

# An Ecohydraulic Approach to the Modernization of Farmer Managed Irrigation Systems in Nepal

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## Glossary of local terms used in this paper

*kulo* canal  
*kula pani choudhari* The head of the farmers irrigation block

## **Abstract**

This paper focuses on the optimization and expansion of farmer managed irrigation systems (FMIS) in Nepal. The three systems under concern namely the Majhara *kulo*, the Budhan *kulo* and the Raj *kulo*, situated at the left bank of the Babai river were constructed in the 1940s by the local community, using their indigenous knowledge. Actually the 5400 hectares (ha) area covered by these FMISs forms the head reach of the Babai Irrigation Project (BIP) which is aimed at providing irrigation water to an additional 8100 ha area after the construction of a new headwork and a 28 km long main canal in 2000. The annual volume of water to be claimed as “priority right” of the FMIS area is 86 million m<sup>3</sup>, whereas the total available water volume is 682 million m<sup>3</sup>.

In this paper it is shown that by replacing the old, leaking diversion constructions by new diversion weirs and control gates, a much better water distribution can be achieved during the low flow periods, while in periods of flood the newly designed irrigation system is able to continue acting as a flood management and protection system.

It is demonstrated that the approach of the FMIS modernization, besides being technically viable, is user as well as environment friendly due to its capacity to preserve the existing water management tradition of the farmers while at the same time, offering the opportunity to substantially extend the total irrigated area.

## **1 Introduction**

Irrigation is vitally important in meeting the food and fibre needs for a rapidly expanding world population that reached six billion in 1999 and is expected to reach about 8.10 billion by 2030. The growing population will result in a considerable additional demand for food. Simultaneously, the water demand for the non agricultural sectors will keep growing in both developed and developing countries. To meet the food requirements of the growing population with growing water demand for the non agriculture sector there is a need to achieve a significant increase in water productivity. In the Nepal’s context this challenge is expressed in terms of increasing the year round water supply from 41% to 90% of the total irrigated area in the period between 2002 and 2027 by means of enhancing the water use efficiency, ground water utilization and making storage arrangements (Water Resource Strategy, 2002 & Irrigation Policy, 2003).

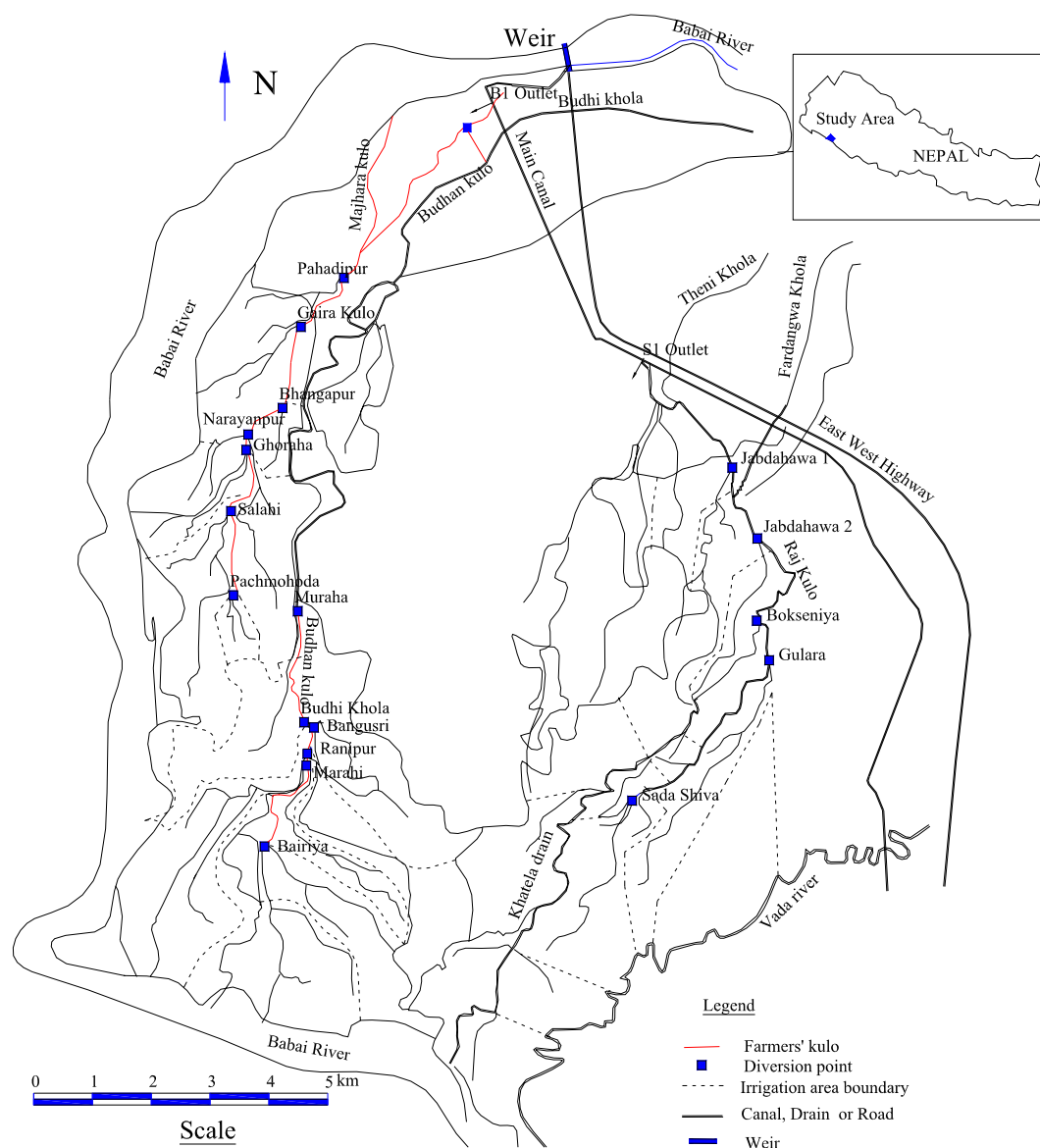
In Nepal thousands of farmer managed irrigation systems (FMIS) have been developed and exploited by the local community over the centuries. It is estimated that there are about 15000 FMIS in the hills and nearly

