and communes, according to the ESA EO Clinic and CISIS datasets

District	Commune	Total area	ESA	CISIS
		km²	*km²*	*km²*
Anlong Veaeng	Anlong Veaeng	391.4	1.7	5.2
	Lumtong	477.2	2.4	-
	Thlat	211.0	0.0	-
	Trapeang Prei	112.9	0.1	-
	Trapeang Tav	340.3	10.0	30.8
Banteay Ampil	Ampil	364.6	0.3	0.1
	Beng	446.9	0.6	8.6
	Kouk Mon	270.5	2.0	6.6
	Kouk Khpos	271.3	0.3	0.7
Chong Kal	Cheung Tien	93.9	1.7	-
	Chong Kal	291.2	12.6	6.9
	Krasang	163.0	0.5	-
	Pongro	292.5	8.6	73.2
Samraong	Bansay Reak	116.9	0.1	6.0
	Bos Sbov I	98.2	0.1	-
	Koun Kriel	1087.8	10.1	1.2
	Ou Smach	20.4	0.2	-
	Samraong I	95.3	2.0	1.3
Trapeang Prasat	Bak Anloung	137.4	0.2	-
	Ou Svay	162.0	0.5	-
	Ph'av	471.1	1.3	-
	Preah Pralay	68.0	0.0	-
	Trapeang Prasat	502.0	0.1	-
	Tumnob Dach	146.4	0.1	0.4
Total			**55.5**	**141.0**

CISIS storage data as listed in the Annex were aggregated per subcatchment for usage in the WEAP model. For Oddar Meanchey, a total of 435 MCM (62.5 MCM in SRE.1 and 372.5 MCM in SRE.2) were included. Total maximum storage capacity in Banteay Meanchey is 192.1 MCM.

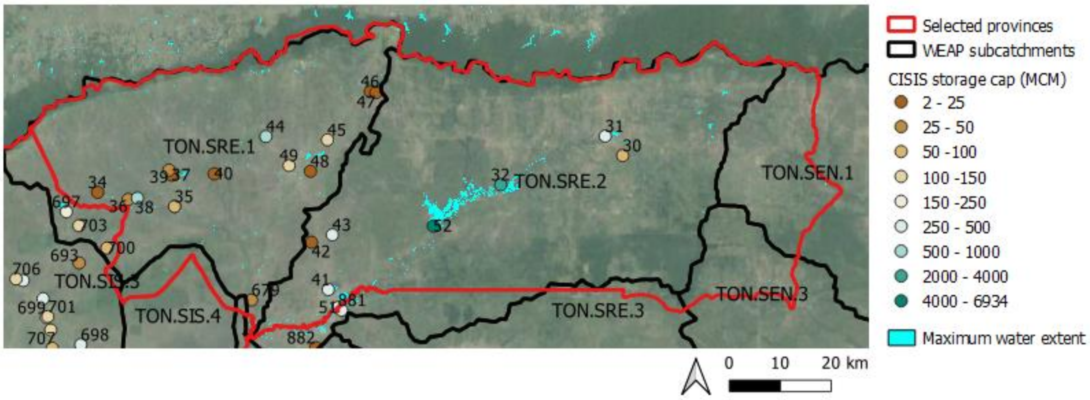

Figure 7. ESA EO Clinic (maximum water extent in 2019 wet season) and CISIS storage data for Oddar Meanchey Province.

2.3 Scenario development

2.3.1 Rationale and overview of scenarios

For the purpose of this study, it was required to perform several scenario runs with varying reservoir storage capacity per subcatchment, for the current situation as well as under climate change. This should provide the necessary insight at the provincial level to quantify the added benefit of developing additional storage capacity, taking into account extreme years and climate change. The key parameter to evaluate is the unmet water demand of agriculture and domestic water use.

In total, 33 model simulations were performed:

- A reference run for 1999-2018;
- 10 simulations with progressively added storage from 10 MCM to 100 MCM per subcatchment, in steps of 10 MCM, forced by the current climate;
- A run to evaluate the expected impact of a first climate change trajectory (CC1) on the provincial water balance, further specified in Section 2.3.2;
- 10 simulations with progressively added storage from 10 MCM to 100 MCM per subcatchment, in steps of 10 MCM, forced by the CC1 climate.
- A run to simulate the likely impact of a first climate change trajectory on the provincial water balance (CC2), further specified in Section 2.3.2;
- 10 simulations with progressively added storage from 10 MCM to 100 MCM per subcatchment, in steps of 10 MCM, forced by the CC2 climate.

2.3.2 Climate change scenarios

As listed above, two possible projections regarding the future climate were used to force the WEAP model. The first one, CC1, is based on the average of the RCP8.5 projections for the 2045-2075 period, according to all 21 General Circulation Models (GCMs) included in the NASA-NEX[1] dataset. Figure 8 presents historical (ERA5) and projected mean temperature according these GCMs, showing a clear increase in temperature over the next decades. Figure 9 indicates the average of all GCMs regarding projected changes in monthly precipitation. Based on the average trends predicted by the models in the NASA-NEX database, the CC1 WEAP run implements an overall temperature increase of 2ºC and an overall 5% precipitation increase throughout the year.

[1] https://www.nasa.gov/nex

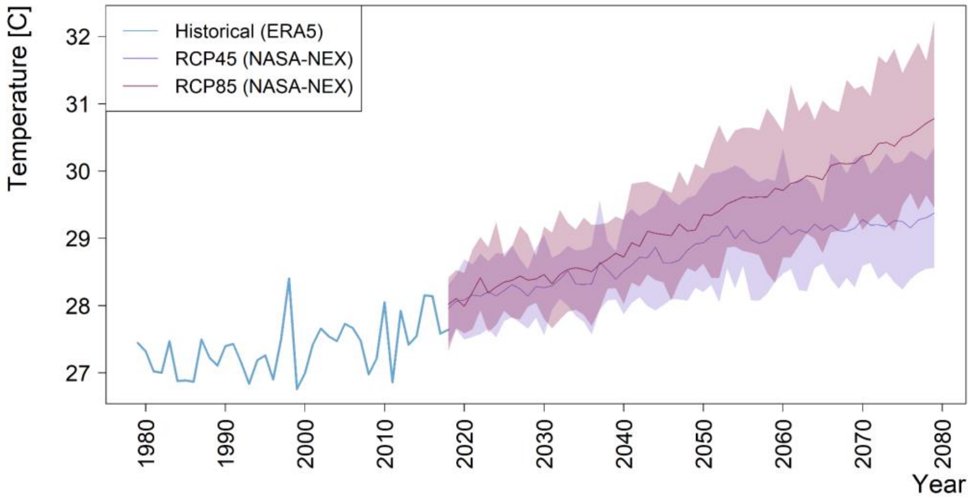

Figure 8. Historical and projected mean temperature under RCP4.5 and RCP8.5 according to the NASA-NEX climate models. Red and blue bands indicate the range of values from the individual models.

