

Downstream Impacts of the Melamchi Inter-Basin Water Transfer Plan (MIWTP) Under Current and Future Climate Change Projections

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Abstract: The Melamchi Water Supply Project (MWSP) is designed to minimize the shortage of drinking water in the Kathmandu valley. Although the project was supposed to be completed by 2008, due to various problems, it is still difficult to forecast the exact date of completion. This paper quantifies the downstream effects of diverting water from the Melamchi (Stage-I), Yangri (Stage-II) and Larke (Stage-III) rivers under current as well as future climate scenarios. The Soil Water Assessment Tool (SWAT) was used in the analysis. Result shows that in the Stage-I water transfer plan, average inflow reduction in the immediate downstream sub-basin in the dry and wet seasons are 36% and 7% respectively, where as in Stage-II the inflow reductions are 38% for the dry season and 8% for the wet season. In Stage-III, inflow reductions are 38% in the dry season and 7% in the wet season.

The impact of the water transfer schemes on various changes in water management within the Melamchi River irrigation command area was also tested. BUDGET (soil, water and salt balance) model was used to quantify crop water requirement of Melamchi River command area when the irrigated area is increased and the cropping pattern is changed. Simulation results of crop water requirement in intensive water use conditions show that present Melamchi River command area can be increased by 2.2 times under current climate projection, whereas the area can be increased 1.4 times in 2030s and by 2.0 times in 2050s.

Key words: Inter-basin water transfer, climate change, SWAT, BUDGET, Koshi basin, Melamchi, Nepal

Introduction

In Nepal, as elsewhere, migration trends from rural to urban areas are growing. As a result, the population of urban centers, especially Kathmandu is increasing at a rapid rate. Meeting water demands in Kathmandu is therefore a major challenge for the government. There are nearly 2.2 million people living in the Kathmandu valley and their daily drinking water demand is about 220 million liters (MWSDB 2008). Recent project document has reported that their daily demand is 330 million liters. National Population Census (CBS 2011) reported that the population of Kathmandu valley is nearly 3.5 million including floating population. Daily available water, however, within Kathmandu valley is about 90 million liters in the dry season and 130 million liters in the wet season (MWSDB 2008). Hence, the Government of Nepal (GON), the donor community and Non-governmental organizations are involved in finding alternative water sources to tackle the water scarcity crisis in Kathmandu. The Melamchi Water Supply Project (MWSP) was identified as a potential solution in 1973. The GON started the implementation of the Melamchi Water Supply Project in 1998 and originally, expected the project to be completed by 2008. However, due to various problems including the issue of downstream hydrological impacts, it is still difficult to predict whether the project will be completed by the extended date of completion; i.e., 2015.

The Melamchi River is located about 50 km North-East of the Kathmandu valley and is one of the tributaries of the Indrawati River. The Indrawati basin is a sub-basin within the Koshi basin (Figure 1). The MWSP diversion points of all stages are situated in the Indrawati River Basin which has a catchment area of 1,228 km². Melamchi, Yangri and Larke Rivers are major tributaries of the Indrawati River and have about 323, 117 and 116 km² catchment area respectively. The project plans to divert 170 MLD (1.97 m³/s) of water from Melamchi river in Stage-I and an additional 170 MLD each from Yangri and Larke tributaries

of the Indrawati River in Stage-II and III (Bhattarai, Pant et al 2002; Mishra and Shilpakar 2001). The project is important and has attracted a lot of attention and interest not only because it is seen as a solution to the drinking water crisis in Kathmandu but also because this is inter-basin water transfer project that is in the process of being implemented in Nepal.

At present, the available water in the Melamchi river basin is being used for irrigation, drinking water supply and sanitation, consumption for forest and vegetation, micro-hydropower generation and water mills (MWSDB 2008). The project has a high level of skepticism among the local community and stakeholders, despite the project compensation package as well as the inclusion of minimum flows of 34.56 MLD (0.4 m³/s) to be released downstream of the diversion (Bhattarai, Pant et al 2002; IUCN 1999; MWSDB 2008). So far, the project has paid about NRs. 880 million to the local community living in project affected areas as cash compensation (MWSDB 2008) and recent project document has reported that project has spent NRs. 900 million till 2011. The demand and grievances of local people plus political circumstances and challenges in engaging the private sector partner have all contributed to delay the completion of the project (Khadka and Khanal 2008).

Although the insufficiency of the prescribed minimum flow releases is one of the main critiques of the project, the few studies that have been carried out to look at water accounting have only focused on the Indrawati River basin (Bhattarai, Pant et al 2002; Mishra and Shilpakar 2001; Sharma 2002). Therefore, this study makes use of the hydrological model developed for the entire Koshi basin to look at the hydrological impacts of the MWSP until the outlet of the Koshi basin at Chatara (Figure 1) under current and future climate change projections. Furthermore, the impact of water transfers on the crop water requirement within the Melamchi River command area was also evaluated.