1700 FMIS in the Terai (southern plain) of Nepal. More than 40 percent of the country's present food production is delivered by the FMIS which serve almost 70 percent of the irrigated area. Various studies have shown that FMIS generally achieve a higher level of performance than the agency managed irrigation systems (AMIS) with regard to the physical condition of the system, the water delivery effectiveness and the agricultural productivity (Lam Y.F., 1996). The farmers do a much better job of governing and organizing their own systems than government officials do on their systems (Ostrom E., 2002). The FMIS are the symbols of democratic values in Nepal. The community owning the system manages the resources on their own. They evolve the rules and regulations on their own and implement them with consensus within the community (Pradhan P., 2000). The diversion and other structures in the FMIS made by the farmers using local materials are normally of a temporary or semi permanent type with significant leakage occurring through these structures. That is why the farmers in the FMIS are bound to run their canals with a much higher discharge than actually required for crop growth. The proper rehabilitation and modernization of the FMIS can be considered as one of the pertinent ways to increase the water productivity and subsequent expansion of the irrigated area.

The goals of the rehabilitation project, discussed in this paper are to extend existing 5400 ha irrigation area with an additional 8100 ha while preserving the "priority water right" of the farmers exploiting the 5400 ha area. This will be realised by limiting the irrigation discharges during the low flow periods, by solving the actual leakage problems. At the same time the damage to the ecosystem, caused by erosion will be resolved by lowering the bottom slopes of the actual main irrigation channels. The quantity of water claimed by the farmers of the FMIS area as their priority right is 86 million m<sup>3</sup>. In this paper we have carried out the analysis of a cascade arrangement of concrete weirs and the change in bed slope after the rehabilitation of the *kulos*. The US Army Corps of Engineers' river analysis system HEC-RAS has been used to simulate the performance of the *kulos* during high and low flow conditions before and after the rehabilitation of the system in order to determine an optimum user friendly structural arrangement of the permanent diversions.

## **2 The study area and unsolved problems**

The study area is the FMIS part of the Babai Irrigation Project (BIP) in the Bardiya district of Nepal, which is located between 81°17' and 81°27' E longitude and 28°17' and 28°25' N Latitude. The East West Highway running almost parallel to the eastern main canal forms the northern boundary and the Babai river forms the southern and the western boundaries of the study area. The Vada river is located at the eastern boarder of the study area. The Babai river is the source river having a catchment area of 3270 km<sup>2</sup> and a high flood discharge of 7500 cubic meter per second (m<sup>3</sup>/s). There are three FMIS in the study area, all located at the left bank of the Babai river namely the Majhara *kulo*, the Budhan *kulo* and the Raj *kulo*. Figure 1 shows the map of the study area with the headworks, the East West Highway, the main canal and the farmers' *kulos* with the names of the diversions.



**Figure 1: The map of the study area showing the headwork, the main canal, the FMIS *kulos* with diversions.**

In 1992 the government constructed a weir cum bridge across the Babai river and the first 5 km of the east main canal as shown in Figure 1. As the bridge on the weir is a part of a national highway, the location of the bridge forced the designers to construct 5 km of the main canal to supply the Raj *kulo* and the Budhan *kulo*. In the period between 1995 and 2000 the BIP extended the east main canal from 5 km to 28 km bringing 8100 ha of dry area under irrigation. The government intervention and subsequent expansion of the irrigation area raised several questions among the farmers of the FMIS regarding their priority water right and modality of rehabilitation of their *kulos*. These questions are vitally important and need to be properly addressed in order to enhance the irrigation efficiency and to achieve better water management in the FMIS area as well as to guarantee sufficient supply of water to the extension area.

The BIP had designed a new canal system in 1982 for the whole eastern area including the FMIS part. However, the farmers of the FMIS area rejected the construction of new canals through fields which were already irrigated from another canal network. The rehabilitation of the existing *kulos* basically by replacing temporary diversions through concrete weirs was the farmers' main demand. In the nearby Rajapur area, the largest FMIS in Nepal, the farmers had rejected the design of diversions making more use of semi permanent gabion structures (Howarth S.E. et. al, 2002.) and the engineers were bound to change the design from crated boulder to concrete diversions. The farmers of the FMIS area being aware of the history of the Rajapur area, found that only permanent diversions were the appropriate solution to their problems.

The main concern of the farmers of the FMIS was to establish the "priority water right" of the existing FMIS before making any water sharing arrangement with the extension area. However, due to the absence of agreement on the modality of irrigation development at the FMIS part the BIP intensified the construction of branch canals in the new area since 2002. Many branch and secondary canals at the new area were completed by 2006 resulting into an increased water demand. The demand for water of both areas needs to be resolved properly in order to avoid the possible water use conflicts between the FMIS and the extension parts.