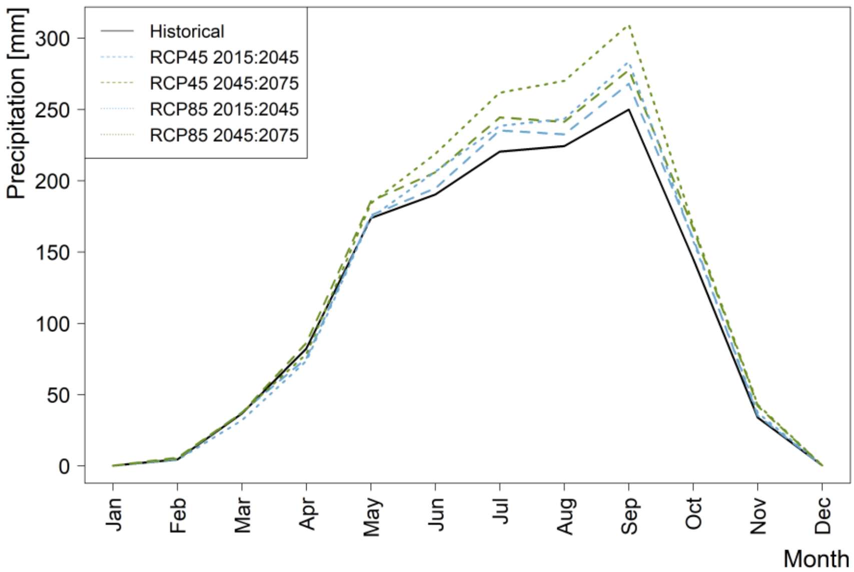

Figure 9. Historical and projected (2015-2045 and 2045-2075) monthly precipitation under RCP4.5 and RCP8.5 according to the NASA-NEX climate models.

As the variability in precipitation projections among the models is much higher than for temperature, a second climate change scenario (CC2) was simulated by the WEAP model to investigate another potential precipitation trajectory. To this end, a GCM with extreme seasonality (drier dry seasons and wetter wet seasons) was selected based on an overall assessment of various precipitation change indicators per model. Figure 10 shows for all GCMs in NASA-NEX the projected changes in three precipitation indicators, based on a 1975-2005 historical period (ERA5 data) and the 2045-2075 future period (RCP8.5). To be suitable for implementation in WEAP as CC2, a GCM should in particular project a substantial decrease in average dry season rainfall (upper panel), and a significant increase in the P99 indicator (lower panel), which is defined as the 99th-percentile of daily precipitation. In other words, the latter indicator is representative of the impacts of climate change on the wettest days of the year. Based on these criteria, the IPSL.CM5A.MR was ultimately selected for usage in WEAP for the CC2 simulations.

This is in line with the findings of MRC, who recommended this model for analyses of extreme seasonality in the Lower Mekong Basin (MRC, 2015).

The extracted change indicators were applied to the historical daily rainfall data to produce a synthetic daily rainfall time series as input to WEAP, which matches the projected changes in the various indicators. Both CC1 and CC2 incorporate the same temperature increase of 2ºC.

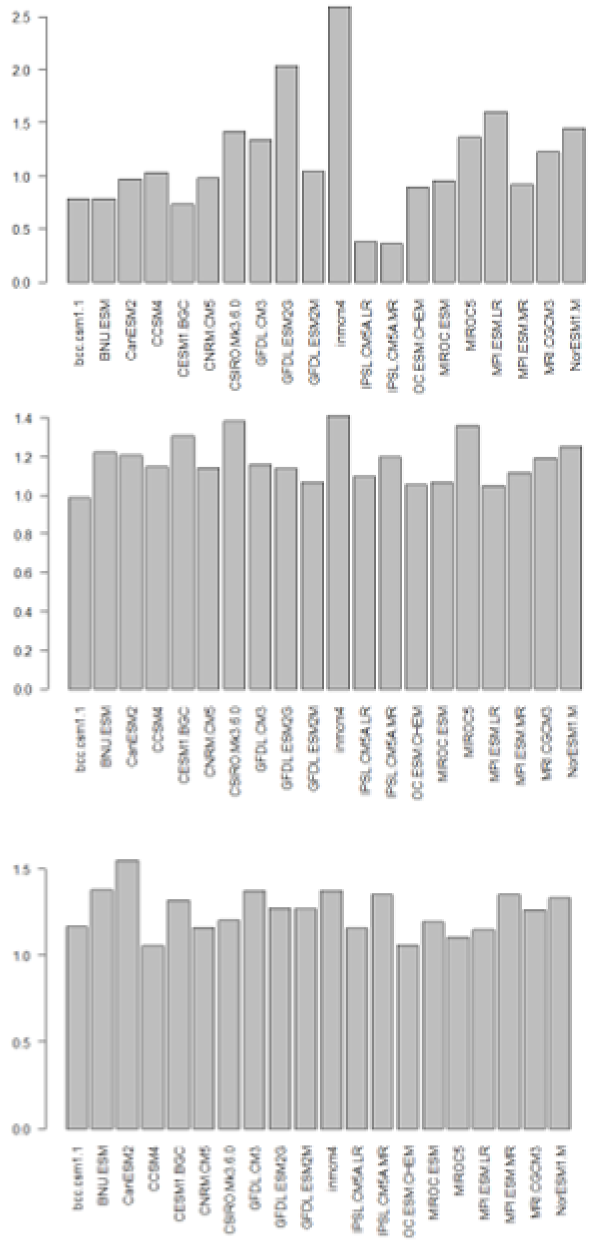

Figure 10. Three indicators of projected changes (unitless) in precipitation patterns for each GCM in NASA-NEX: change in average daily precipitation in dry season (top), change in average daily precipitation in wet season (top), change in P99 (99th-percentile of daily precipitation, bottom).