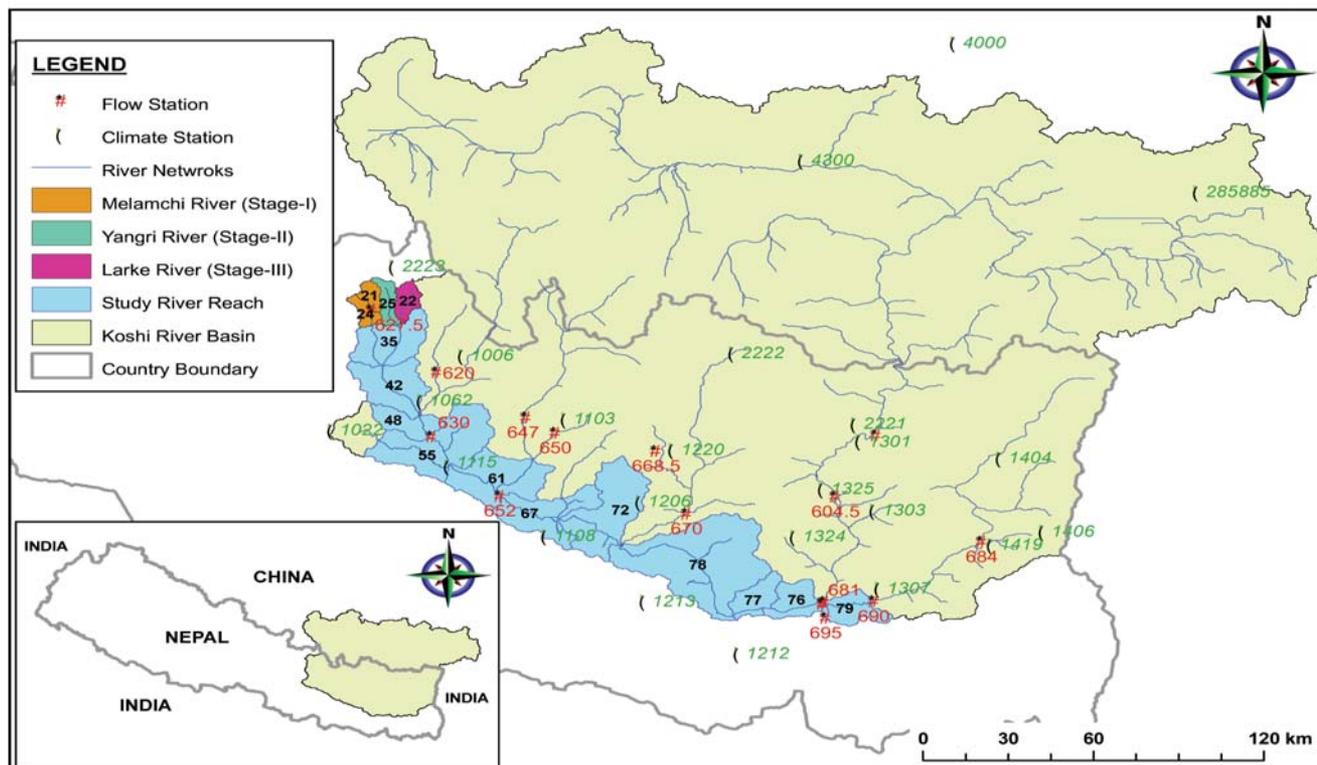


Figure 1. The Study Basin and Observed Climate and Flow Stations.

Data and Method

Quantification of water availability

The Soil and Water Assessment Tool (SWAT) model was setup for the Koshi basin as a part of the Indo-Ganges Basin Focal project (www.slideshare.net/cpwfbfp/indoganges-basin-focal-project). SWAT is a continuous, physically based, semi-distributed hydrological public domain model jointly developed by USDA Agricultural Research Service (USDA-ARS) and Texas AgriLife Research, part of Texas A&M University System. SWAT is a river basin-scale model to quantify impact of land management practices on water quantity, sediment and water quality in large complex watersheds with varying soils, land use and management conditions over a long period of time (Arnold, Srinivasan et al 1998; Bharati, Pant et al 2011; Neitsch, Arnold et al 2005). For this study, the Koshi basin is divided into 79 sub-basins and delineated with the basin outlet at Chatara-Kothu. Detailed description of the methodology as well as results from the water balance analysis of the whole Koshi basin is in preparation. Therefore, in this paper, only the results related to the downstream impacts of the MWSP will be discussed.