### **3 Field study and data collection**

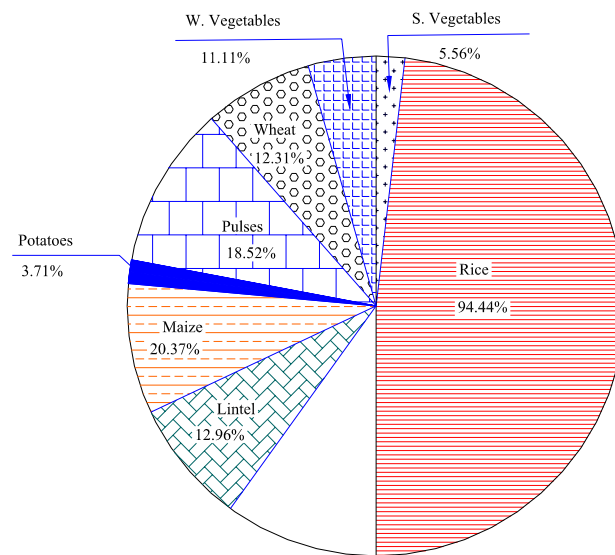
A field study was conducted by the first author in November, 2006. Participatory approaches were used to identify the irrigation related problems of the farmers, which included focus group discussions with the farmers of different *kulos*. Site visits accompanied by the head of the farmers' institution called *kula pani choudhari* were conducted along all three FMIS *kulos* during which the condition of existing temporary diversion structures, flood dispersion patterns and the existing leakages through the diversion structures were carefully observed. It was observed that the indigenous strategy of the local farmers in keeping completely open all the outlets to field channels during the rainy season is very effective in dispersing flood flows from the *kulos*. During the dry season the same *kulo* network is used for providing irrigation water to the fields. The farmers wanted to preserve their indigenous knowledge and the tradition of dual function of their *kulo* network.

The Environmental Impact Assessment study of the command area development works of the BIP conducted in 2004 had the requirement of presenting the project development plan to public hearing in order to get the farmers' consent on the plan. The cascade arrangement of permanent concrete diversions capable of preserving the flood dispersion tradition of the farmers and supplying water to the field channels effectively without leakage during low flows was accepted as a suitable solution to FMIS *kulo* rehabilitation by both the farmers and the BIP. The BIP provided the detailed longitudinal and cross section survey data of the Majhara *kulo*, the Budhan *kulo* and the Raj *kulo* and other designs and drawings prepared so far for this study. Several discussions were held with Water Users' Association WUA representatives and BIP officials regarding the FMIS rehabilitation and the increase of water use efficiency at the FMIS area. Previous study reports of the BIP and meteorological data were collected from the BIP, the Department of Irrigation and the Department of Hydrology and Meteorology.

## 4 Analyses and Results

### 4.1 Existing cropping pattern and its water requirement

The existing cropping pattern of the study area was determined in 2004 during the EIA study by means of questionnaire survey of 34 farmers from 4 villages representing the FMIS area. The cropping pattern was found to be 179% which is shown in Figure 2. The total cultivated area was 5400 hectare (ha), out of which 5100 ha was covered by rice and 300 ha by summer vegetables. In the winter lintel, wheat, pulses, winter vegetables and potatoes covered 700, 665, 1000, 600 and 200 ha respectively. Maize was the only crop cultivated in the spring season in 1100 ha of lands. The farmers of the FMIS area have been cultivating these crops since long ago with sole use of the east part's share of water from the Babai river and hence they claim the water needed to continue their present cropping pattern as their "priority right".

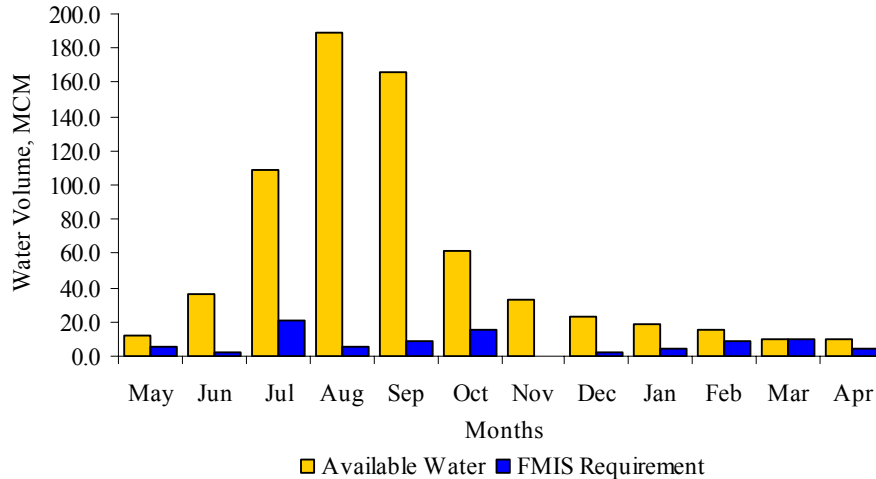


**Figure 2: Existing cropping pattern in the FMIS area based on survey in 2004.**

The crop water requirements (CWR) per hectare of different crops other than rice have been determined taking field application efficiency at 0.60. Due to the existence of a constant water pool in rice fields, the CWR calculation has been performed taking the deep percolation equal to 3 mm per day during the growth and 55 mm of water consumption during the two weeks needed in the preparation of the crop area. The combined main and branch canal efficiency has been taken at 50% in determining the intake water requirements. The CWR of each crop multiplied by the respective area gives the total water demand of particular crop and the sum of water demands for all crops resulting into the total water requirement. The monthly water requirement for the FMIS area and the available water in the main canal are presented in Table 1 and Figure 3. The total water requirement of the FMIS is 86.16 million m<sup>3</sup> (MCM) whereas the total available water for the eastern part is 683.2 MCM. Figure 3 indicates the plenty of surplus water from June to January. February and March are the most stressed months which is similar to the field situation.