3 Results

3.1 Current water balance and unmet demand

Figure 11 presents annual values for the different water balance components computed by the WEAP model for Oddar Meanchey. Clearly, the province is a water-producing area, thanks to the natural vegetation that is still in place. On average over the 1999 – 2018 period, 201 mm/yr (1.2 BCM/yr) of water leaves the province through the Sreng River. Over the same period, 167 mm/yr (1.0 BCM/yr) on average was added to the regional groundwater reserve.

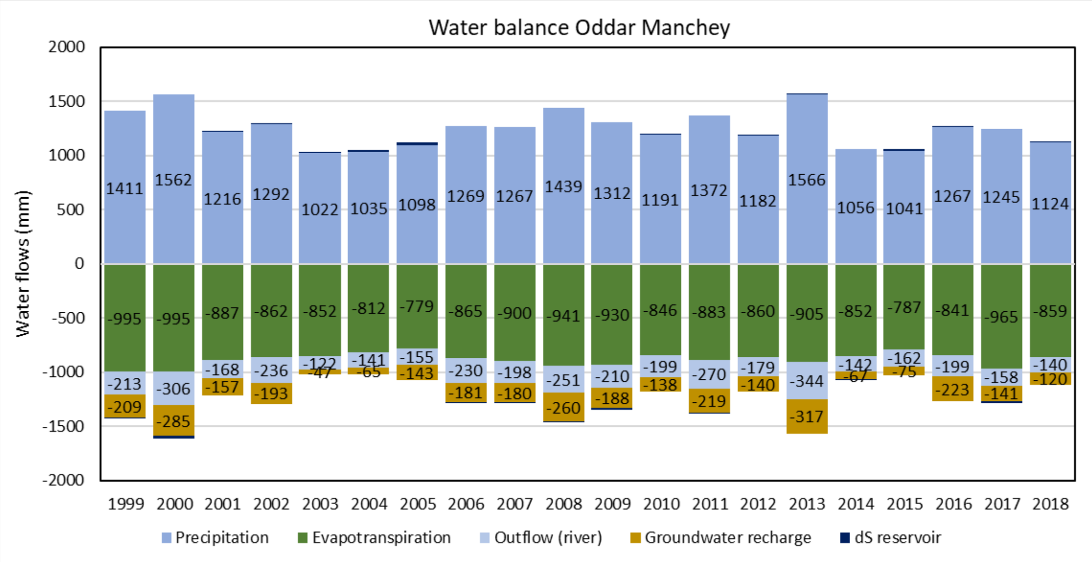

Figure 11. Water balance of Oddar Meanchey as produced by the WEAP model. All values are in mm/year.

Although the runoff produced in Oddar Meanchey is substantial and benefits downstream areas, the province itself is known to suffer from water shortages in dry periods. Table 2 shows how unmet demands occur for both domestic use and the irrigation sector in the 20 years under consideration. In this analysis, it is assumed that the 20-year period suffices to capture typical climate variability in Oddar Meanchey. Particularly the storage capacity in SRE.1 appears to be insufficient to avoid water shortages, as unmet demands occur in most years of the modeling period.

Table 2. Unmet demand (supply requirement minus supply delivered) for irrigation (Irri) and domestic (Dom) sectors in Oddar Meanchey. All values are in MCM/yr.

	SRE.1			SRE.2			Oddar Meanchey		
	Dom	*Irri*	*Total*	*Dom*	*Irri*	*Total*	*Dom*	*Irri*	*Total*
1999	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2001	0.4	12.1	12.5	0.0	0.0	0.0	0.4	12.1	12.5
2002	0.5	24.4	24.9	0.0	0.0	0.0	0.5	24.4	24.9
2003	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2004	1.6	3.3	4.8	0.0	0.0	0.0	1.6	3.3	4.8
2005	2.6	105.1	107.8	0.5	55.6	56.1	3.1	160.8	163.9
2006	0.6	15.8	16.4	0.1	15.1	15.2	0.8	30.8	31.6
2007	0.9	0.3	1.2	0.0	0.0	0.0	0.9	0.3	1.2

2008	0.2	0.0	0.2	0.0	0.0	0.0	0.2	0.0	0.2
2009	0.0	0.9	0.9	0.0	0.0	0.0	0.0	0.9	0.9
2010	0.5	11.0	11.4	0.0	0.0	0.0	0.5	11.0	11.4
2011	0.4	0.1	0.4	0.0	0.0	0.0	0.4	0.1	0.4
2012	1.2	63.5	64.6	0.0	0.0	0.0	1.2	63.5	64.6
2013	0.7	1.1	1.7	0.0	0.0	0.0	0.7	1.1	1.7
2014	0.2	15.9	16.2	0.0	0.0	0.0	0.2	15.9	16.2
2015	1.2	30.7	31.8	0.0	0.0	0.0	1.2	30.7	31.8
2016	1.1	35.6	36.7	0.0	0.0	0.0	1.1	35.6	36.7
2017	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2018	0.3	3.5	3.7	0.0	0.0	0.0	0.3	3.5	3.7
Average	**0.6**	**16.2**	**16.8**	**0.0**	**3.5**	**3.6**	**0.6**	**19.7**	**20.3**

To put the unmet demand values into perspective, it is helpful to quantify the "coverage" indicator in WEAP, which is defined as the degree to which the supply delivered meets the total supply requirement of a demand node (in %). Figure 12 depicts the average dynamics of the coverage parameter throughout the year, for irrigation in Oddar Meanchey. However, the severity of water shortages can vary greatly between years. The curve for 2005 (the year with the highest unmet demand) is also plotted to illustrate this. During several weeks in 2005, water supply in SRE.1 subcatchment was below 20% of the irrigaiton water requirement.