Simulation of Crop Water Requirement (CWR)

BUDGET (soil, water and salt balance) model was used to simulate net crop water requirement for agricultural command area of the Melamchi River. BUDGET is a field based model developed by faculty of applied bioscience and engineering, Katholieke Universiteit of Leuven, Belgium. BUDGET requires length and crop coefficient (K_c) for the four growth stages: initial, crop development, mid-season and late season stage (Shrestha, Geertset al 2010). Reference evapo-transpiration ($E T_o$), rainfall, crop parameters and soil type are essential parameters to evaluate net irrigation

requirement (NIR). In this study, 80% dependable rainfall ($R_m - 0.8429 \times S_D$) is taken to evaluate NIR, where R_m is mean rainfall and S_D is standard deviation. Likewise, ET_o is evaluated from climate data (temperature, wind speed, sunshine hour and vapor pressure) using New LocClim (local climate estimator) developed by FAO in 2005. Henceforth, comparison between gross irrigation requirement (GIR) and water available in the stream was done in different scenarios.

Downscaled climate data

In this study, MarkSim weather generator was used to downscale climate data from Global Circulation Model (GCM) (gismap.ciat.cgiar.org/MarkSimGCM/) (Jones, Thornton et al 2002). GCMs used to generate daily climate data are CNRM-CM3, CSIRO-Mk3.5, ECHam5, and MIROC3.2 and the projected data are average of these four GCMs. In addition, statistical downscaled daily climate data is also used in this study. Scenarios families of the Special Report on Emissions Scenarios (SRES), period of projection and climate variables considered in this study are presented in Table 1. Therefore, five projected scenarios in total (two from MarkSim and three from statistical) are considered to simulate future water availability. Future projected climate data from MarkSim downscaled techniques are A2 and B1; and from Statistical downscaled techniques are A1B, A2 and B1 of the SRES families. In the study, period of future simulation are 2030s (average from 2016 to 2045) and 2050s (average from 2036 to 2065), whereas period of base line (BL) is 2000s (from 1971 to 2000).

The Melamchi Water Supply Project (MWSP)

The downstream impact study is carried out for 11

	GCMs Downscaled	Statistical Downscaled
SRES families	BL, A2 and B1	BL, A1B, A2 and B1
Period of projection	2000s (1971-2000) for BL 2030s (2016-2045) for A2 and B1 2050s (2036-2065) for A2 and B1	(1971-2000) for BL (2001-2100) for A1B, A2 and B1
Climate variable	Rainfall, Temperature (Max and Min), Solar Radiation	Rainfall, Temperature (Max and Min), Solar Radiation, Relative Humidity and Wind Speed

Table 1. SRES Families and Projection Period of Downscaled Climate Data.

among 79 sub-basins of the Koshi basin. The sequential order of 15 sub-basins and sub-basin numbers are in Figure 2. The study river reach starts from sub-basin 35 and ends at sub-basin 79. The Indrawati, Sun Koshi, Rosi, Tama Koshi, Likhu, Dudh Koshi, Arun and Tamor Rivers flows into the main river reach (Figure 2). The location of water transfer in Stages I, II and III are at the outlet of sub-basins 24 in Melamchi, 25 in Yangri and 22 in Larke rivers respectively (Figure 2). In Stage-I, the calibrated model is re-run by setting planned monthly water transfer in sub-basin 24 by using the water use option in the SWAT model. The model is then re-run according to the monthly water transfer plan from sub-basins 25 and 22 respectively in Stages II and III.

Result and Discussion

Water availability in headwork of MWSP in current climate scenario

As explained above, the outlets of sub-basins number 24, 25 and 22 are the locations for MWSP's water transfer sites in Stages I, II and III respectively. The effective catchment areas of these three transfer stages are 148, 110 and 114 km² respectively. Figure 3 represents flow duration curves and monthly flow volume at the

three water transfer locations. The study result show that downstream flow availability at the driest month will be approximately more than 13% of the river flow of that month. The total available annual simulated water is 499 MCM, 443 MCM and 448 MCM respectively in Melamchi, Yangri and Larke river sub-basins (Table 2). The flow volume of 401 MCM, 348 MCM and 355 MCM occurred within five monsoonal months (June to October). Therefore, seasonal water flow varies significantly in the rivers and more than 80% of the total annual flow occurred within these monsoonal months. Hence in the study, June to October is considered as wet season and the other seven months are dry season.