**Table 1: Water availability and requirement of the FMIS area, MCM**

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Available	18.4	15.4	10.2	9.4	12.0	35.8	109.1	189.0	166.4	61.4	32.8	23.8	683.2
Required	5.11	9.84	10.41	2.64	3.63	1.27	21.15	5.29	9.33	15.09	0.16	2.24	86.16



**Figure 3: Monthly water supply and demand scenario at the FMIS area.**

#### 4.2 Arrangement of fixed constructions

The cascades of concrete weirs as a replacement of the temporary diversions in the FMIS *kulos* have been planned based on the longitudinal and cross section survey data of all *kulos* provided by the BIP. The cascade arrangement of diversions showing the name of each diversion, distance from the main canal in km, the drop height and the channel bed slope to be realized after the rehabilitation are presented in Figure 4. One of the important aspects to be considered is the change in bed slope before and after construction of the permanent diversions. In the Majhara *kulo* the steepest bed slope after the rehabilitation will be 0.00107 m/m (1:936) at the section between Bhangapur and Narayanpur, where the present average bed slope is 0.00236 m/m (1:423). In the Budhan *kulo* the future steepest bed slope will be 0.0012 m/m (1:833) in the sector between Padnaha and Ranipur instead of the present bed slope of 0.00175 m/m (1:570). Similarly in the Raj *kulo* the section between Bokseniya and Gulara will get a steepest slope of 0.00135 m/m (1:743) replacing the 0.00333 m/m (1:300) present situation. All these facts show that, after the rehabilitation, in addition to solving the leakage problems, the stability of the channel bed will also be enhanced, by this contributing to solving the erosion problem and to the overall ecological stability of the environment.

#### 4.3 Simulations using HEC-RAS

##### 4.3.1 Approaches and assumptions

The US Army Corps of Engineers' river analysis system HEC-RAS, a computer programme that allows performing one-dimensional steady and unsteady flow river hydraulic calculations, has been used for the steady flow simulations of all three FMIS *kulos*. The present and future water level characteristics of the *kulos* at different discharges have been studied through simulations of channels having leaky diversions at

present and leak proof concrete diversions in the future. The existing diversion structures are made from crated boulders or a brushwood-boulders combination showing a similar leakage behaviour. In HEC-RAS they have been modelled as multiple obstructions of 1.25 m wide solid blocks with a 0.25 m gap between them.