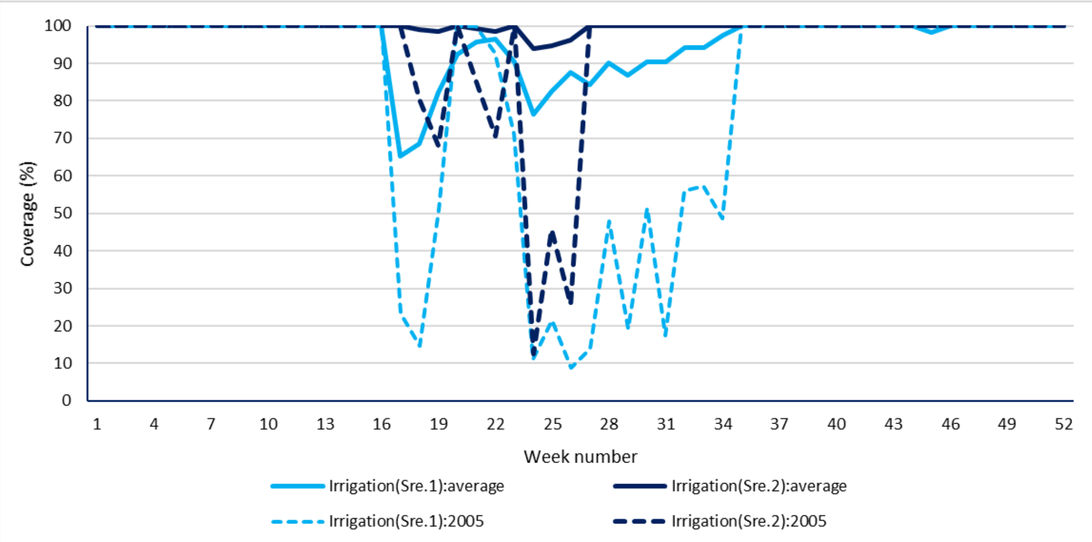

Figure 12. Coverage (supply delivered divided by supply required) of irrigation demand in Oddar Meanchey Province. Continuous lines plot average values per week for both WEAP model units SRE.1 and SRE.2. Dashed lines show the values for 2005, the year with the greatest unmet demand in the period of analysis.

The fact that Oddar Meanchey is water-producing while at the same time experiencing significant unmet water demands, is indicative of a lack of storage capacity in the province. Particularly in the western part of the province, the total storage capacity of 62.5 MCM appears insufficient to buffer the water needed for domestic and agricultural use in periods of drought. As WEAP computes the storage of water in the reservoirs on a weekly basis, the intra-annual patterns of precipitation, demands and storage can be analyzed to determine the nature of the shortages. Figure 13 examines the cause of the high unmet irrigation demand occuring in 2005 in SRE.1 subcatchment. The graph shows that reservoir storage is far below the average amount throughout the year, and even close to zero for a large part of the year. The reason for this lack of water can be found in the rainfall dynamics in the preceding year 2004. This was an erratic year in terms of rainfall, with a peak of 156 mm/week (= 382 MCM) in week 24, which could not be stored due to a lack of capacity. As rainfall amounts in the remainder of the year were far below average, this resulted in insufficient water availability at the start of the wet season irrigation in early June.

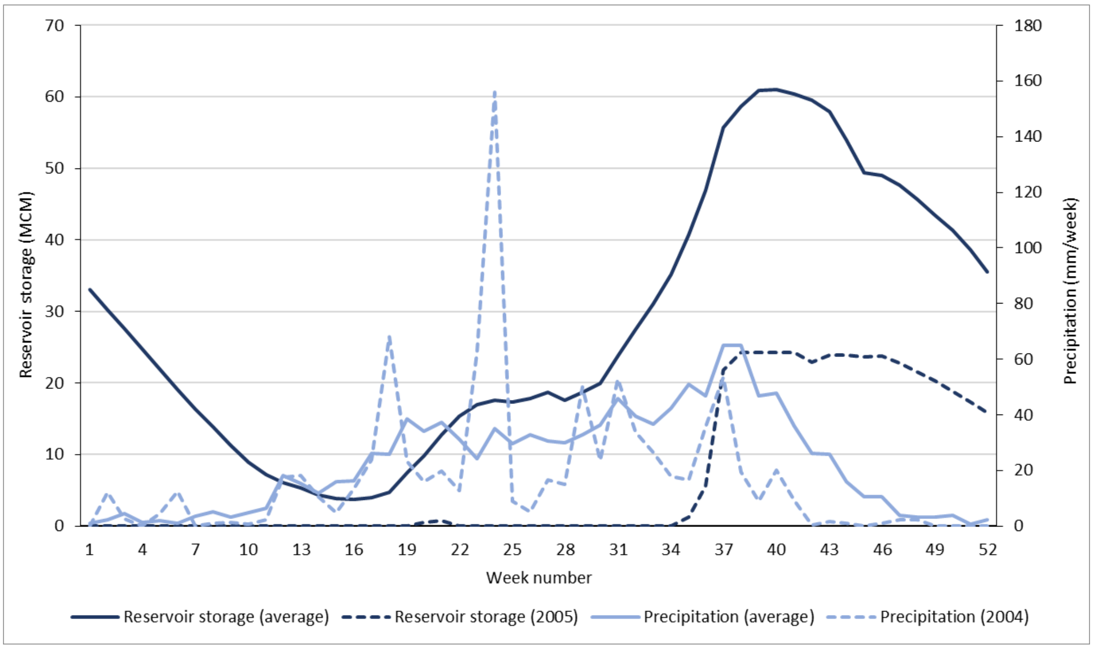

Figure 13. Reservoir storage in SRE.1 on average for 1999-2018 and in the year 2005. Clearly, storage is close to zero for a large part of that year. This is due to the precipitation pattern in the preceding year (2004), which had a highly concentrated rainfall peak relatively early in the year and very low rainfall afterwards.

3.2 Water balance under climate change

Figure 14 and Figure 15 present the water balance for the two climate scenarios implemented in WEAP; an overall slightly wetter climate (CC1), and a scenario with more extreme seasonality (CC2). Interestingly, for most years, the additional water available from rainfall in the CC1 scenario leads to an increased evapotranspiration, as this water can be partly put to (human or natural) use in the province due to the even distribution of the extra rainfall over time. This is however not the case in the CC2 scenario, where evapotranspiration is mostly lower than in the historical situation, and especially river flow out of the province substantially increases. This is due to the fact that especially the additional rainfall on the wettest days cannot be stored, either in the soil profile or in artificial reservoirs.