Downstream impact on reaches of Koshi Basin in

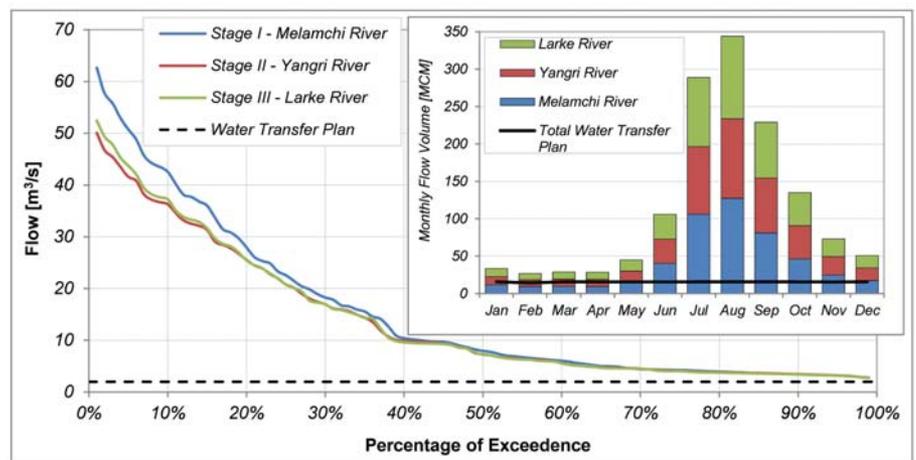


Figure 3. Flow Duration Curve and Monthly Flow Volumes Derived from Simulated Monthly Flows at all three stages of the MIWTP in Current Climate Scenario.

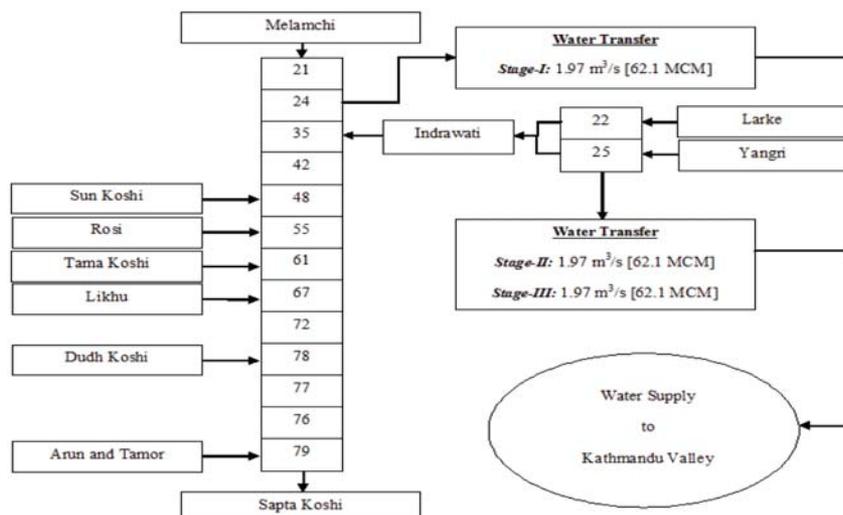


Figure 2. Melamchi Inter-basin Water Transfer Plan and Flow Network in the Koshi Basin (The numbers in the figure refer to sub-basin numbers, which can also be seen in Figure 1).

current climate scenario

The three rivers Melamchi, Yangri and Larke meet at sub-basin 35. Therefore, water transfer in all stages will influence sub-basin 35 as well as the downstream sub-basins. Figure 4 shows the comparison of annual and seasonal average water flow. Reduction in flows will occur in sub-basin 24 after Stage-I and subsequently it will occur in sub-basin 25 and 22 after Stages II and III. Once the MWSP becomes operational, the annual average discharges flowing into sub-basin 35 will reduce by 12%, 14% and 14% due to the water transfer plan of Stages I, II and III respectively (Figure 4). Likewise, in the Koshi basin outlet, at Chatara-Kothu, cumulative effects of all water transfer Stages (I, II and III) on