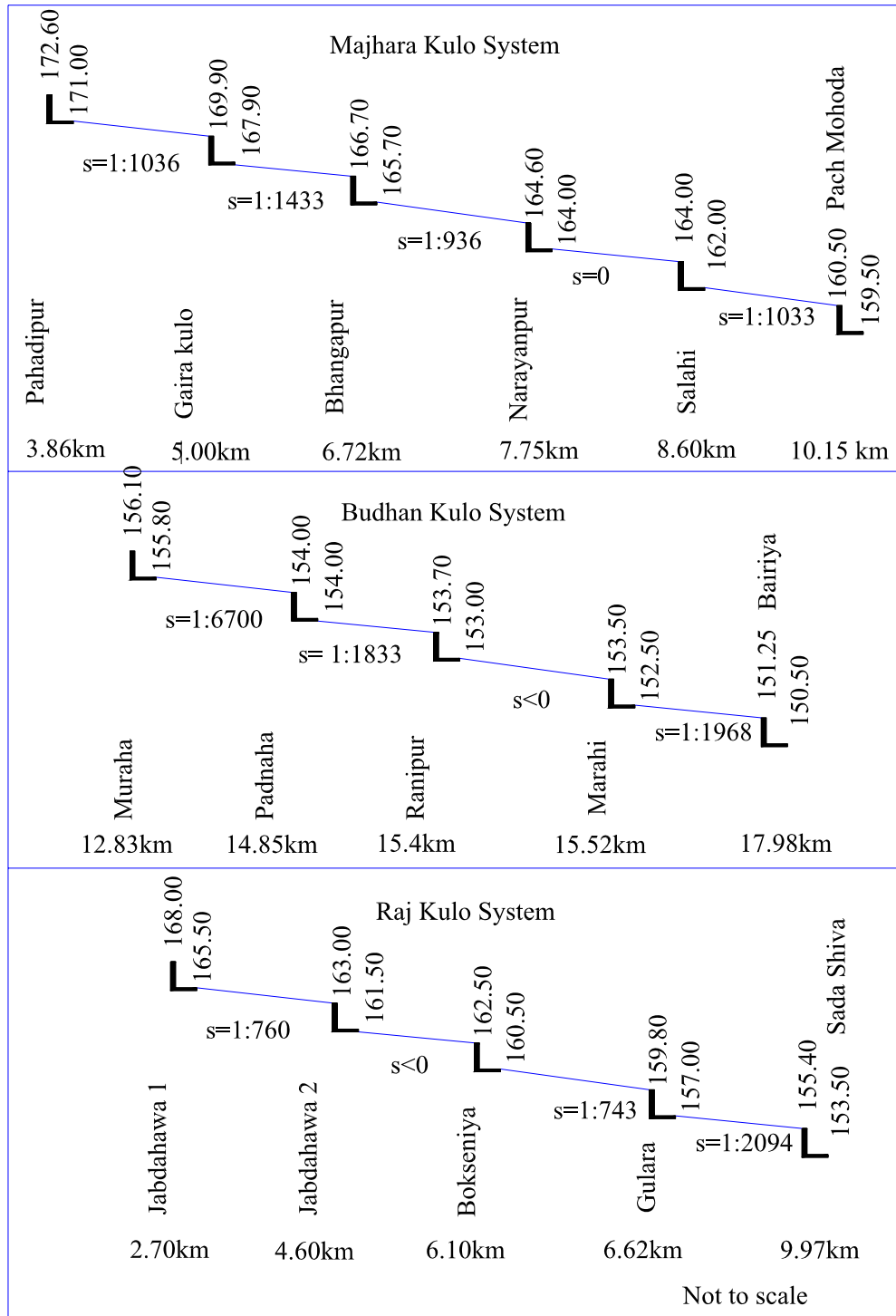


Figure 4: Schematic view of the proposed cascades of concrete weirs showing *kulo* system names, locations, levels and the bed slopes to be realized.

The top level of the obstruction has been set equal to that of the existing temporary diversion at each site as determined from the field survey. The lateral outlets have been modelled as free flow lateral weirs while the split flow optimization command of HEC-RAS has been used to assess the flow distribution between the lateral outlet and the *kulo*. The crest levels of weirs, scouring sluices and lateral outlets in the future situation have been worked out from the discussion with the farmers in order to fit the operation of the new structures to the farmers' demands. Based on these levels the design will be optimized using multi-criteria analysis. Figure 5 shows how the present situation and the future proposed situations of the diversion weirs have been simulated in HEC-RAS. The farmers will continue their tradition of high flow dispersion during the rainy season and providing the year round irrigation by their *kulo* network due to the long established social settings. Hence the main focus of the simulation is to find the structural arrangement giving similarity in flow dispersions at the present and future situations at all the diversion points, but while saving substantial amount of water in the dry season.

The peak discharges in the Budhan *kulo* and the Raj *kulo* are governed by the runoff from their catchments. The Majhara *kulo* is vulnerable to floods in the Babai river since it still draws water from its original intake at the Babai river, in addition to the regulated flow from the main canal. The Budhan *kulo* carries run off from the *Budhi* river and the Raj *kulo* carries the run off from the Theni and the Fradangwa rivers. The peak flows in these rivers have been estimated applying the in Nepal widely used Medium Irrigation Project (MIP) method (M3 Manual). The catchment areas of each river and the calculated peak discharges are presented in Table 2. The peak flows taken for the analysis at the Budhan and the Raj *kulos* are 25 and 85 m<sup>3</sup>/s. For the case of the Majhara *kulo* the peak flow of 25 m<sup>3</sup>/s is assessed based on the maximum carrying capacity of the upstream cross section. The peak and low discharges taken for the simulation are shown in Table 3.

#### 4.3.2 Simulation Results

The water surface profiles obtained from the HEC-RAS analysis during the peak and low flows of the Majhara *kulo* at the present and future situations are presented in Figure 6a. At present, the low flow profile is almost parallel to the bottom without forming any pool at the diversion sites indicating the leakage through the pores, whereas the low flow profile for the future situation shows a significant rise in water level near the diversion sites indicating the presence of leak proof structures. The low flow profile at present downstream of the Salahi diversion shifts from below to above the future situation profile indicating the significant

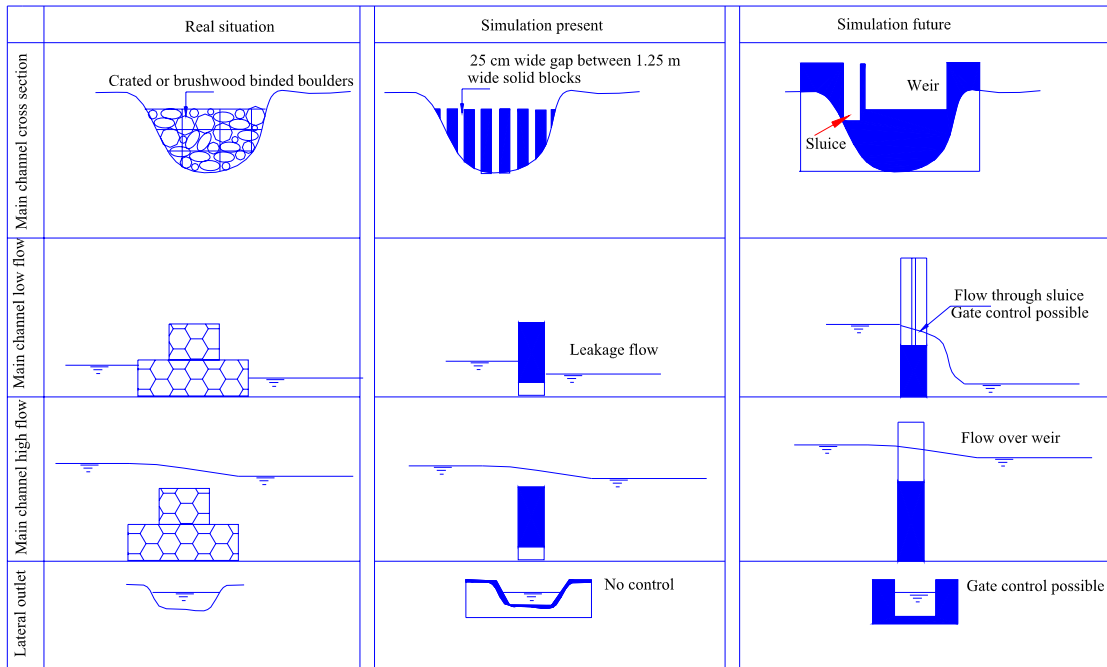
**Table 2: Estimated peak flows and catchment area of the natural drains**