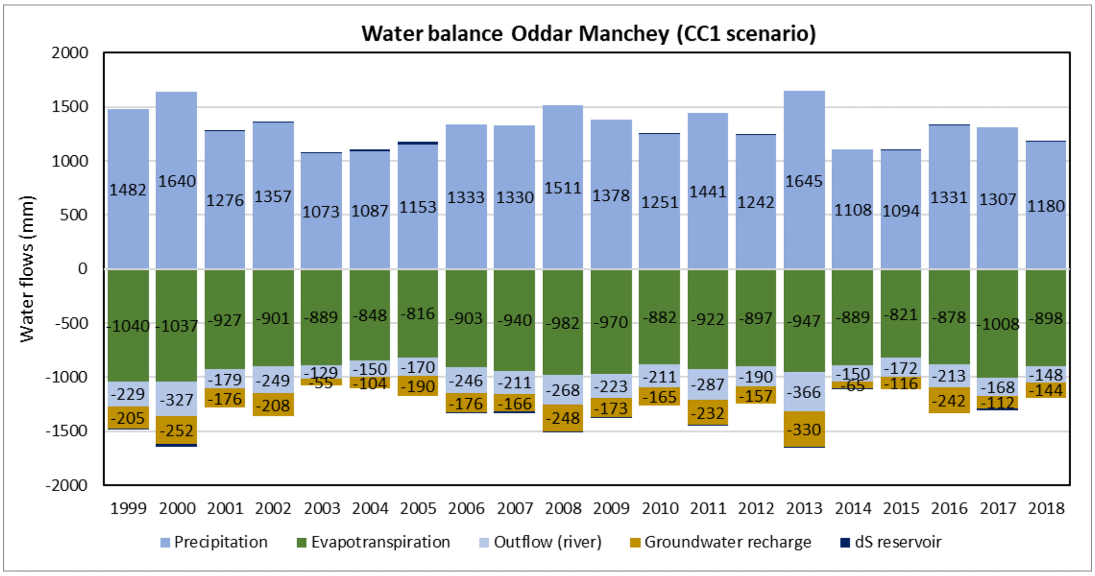

Figure 14. Water balance of Oddar Meanchey as produced by the WEAP model for the CC1 climate scenario. All values are in mm/year.

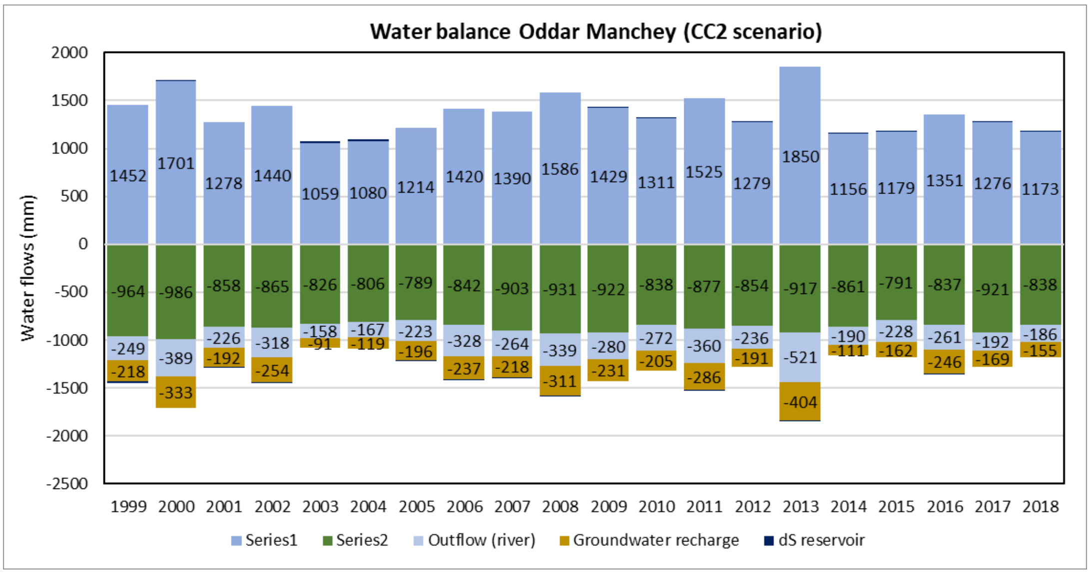

Figure 15. Water balance of Oddar Meanchey as produced by the WEAP model for the CC2 climate scenario. All values are in mm/year.

3.3 Development of additional storage capacity

The impact of developing additional storage capacity in Oddar Meanchey on unmet domestic and agricultural water demand was evaluated by performing a set of scenario runs. Table 3 shows the yearly total water shortage in the province for each of the scenarios, each expanding the provincial storage capacity by 10 MCM. The non-linear nature of the hydrological processes involved is clear from these results, with an additional 10 MCM sometimes having only a minor impact, while in other cases the unmet demand is reduced with more than 10 MCM. The result show that e.g. when storage is expanded by 20 MCM, unmet demands are eliminated in 6 additional years compared to the reference run. For three years (2005, 2006, 2016), even an expansion of 100 MCM is insufficient to completely eliminate water shortages. Interestingly, unmet demand in 2005 stabilizes from 60 MCM of additional storage, as apparently there is simply not enough water supplied to buffer for meeting the demands.

Table 3. Total yearly unmet water demand (MCM) for domestic and agricultural use, for the reference situation and 10 scenarios with additional storage development. The red colour indicates the magnitude of the unmet demand relative to the reference model run for each year.

Add. storage (MCM)	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
0	0.0	0.0	12.5	24.9	0.0	4.8	163.9	31.6	1.2	0.2	0.9	11.4	0.4	64.6	1.7	16.2	31.8	36.7	0.0	3.7
10	0.0	0.0	11.9	23.8	0.0	4.7	155.3	24.7	1.1	0.1	0.0	10.4	0.2	64.4	1.5	10.5	31.7	36.5	0.0	3.0
20	0.0	0.0	4.3	14.1	0.0	4.5	137.9	23.9	1.0	0.0	0.0	7.4	0.0	63.4	1.4	2.3	30.5	36.4	0.0	0.0
30	0.0	0.0	0.0	4.0	0.0	4.4	125.0	14.9	0.8	0.0	0.0	1.2	0.0	55.2	0.9	0.0	29.0	36.2	0.0	0.0
40	0.0	0.0	0.0	0.0	0.0	4.2	113.5	12.4	0.7	0.0	0.0	0.0	0.0	39.9	0.0	0.0	27.4	35.7	0.0	0.0
50	0.0	0.0	0.0	0.0	0.0	3.9	107.3	8.0	0.5	0.0	0.0	0.0	0.0	30.9	0.0	0.0	21.0	33.4	0.0	0.0
60	0.0	0.0	0.0	0.0	0.0	0.7	105.7	8.0	0.0	0.0	0.0	0.0	0.0	18.1	0.0	0.0	9.2	32.6	0.0	0.0
70	0.0	0.0	0.0	0.0	0.0	0.5	105.7	6.3	0.0	0.0	0.0	0.0	0.0	11.2	0.0	0.0	6.3	32.3	0.0	0.0
80	0.0	0.0	0.0	0.0	0.0	0.3	105.7	4.7	0.0	0.0	0.0	0.0	0.0	2.4	0.0	0.0	1.0	29.6	0.0	0.0
90	0.0	0.0	0.0	0.0	0.0	0.2	105.7	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	23.3	0.0	0.0
100	0.0	0.0	0.0	0.0	0.0	0.0	105.7	2.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.2	0.0	0.0

Table 4 shows the results of the set of model runs which involve an overall slightly wetter climate (CC1). Interestingly, overall unmet demands are lower already in the reference run. Although the increase in temperature leads to higher water consumption and thus potential greater shortages, this is compensated by the increase in rainfall in the wet season, which can under current conditions apparently already be sufficiently stored to reduce unmet demands somewhat. The figure shows that the potential of additional storage to reduce water shortages significantly is even greater under a changed climate, with shortages in 19 out of 20 years completely eliminated in the +100 MCM storage capacity scenario.