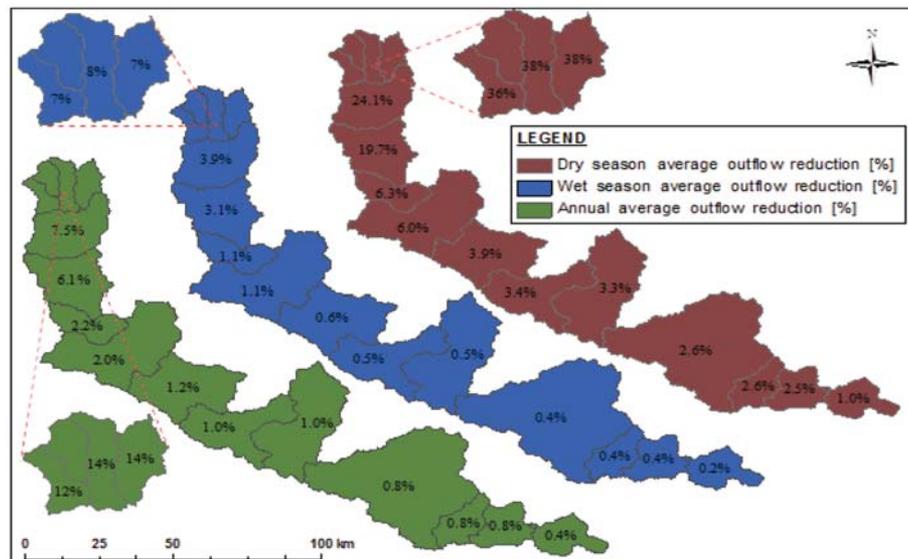


Figure 4. Percent Flow Reduction Due to MIWTP in Affected Sub-basins for Annual, Dry Season (Nov-May) and Wet Season (Jun-Oct).

annual average flow is 0.4%. Seasonal results show that in the Stage-I water transfer plan, average inflow reduction in sub-basin 35 in the dry and wet seasons are 36% and 7% respectively, whereas in Stage-II the inflow reduction are 38% for the dry season and 8% for the wet season. In Stage-III, flow reductions are 38% in the dry season and 7% in the wet season (Figure 4). Furthermore, in the Koshi basin outlet, at Chatara-Kothu, cumulative effects of all water transfer stages (I, II and III) on average flow reduction in the dry and wet seasons are 1.0% and 0.2% respectively.

Water availability in headwork of MWSP in future climate scenarios

The annual simulated flow under the current climate and the range of projected flows under climate change scenarios are presented in Table 2. The water availability ranges and means of projected flows as shown in Table 2 represent the results from five projected future climate scenarios (two from MarkSim and three from statistical downscaled data) for A2, B1 and A1B scenarios. Results show that on an average, flows in the rivers will decrease in the projection period of 2030s and 2050s when compared to the current flows.

	Current flow (MCM)	Range and Mean of projected flow (MCM)	
	(1976-2005)	2030s	2050s
Before MWSP:			
Melamchi river	499	312 - 347 (333)	316 - 359 (340)
Yangri river	443	306 - 336 (324)	306 - 340 (325)
Larke river	448	302 - 342 (323)	299 - 349 (322)
After MWSP:			
Melamchi river	437	250 - 285 (271)	254 - 297 (278)
Yangri river	381	244 - 274 (262)	244 - 278 (263)
Larke river	386	240 - 280 (261)	237 - 287 (260)

Table 2. Range of Change on Annual Water Availability in Future Climate Change Scenario.

Downstream impact on reaches of Koshi Basin in future climate scenarios

Figure 5 illustrates change in water availability in the sub-basins falling within the MWSP sub-basins under future climate change projections from 2030s and 2050s under SRES scenario A2 (downscaled using Marksim). Results of future projection in 2030s (Figure 5 (a)) show that annual flow in the Melamchi, Yangri and Larke rivers will change by +1%, +2% and +2% respectively than the current flows, whereas the wet season flow will change by -1%, 0% and +2% and dry season flow by +5%, +10% and +2% respectively. Similarly, in 2050s (Figure 5 (b)), the annual

flow in the Melamchi, Yangri and Larke rivers will change by +3%, +4% and +5% than the current flows, whereas the wet season flow will change by +2%, +2% and +6% and dry