River	Budi river	Theni river	Fardangwa river
Catchment Area, km <sup>2</sup>	6.5	5	16
Peak Discharge, m <sup>3</sup> /sec	25	25	60

**Table 3: Peak and low discharges used in the HEC-RAS analysis of different *kulos*, m<sup>3</sup>/sec**

Kulo	Peak Discharge, m <sup>3</sup> /s	Low Discharge, m <sup>3</sup> /s
Majhara	25.0	1.0
Budhan	25.0	2.0
Raj	85.0	1.5





**Figure 5: Real situation and HEC-RAS simulation of diversions and outlets at the present and future situations.**

Leakage flow in the present situation. In the upstream reaches of the *kulo* the channel widths are higher, resulting in higher leakage flows and by this causing much difficulty to the farmers in diverting water to the fields during low flows. On the other hand, the downstream reaches get leaked water even if it is not needed. The low flow profile at the future situation has been simulated assuming free flow without any gate control. Gate operation at the lateral outlets and sluices will make it possible to run the branch canals in their full capacity on rotational basis. The upper two profiles in Figure 6a are the water surface profiles of the peak flow in the present and future situations. Closeness of both the profiles along most of the *kulo* length demonstrates similarity in flow situations at present and in the future. The biggest differences appear at the diversions where leakage flow is replaced by flow over the structures. Figure 6b and 6c represent the water surface profiles of the Budhan *kulo* and the Raj *kulo* showing much similarity with the profiles of the Majhara *kulo*. In the Raj *kulo* the future peak flow profile downstream of the spillway passes slightly above the present one, indicating the reduction of channel discharge after the spillway. The similarity in dispersion pattern in present and future situations proves the appropriate sizing of the permanent diversion structures for keeping the existing canal systems intact and functionally consistent with the farmers' tradition of water management and flood protection.

Figure 7 shows the dispersion pattern of peak flows in present and future situations for all 3 systems. The upstream discharge of 85 m<sup>3</sup>/s at the Raj *kulo* is reduced to 20 and 21 m<sup>3</sup>/s respectively in diversion number 5. In the Budhan and the Majhara *kulos* the peak discharge of 25 m<sup>3</sup>/s is reduced to 6 m<sup>3</sup>/s at diversion no 5 in the present as well as in the future situation. The discharge ratios between the “future” and the “present” situations at the Raj *kulo* during an upstream peak flow of 85 m<sup>3</sup>/s are 0.72, 0.81, 0.79, 0.76 and 0.95 at the first to fifth diversions respectively. In the Budhan *kulo* during an upstream peak discharge of 25 m<sup>3</sup>/s, the

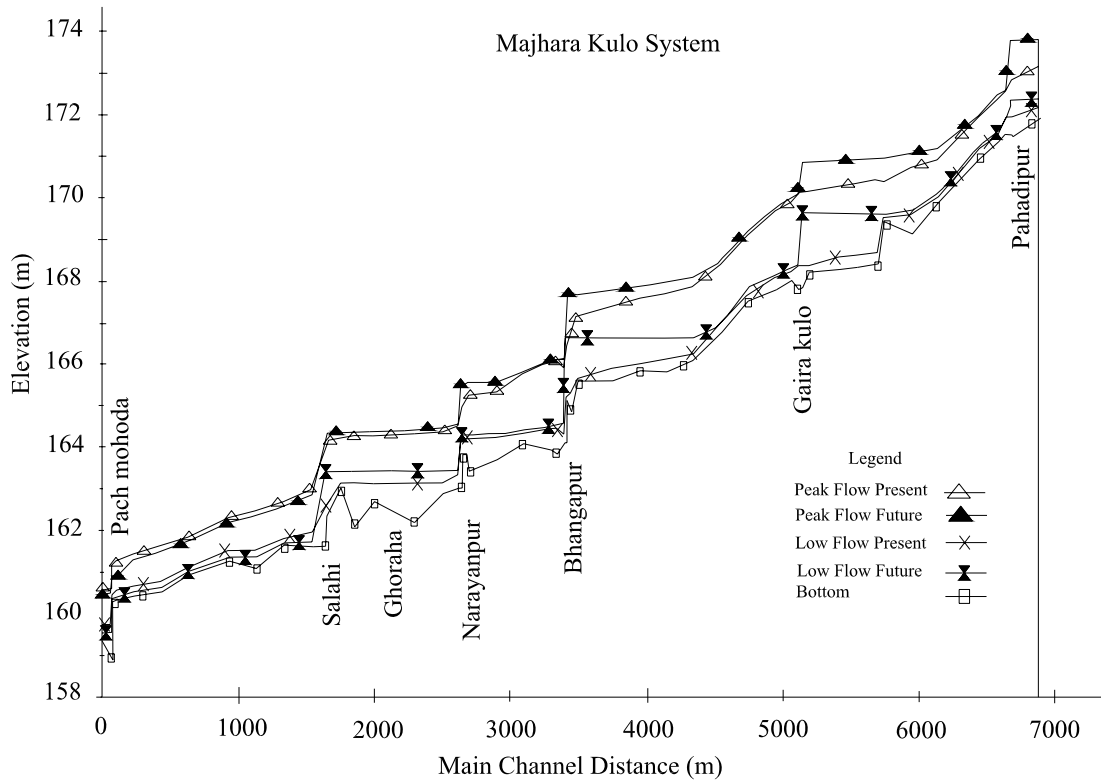


Figure 6a: Water surface profiles obtained from the HEC-RAS simulation of the Majhara *kulo* for present and future situations and for peak and low flow, respectively.