Table 4. Total yearly unmet water demand (MCM) for domestic and agricultural use, under climate change (CC1) and 10 scenarios with additional storage development. The red colour indicates the magnitude of the unmet demand relative to the reference model run including climate change, for each year.

Add. storage (MCM)	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
0	0.0	0.0	8.4	18.1	0.0	1.8	110.4	15.1	1.1	0.2	0.0	9.4	0.4	56.7	1.6	11.6	24.8	36.0	0.0	1.3
10	0.0	0.0	7.6	17.2	0.0	1.7	99.4	15.0	1.0	0.0	0.0	8.6	0.2	56.5	1.4	7.3	24.6	35.8	0.0	0.4
20	0.0	0.0	1.7	7.6	0.0	1.5	94.3	14.4	0.8	0.0	0.0	4.7	0.0	55.6	1.3	0.0	23.1	35.7	0.0	0.0
30	0.0	0.0	0.0	2.3	0.0	1.3	94.3	13.3	0.6	0.0	0.0	0.0	0.0	48.7	0.6	0.0	21.5	35.6	0.0	0.0
40	0.0	0.0	0.0	0.0	0.0	1.1	94.3	7.1	0.5	0.0	0.0	0.0	0.0	33.8	0.0	0.0	19.5	33.8	0.0	0.0
50	0.0	0.0	0.0	0.0	0.0	0.5	94.3	2.9	0.0	0.0	0.0	0.0	0.0	25.6	0.0	0.0	9.8	32.4	0.0	0.0
60	0.0	0.0	0.0	0.0	0.0	0.4	94.3	0.0	0.0	0.0	0.0	0.0	0.0	13.2	0.0	0.0	7.6	27.7	0.0	0.0
70	0.0	0.0	0.0	0.0	0.0	0.2	94.3	0.0	0.0	0.0	0.0	0.0	0.0	7.5	0.0	0.0	1.4	19.7	0.0	0.0
80	0.0	0.0	0.0	0.0	0.0	0.1	94.3	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	11.2	0.0	0.0
90	0.0	0.0	0.0	0.0	0.0	0.0	94.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.1	0.0	0.0
100	0.0	0.0	0.0	0.0	0.0	0.0	94.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 5 shows the results of the set of model runs which involve a climate with more extreme seasonality (CC2). The impact on unmet demands with zero additional storage differs per year, e.g. a higher unmet demand in 2001 and a lower unmet demand in 2002, when compared to the historical climate. This is due to the non-linear changes in daily precipitation dynamics that were applied in this scenario. Again, similar to CC1, the benefit of additional storage capacity is higher than under the historical climate, with now shortages in 19 out of 20 years completely eliminated in the +80 MCM storage capacity scenario

Table 5. Total yearly unmet water demand (MCM) for domestic and agricultural use, under climate change (CC2) and 10 scenarios with additional storage development. The red colour indicates the magnitude of the unmet demand relative to the reference model run including climate change, for each year.

Add. storage (MCM)	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
0	0.0	0.0	17.4	17.7	0.0	1.4	77.8	22.7	1.0	0.2	3.3	14.6	0.6	44.0	1.6	22.2	31.3	37.7	0.0	6.5
10	0.0	0.0	17.2	16.6	0.0	1.2	77.8	22.2	0.9	0.1	0.0	14.4	0.5	43.8	1.5	10.0	31.1	37.5	0.0	5.9
20	0.0	0.0	16.2	9.3	0.0	1.0	77.8	20.6	0.7	0.0	0.0	12.9	0.3	43.0	1.3	5.1	29.8	36.5	0.0	2.9
30	0.0	0.0	12.6	3.4	0.0	0.9	77.8	16.9	0.5	0.0	0.0	8.2	0.0	37.3	0.0	0.0	28.1	34.4	0.0	0.0
40	0.0	0.0	4.4	0.0	0.0	0.7	77.8	9.1	0.0	0.0	0.0	1.7	0.0	22.1	0.0	0.0	26.4	31.5	0.0	0.0
50	0.0	0.0	0.0	0.0	0.0	0.0	77.8	2.8	0.0	0.0	0.0	0.0	0.0	15.3	0.0	0.0	18.5	23.3	0.0	0.0
60	0.0	0.0	0.0	0.0	0.0	0.0	77.6	0.0	0.0	0.0	0.0	0.0	0.0	4.9	0.0	0.0	8.0	15.1	0.0	0.0
70	0.0	0.0	0.0	0.0	0.0	0.0	77.5	0.0	0.0	0.0	0.0	0.0	0.0	1.6	0.0	0.0	4.3	6.8	0.0	0.0
80	0.0	0.0	0.0	0.0	0.0	0.0	77.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
90	0.0	0.0	0.0	0.0	0.0	0.0	77.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
100	0.0	0.0	0.0	0.0	0.0	0.0	77.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Figure 16 synthesizes the scenario results of unmet water demands. The curve for the historical climate shows that especially in the current situation with relatively low storage capacity in Oddar Meanchey, the marginal benefit of developing additional storage is relatively high. Over the first 50 MCM of extra storage, a total of 10 MCM reduction on average of unmet demand is achieved (whereas this is only 4 MCM reduction over the second 50 MCM of additional development). In dry years with significant shortages such as 2005 and 2012, the beneficial impact of adding a first 50 MCM of storage is even much higher, at 56 MCM and 34 MCM respectively (see Table 3). A similar phenomenon is observed for the two climate change simulations. At the same time, the occurrence of an overall wetter (CC1) or more erratic (CC2) climate enhances the potential benefits to be gained from additional buffering of water, as extra water can be put to beneficial use. This leads, for example, to a reduction of 19% and 32% of unmet demands respectively for under CC1 and CC2 conditions, in case 50 MCM of additional storage capacity is developed.