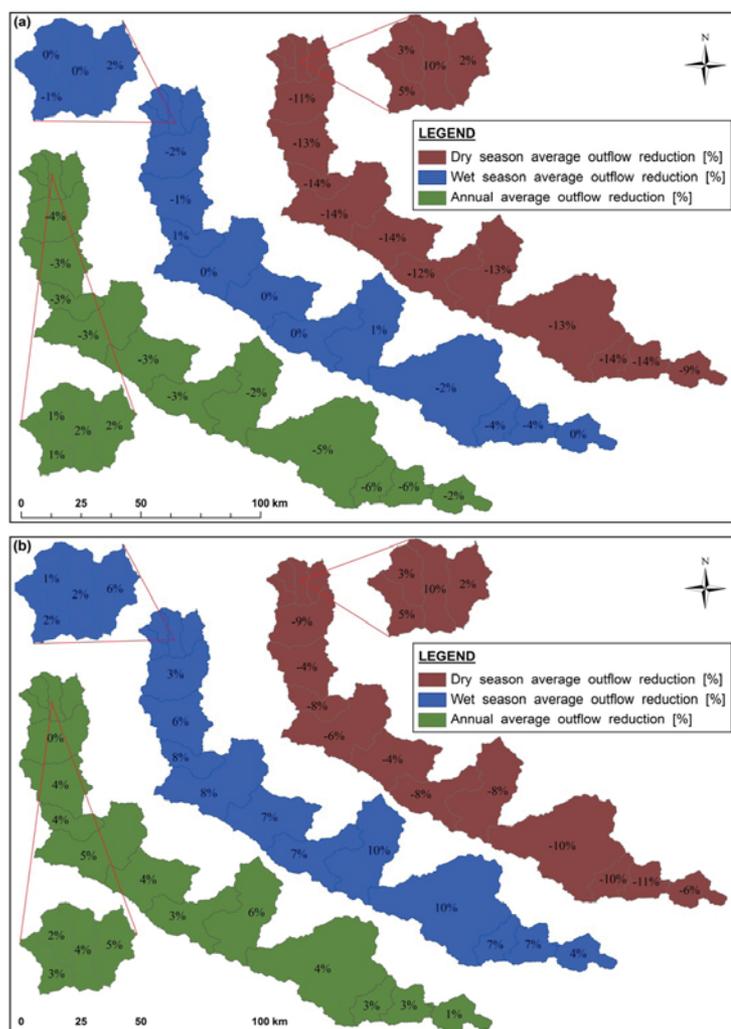


Figure 5. Percentage Change of Projected Flow in Affected Sub-basins for Annual, Dry Season (Nov-May) and Wet Season (Jun-Oct), (a) in 2030s and (b) in 2050s; under Climate Change Projection Scenario of Marksim-A2.

Crop type	Irrigated area (ha)	Cropping duration (day)	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
			1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Paddy	101	150																								
Wheat	74	135																								
Maize	289	125																								
Millet	188	105																								
Barley	4	120																								
Pulses	47	100																								
Oilseed	52	110																								
Potato	62	130																								
Vegetable	50	105																								

Crop type	Irrigated area (ha)	Cropping duration (day)	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
			1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Early paddy	161	90																								
Main paddy	289	105																								
Wheat	74	120																								
Maize	128	105																								
Vegetable	215	180																								

Table 3. Existing Cropping Pattern and Crop Calendar of the Melamchi River Command Area (top) and the Cropping Pattern Recommended by Department of Irrigation (DOI) (bottom) Scenario.

season flow by +5%, +10% and +2% respectively. Likewise, in the Koshi basin outlet, at Chatara-Kothu, annual outflow will change by -2% in 2030s and +1% in 2050s climate change projection. Similarly, wet season outflow from Koshi basin will change by -9% in 2030s and -6% in 2050s, whereas dry season outflow will reduce by 21% in 2030s and 19% in 2050s climate change projections.

Impact on agricultural command area of Melamchi River in current and future scenario

According to simulation results, MIWTP will not have considerable impact on the hydrology of downstream sub-basins except in immediate sub-basins 35 and 42 (Figure 4). After implementation of the project, dry season flows (Nov-May) will drop by 24.1% and 19.7% in sub-basins 35 and 42 respectively. Therefore, in this study only impact of Stage-I water transfer plan on the exiting irrigation system in Melamchi River basin is evaluated. At present, nearly 289 hectares (MWSDB 2008) of downstream agricultural lands are irrigating from Melamchi River.

The cropping pattern, area and calendar were used to evaluate crop water requirement in the agricultural command area of the Melamchi River (Table 3). The existing cropping pattern in the study area was identified through farmer discussions, statistical information on Nepalese Agriculture (2005). The recommend cropping patterns are from the Department of Irrigation for the Melamchi command area. The crop characteristics and crop duration are taken from Raes (2002) and McDonald (1990). For simulation, initial soil water content is considered to be 50% of Total Available Water (TAW), where TAW is difference between field capacity and wilting point.

Figure 6 illustrates simulated monthly Crop Water Requirement (CWR) for the existing cropping

pattern as well as the recommended cropping pattern scenarios. Figure 6 shows that irrigation is only required in the dry season. In the existing cropping pattern scenario, intensive irrigation is required in April (130 mm). In the recommended cropping pattern, irrigation is required in March (158 mm).

Results show that the water scarcity is only during the dry season. Figure 7 shows that water for irrigation is sufficient in driest month even after implementation of MWSP. Other water uses such as drinking water and operating water mills are not accounted in this study. These demands

do not have considerable impact on irrigation systems because spring sources (ground water) are used for drinking purposes and water used in mills is immediately returned to the river (MWSDB 2008). In addition, tributaries of Melamchi River are adding more water to the river before the confluence of Indrawati river (MWSDB 2008).