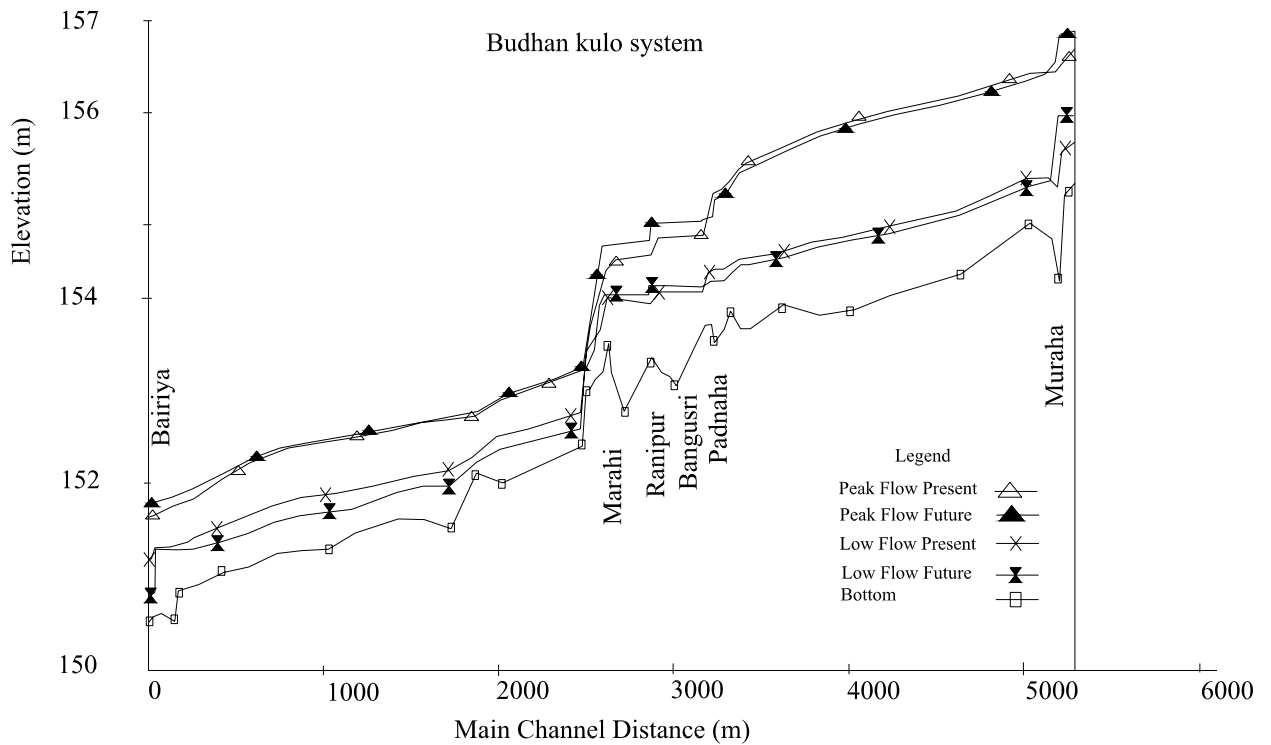


Figure 6b: Water surface profiles obtained from the HEC-RAS simulation of the Budhan *kulo* for present and future situations and for peak and low flow, respectively.