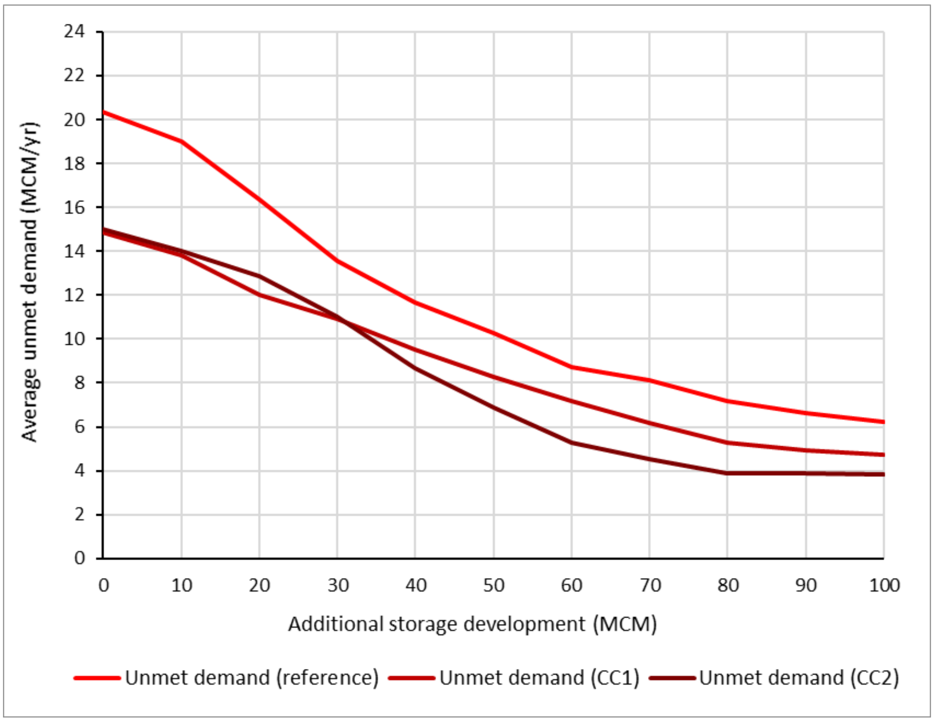

Figure 16. Impacts of developing additional storage capacity, expressed in reduced average unmet water demand for water.

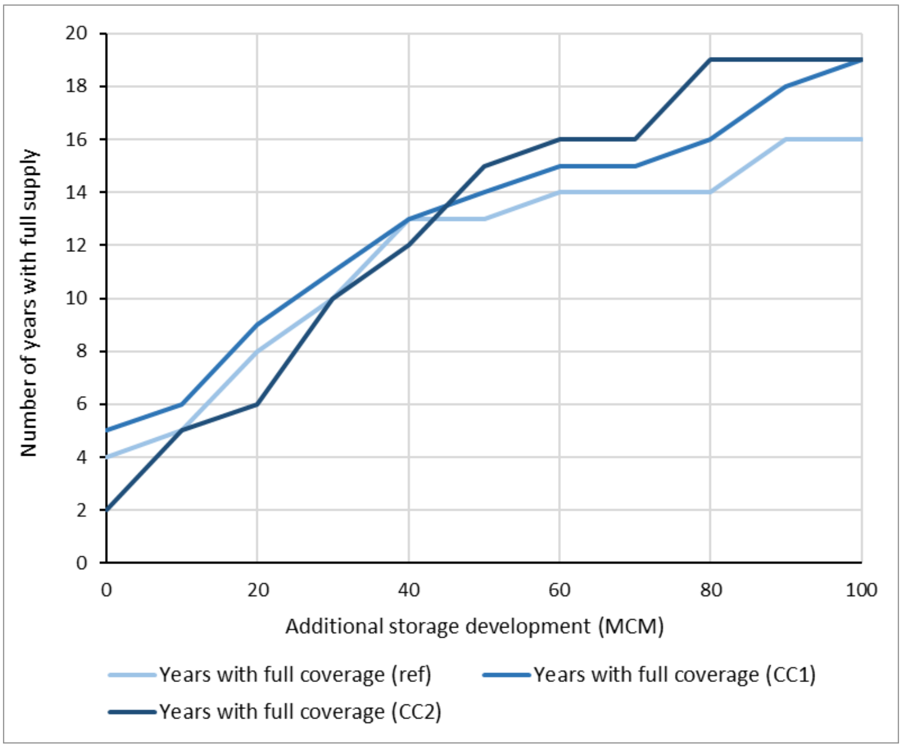

Figure 17. Impacts of developing additional storage capacity, expressed in the number of years without water shortages (full coverage).

4 Conclusions

A main conclusion to be drawn from the analysis is that the development of additional storage capacity is likely to reduce unmet domestic and agricultural water demand in Oddar Meanchey. Only in the most extreme dry year in a 20 year period, a point is reached (at 60 MCM of storage development) where no additional benefit is gained from further development because simply not enough water is available from the preceding rainy season. Under both simulated future conditions related to precipitation dynamics and temperature change, there is further benefit to be had from additional storage development as higher rainfall extremes can be buffered to mitigate water shortages in subsequent dry periods.

An interesting observation is that the marginal benefit of additional water storage capacity generally decreases with total storage capacity in the province. This means that a cost-benefit analysis will be instrumental to inform a regional water retention strategy.

The observation of having the greatest unmet demands in western OM (e.g. Banteay Ampil District) is very well in line with the results of the drought hazard mapping peformed under the same project, which saw communes in these areas having high drought hazard index values. This indicates that the lack of water storage has its impacts on e.g. vegetation / crop health and land surface temperature in these areas. In the WEAP schematization, the Reservoir nodes are representative of a much larger amount of smaller and larger ponds and reservoirs at lower levels of spatial disaggregation. Additional storage development should focus at the communes within western OM where high drought hazard values are calculated.