Figure 8 depicts comparative scenarios of gross irrigation requirement with 40% overall irrigation efficiency and change in Melamchi River command area. The plots are demand versus supply curves. Each plot represent water use in four scenarios; (i) existing cropping pattern before operation of MWSP, (ii) existing cropping pattern after operation of MWSP, (iii) recommended cropping pattern before operation of MWSP, and (iv) recommended cropping pattern after operation of MWSP. Under the recommended cropping pattern, results show that the present Melamchi River command area can be increased by 120% under current climate scenarios (Figure 8(a)), whereas the area can be increased by 40% in 2030s (Figure 8(b)) and by 97% in 2050s climate projection scenarios (Figure 8(c)).

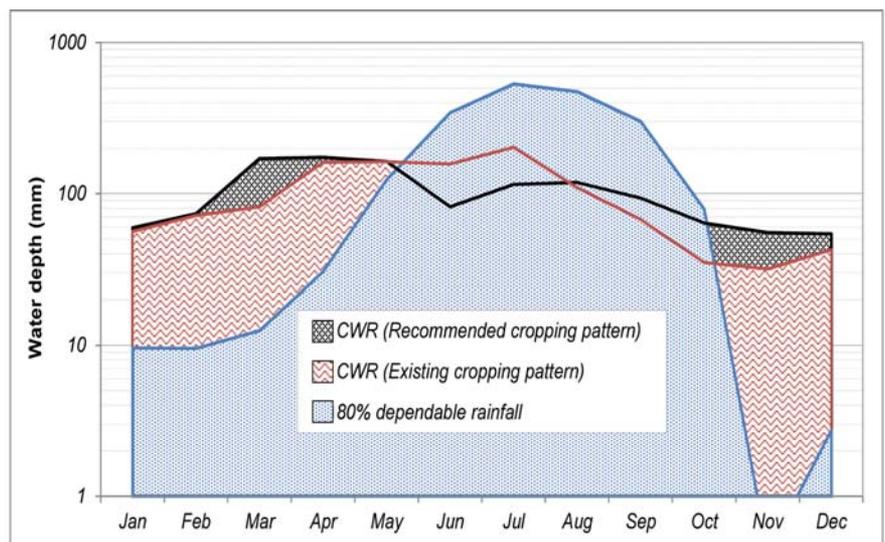


Figure 6. Comparison of 80% Dependable Rainfall and Monthly Crop Water Requirement for Crops in Melamchi River Command Area.

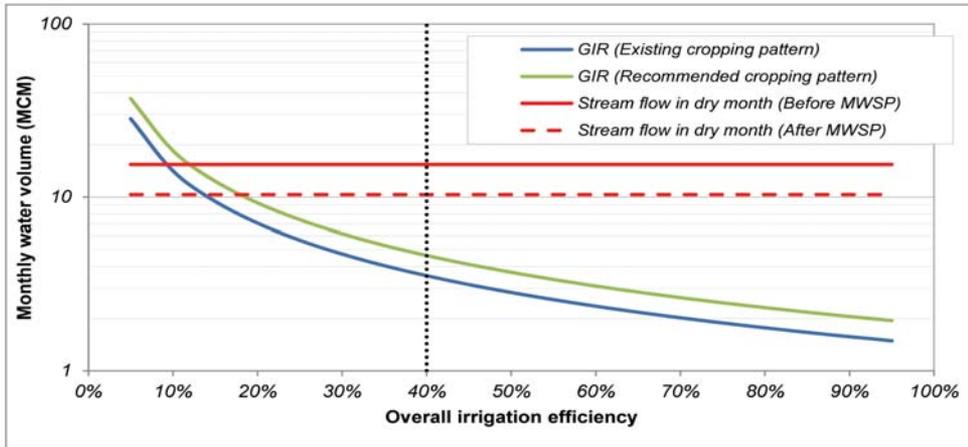


Figure 7. Comparison between Gross Irrigation Requirement and Stream Flow in April.