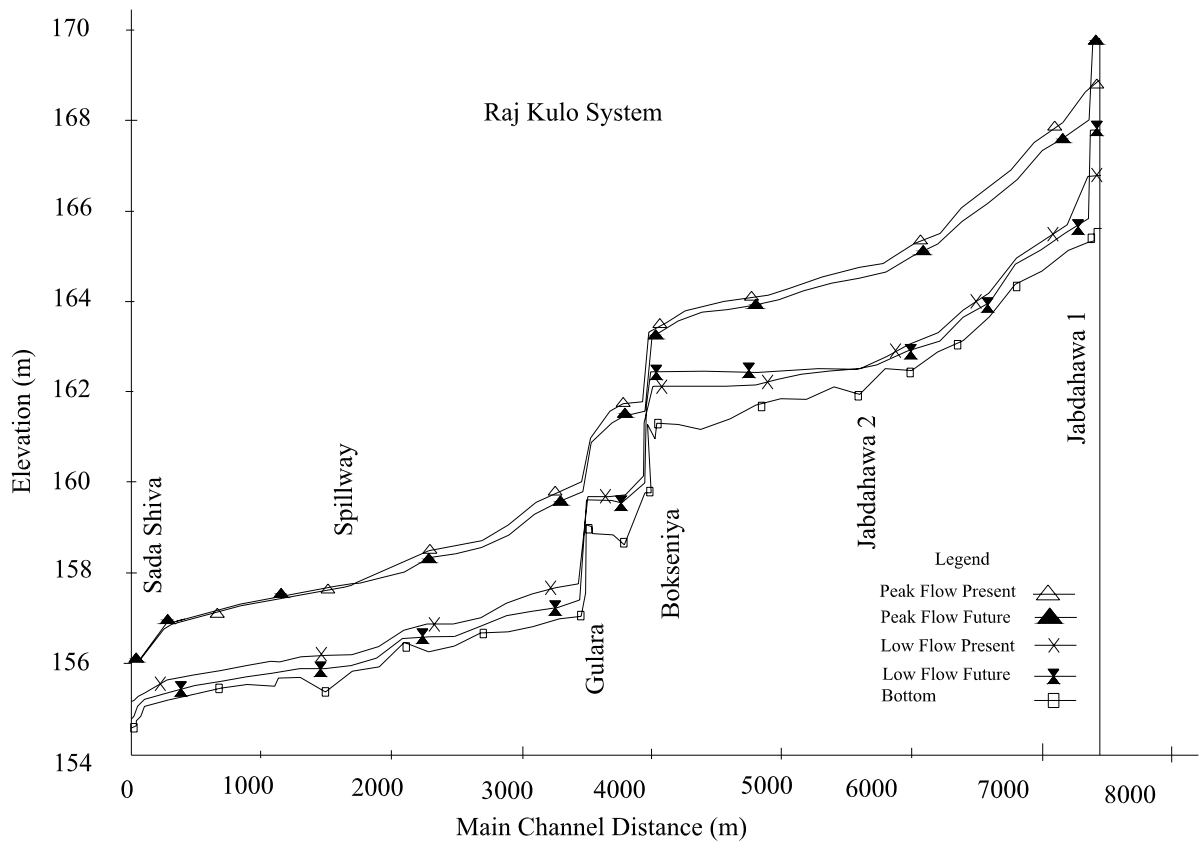


Figure 6c: Water surface profiles obtained from the HEC-RAS simulation of the Raj *kulo* for present and future situations and for peak and low flow, respectively.

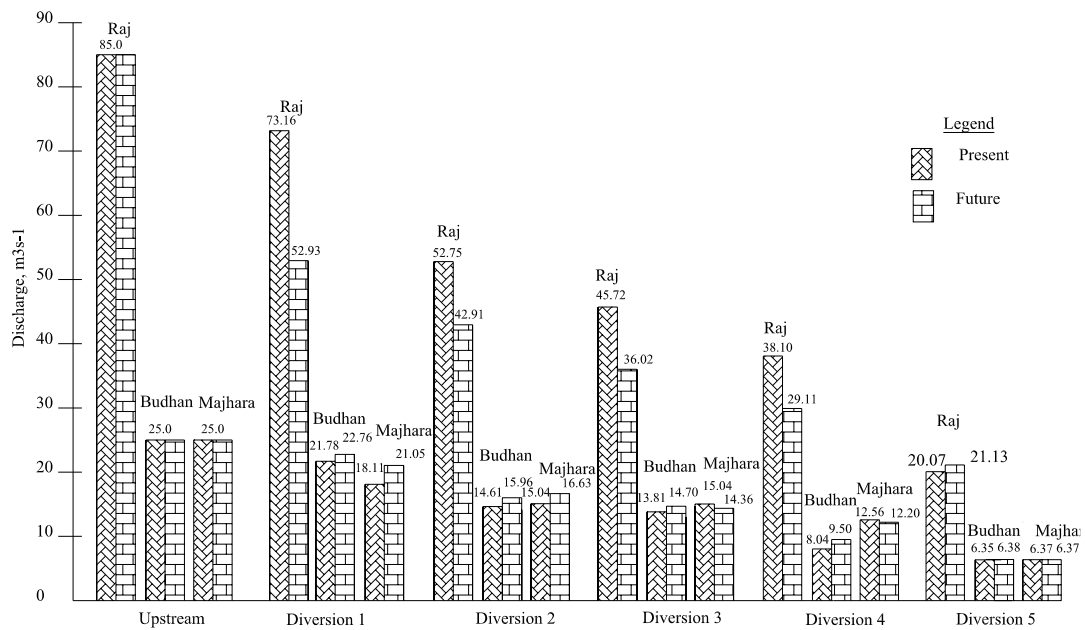


Figure 7: High flow dispersion patterns at present and future situations of the Majhara, Budhan and Raj *kulos*

respective ratios are 1.04, 1.09, 1.06, 1.18 and 1.00 whereas for the Majhara *kulo* with the same upstream discharge as the Budhan *kulo* the respective values are 1.16, 1.11, 0.95, 0.97, and 1.00.

## 5 Discussions and Conclusions

Our study has given an answer to the farmers' question of preserving their priority water right which is extremely important to determine the farming possibility at the new area using the remaining water. It has cleared ways for further water sharing arrangements between the FMIS and the new areas. There is a great possibility of saving water and increasing the production of winter and spring crops in the FMIS area even without additional abstraction of water controlling leakage and using efficient water management practices.

The HEC-RAS analysis of the present and future situations of all the three *kulos* has proved the appropriateness of the proposed arrangement of leak proof diversion structures while maintaining the farmers' tradition of flood dispersion practice. The solution of installing a cascade of diversion weirs similar to the existing diversion strategy was proven to be the most viable alternative from both social and technical considerations.

The similarity in dispersion pattern at the present and future situations proves the appropriate sizing of the permanent diversion structures which is important for keeping the existing canal systems intact and functional consistent with the farmers' tradition of water management and flood protection.

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