5 References

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Annex 1: CISIS database Oddar Meanchey and Banteay Meanchey

Subcatchment	District	Commune	X	Y	Reservoir surface area (ha)	Maximum Storage Capacity (MCM)
TON.SIS.3	Phnom Srok	Pun Ley	304403	1528185	300	6.00
TON.SIS.3	Serei Sophon	Makak	279421	1512561	390	1.10
TON.SIS.3	Thmar Puok	Thmar Puok	297254	1549615	30	0.75
TON.SIS.3	Thmar Puok	Kouk Romeat	278594	1544024	75	1.13
TON.SIS.3	Thmar Puok	Kouk Romeat	264700	1543118	50	1.25
TON.SIS.3	Thmar Puok	Kouk Romeat	281367	1542494	30	0.65*
TON.SIS.3	Thmar Puok	Kouk Kathen	297578	1533546	340	7.50
TON.SIS.3	Thmar Puok	Phum Thmey	290812	1538876	180	3.89*
TON.SIS.3	Thmar Puok	Phum Thmey	291115	1539068	120	2.60*
TON.SIS.3	Thmar Puok	Kamrou	286282	1546152	314	6.79*
TON.SIS.3	Thmar Puok	Thmar Puok	290164	1542592	257	5.56*
TON.SIS.3	Thmar Puok	Kouk Romeat	276999	1553536	110	1.60
TON.SIS.3	Thmar Puok	Kamrou	284854	1546465	105	2.27*
TON.SIS.3	Thmar Puok	Kouk Kathen	291983	1532850	89	1.93*
TON.SIS.3	Thmar Puok	Phum Thmey	291687	1536432	141	3.05*
TON.SIS.3	Svay Chek	Ta Ben	276805	1525254	230	5.75
TON.SIS.3	Svay Chek	Treas	281547	1534451	15	0.15
TON.SIS.3	Svay Chek	Treas	280665	1534837	15	4.50
TON.SIS.3	Svay Chek	Ta Phou	288845	1525826	26	1.50
TON.SIS.3	Svay Chek	Ta Phou	286786	1520453	189	4.09*
TON.SIS.3	Svay Chek	Ta Phou	292236	1527647	266	5.75*
TON.SIS.3	Svay Chek	Roluos	280385	1526757	82	1.77*
TON.SIS.3	Svay Chek	Phkam	297645	1524867	42	0.91*
TON.SIS.3	Svay Chek	Phkam	297775	1529749	261	5.65*
TON.SIS.3	Svay Chek	Saroung	296326	1521157	61	1.32*
TON.SIS.3	Svay Chek	Saroung	296113	1523405	100	2.16*
TON.SIS.3	Svay Chek	Treas	283991	1532707	3	0.06*
TON.SIS.3	Svay Chek	Svay Chek	260046	1534863	39	0.84*
TON.SIS.4	Phnom Srok	Pouy Char	313552	1525449	1194	22.82
TON.SIS.4	Phnom Srok	Spean Sreng	323822	1518879	2747	59.42*
TON.SIS.4	Preah Neth Preah	Preah Neth Preah	302315	1502652	300	6.00
TON.SIS.4	Preah Neth Preah	Phnom Leab	320554	1506141	10	0.25
TON.SIS.4	Preah Neth Preah	Chob Vary	304781	1507564	57	1.23*
TON.SIS.4	Preah Neth Preah	Preah Neth Preah	297585	1499307	272	5.88*
TON.SIS.4	Preah Neth Preah	Chob Vary	305626	1510145	44	0.95*
TON.SIS.4	Preah Neth Preah	Tean Kam	310805	1515361	347	4.50

TON.SIS.6	O Chrov	Seung	269116	1512420	88	1.90*
TON.SIS.6	O Chrov	Nimit	244403	1504837	703	1.00
TON.SIS.6	O Chrov	Koub	257484	1511451	178	3.85*
TON.SIS.6	Serei Sophon	Teuk Thlar	275463	1504646	325	1.00
TON.SIS.6	Malai	Beung Beng	219017	1494814	335	7.25*
TON.SRE.1	Banteay Ampil	Beng	315983	1560698	863	21.58
TON.SRE.1	Banteay Ampil	Ampil	300887	1563478	8	0.20
TON.SRE.1	Banteay Ampil	Kouk Khpos	315983	1560698	65	1.63
TON.SRE.1	Banteay Ampil	Kouk Mon	306866	1562097	35	0.63
TON.SRE.1	Banteay Ampil	Kouk Mon	315396	1566862	19	0.38
TON.SRE.1	Banteay Ampil	Kouk Mon	308700	1562340	558	12.07*
TON.SRE.1	Banteay Ampil	Kouk Mon	314869	1567859	43	0.77
TON.SRE.1	Banteay Ampil	Kouk Khpos	323755	1567107	8	0.24
TON.SRE.1	Samraong	Bansay Reak	333908	1574463	603	13.04*
TON.SRE.1	Samraong	Koun Kriel	345973	1573791	102	2.21*
TON.SRE.1	Samraong	Koun Kriel	354382	1583286	6	0.13*
TON.SRE.1	Samraong	Koun Kriel	355472	1583054	11	0.24*
TON.SRE.1	Samraong	Samraong	342638	1567632	22	0.48*
TON.SRE.1	Samraong	Samraong	338449	1568754	107	2.31*
TON.SRE.1	Phnom Srok	Nam Tao	331076	1542337	30	0.65*
TON.SRE.1	Thmar Puok	Banteay Chhmar	294748	1559652	210	1.50
TON.SRE.1	Thmar Puok	Banteay Chhmar	302703	1552536	81	1.75*
TON.SRE.1	Thmar Puok	Banteay Chhmar	297221	1556932	124	2.68*
TON.SRE.2	Anlong Veaeng	Anlong Veaeng	403923	1570713	100	3.50
TON.SRE.2	Anlong Veaeng	Anlong Veaeng	400490	1574534	417	20.85
TON.SRE.2	Anlong Veaeng	Trapeang Tav	379985	1564987	3075	153.75
TON.SRE.2	Chong Kal	Chong Kal	346139	1544365	421	12.60
TON.SRE.2	Chong Kal	Pongro	342872	1553670	18	7.46
TON.SRE.2	Chong Kal	Pongro	346934	1555125	370	7.46
TON.SRE.2	Chong Kal	Chong Kal	348011	1540837	271	5.86*
TON.SRE.2	Chong Kal	Pongro	366749	1556843	6934	149.98*
TON.SRE.2	Srei Snam	Chrouy Neang Nguon	340149	1530170	66	1.43*
TON.SRE.2	Srei Snam	Sleng Spean	348761	1540332	444	9.60*
TON.SRE.2	Srei Snam	Sleng Spean	343691	1532971	2	0.04*
Total OM						**435.0**
Total BM						**192.1**

**These storage capacities are not included in CISIS, but calculated based on reservoir suface area and the average depth of 2.2.m derived from reservoirs with all characteristics available*