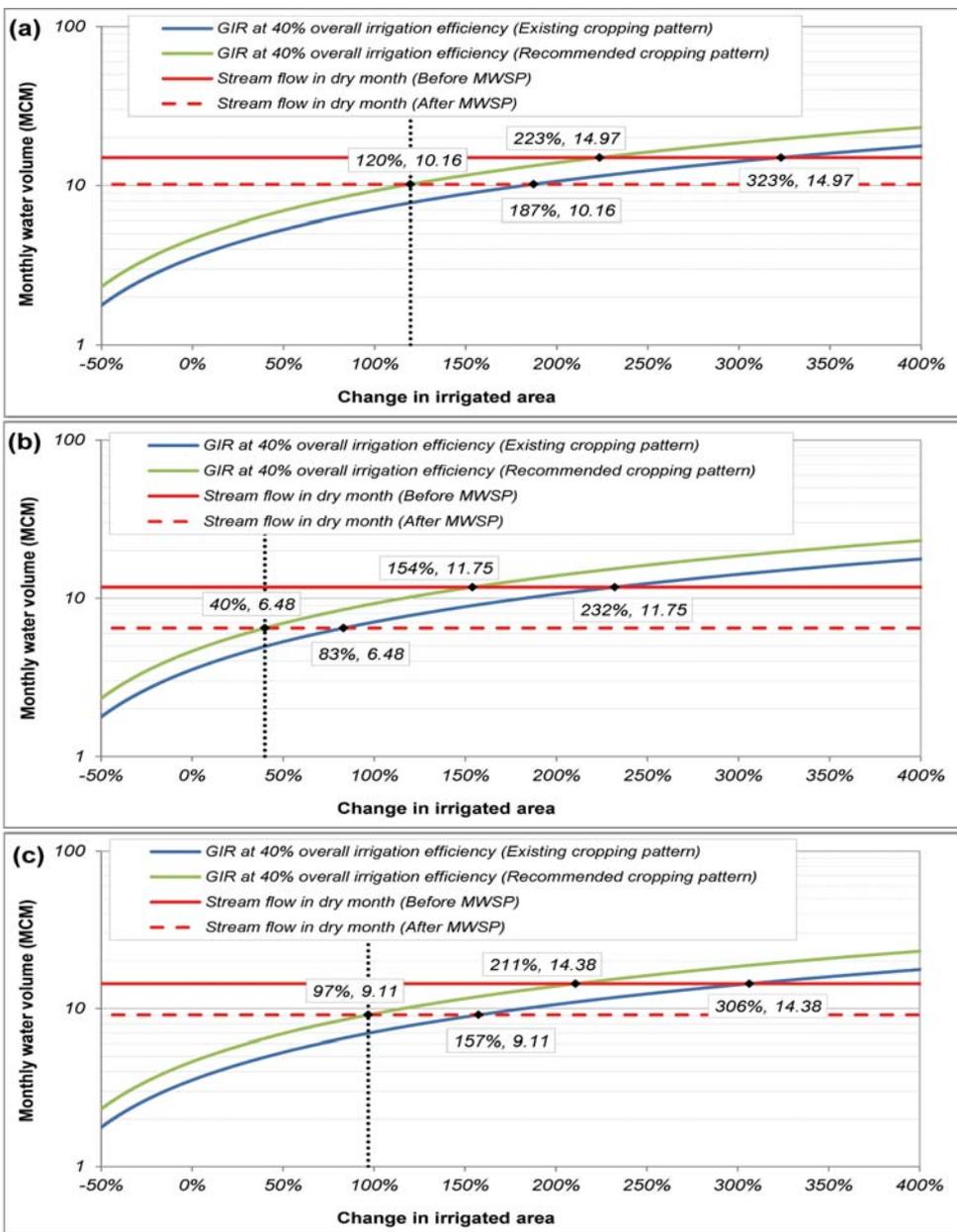


Figure 8. Comparison between Gross Irrigation Requirement and Stream Flow in the Driest Month (April) with Change in the Melamchi River Command Area under (a) Current Climate Scenario, (b) Future Climate Scenario in 2030s, and (c) Future Climate Scenario in 2050s.

Conclusion

Although the debate on downstream hydrological impacts of the MIWTP is affecting the progress of the project, detailed quantification of the impacts in downstream sub-basins have not been done. Therefore, this paper serves to fill this gap. The simulated results show that in the Stage-I water transfer plan, average inflow reduction in sub-basin 35 in the dry and wet seasons are 36% and 7% respectively, whereas in Stage-II the inflow reduction are 38% for the dry season and 8% for the wet season. In Stage-III, inflow reductions are 38% in the dry season and 7% in the wet season. Furthermore, in the Koshi basin outlet, at Chatara-Kothu, cumulative effects of all water transfer Stages (I, II and III) on average outflow reduction in the dry and wet seasons are 1.0% and 0.2% respectively. Therefore, MIWTP has considerable hydrological impacts on the sub-basin that is immediately downstream of the transfer points but not further downstream towards the basin outlet.

Simulation results of crop water requirements show that water stress problem will not occur in the Melamchi River command area under current and future climate scenarios, if the command area remains the same as present. Furthermore, by changing the cropping pattern to the recommended cropping pattern from DOI, present Melamchi River command area can be increased by 2.2 times under the current climate scenario, by 1.4 times under climate change projections from 2030s and by 2.0 times under climate change projections from 2050s. As water availability is only a constraint during

dry months, if in system water storage methods are introduced to reserve excess water of the wet season, the command area can be further increased. In this case, the available of cultivable land might be the constraining factor.

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