Design of Water Distribution System: Appropriateness of Structured System in Large Irrigation Projects in Nepal

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Abstract: Many large irrigation projects in Nepal operate under command area development works that emphasize on-farm water distribution and management. These projects have specific design characteristics that were planned to comply with available water resources, climatic conditions, soil type, and water distribution technology. The water distribution technologies differ based on the design needs of each individual project and the design preferences of various foreign consulting firms. This article focuses on the issues of planning and designing water distribution systems of large irrigation systems at the irrigation service delivery level. The layout planning of an irrigation system is an important aspect of design for water distribution, typically guided by hierarchical system. This article also highlights the existing canal hierarchy of these systems and their appropriateness for efficient water distribution. Furthermore, the appropriateness of the structured system is also examined in the Sunsari Morang Irrigation Project. The article concluded with some suggestions for planning and designing command area development works of forthcoming large irrigation projects such as the Sikta Irrigation Project, the Babai Irrigation Project, and the Mahakali Irrigation Project Stage-III.

Keywords: Irrigation, water distribution systems, Sunsari Morang Irrigation Project, Nepal

Introduction

Irrigation in Nepal has been practiced since time immemorial by farming communities. Historic evidence shows the existence of irrigation systems in Kathmandu Valley since the Lichchhabi Era. State-sponsored irrigation systems called Raj Kulos were also constructed during the Malla Era. Many Farmer Managed Irrigation Systems (FMIS) exist all over the country and constitute a significant share of irrigated agriculture. The government's involvement in the development of large scale irrigation systems started with the construction of the Chandra Nahar (Canal) in Saptari district in 1922-28 AD. Prior to the democratic regimes beginning in the 1950s, a few more irrigation systems were developed under the state sponsorship such as the Juddha Nahar in Sarlahi, the Jagadishpura Reservoir in Kapilvastu, and the Phewa Dam in Kaski. With the promulgation of democratic system in 1952 AD and the implementation of the first Five-Year Plan (1956-1961), new horizons had opened in irrigation development. Up to the 1970s many large irrigation systems1 were constructed focusing mainly on recently cleared forest and the cultivated lands of the terai and valleys. The implementation of these large irrigation systems expanded the supplementary irrigation coverage mainly for paddy cultivation. To enhance this foundation of irrigation to accommodate other crops and terrains, Nepal began employing the concept of Command Area Development (CAD) in the 1980s and modernized existing large irrigation systems under the guidance of the Department of Irrigation (DoI). In addition, newly constructed medium and large irrigation systems were also planned and designed with CAD principles. The CAD works had mainly focused on the construction of irrigation and drainage networks up to the farm fields with adequate water division structures and field channels to provide irrigation to 3-5 ha of farm blocks.

CAD works in large irrigation systems are being implemented under various programs and projects and while they offer many advantages, they also pose significant issues and challenges in irrigation performance and sustainable operation and maintenance. The main issues are related to the planning and design of water distribution structures and their appropriateness in the context of participatory irrigation management. This article tries to highlight the different types of water distribution structures that exist in these large irrigation systems and to analyze their appropriateness for system operation and maintenance.

Irrigation Development Practices

All the large irrigation systems constructed by the Government in Nepal exhibit three types of irrigation development practices based on intensity of irrigation required: Extensive Development (ED), Intensive Development (ID) and Command Area Development (CAD). The Extensive Development of irrigation (ED) aims to provide supplementary irrigation to paddy crops with limited irrigation networks. Most of the irrigation systems constructed in early 1960s and 1970s were based on this concept aiming to protect crops during long droughts. ED intends to provide irrigation water to as many farmers as possible with less irrigation duty. The canal system network of ED serves only up to 300-500 ha of command area. Some examples of ED are the Sunsari-Morang Irrigation Project (SMIP) stage-III remaining area in Morang district and the Kamala Irrigation System in Dhanusha and Siraha districts.

Intensive Development of irrigation (ID) aims to provide assured irrigation up to the farm field through the construction of tertiary canals within an irrigated area of 30 to 50 ha. However, ID lacks development of field channels and land management practices. The main objective of Command Area Development (CAD) is to improve rational utilization of irrigation water by optimizing agriculture production and productivity from irrigated areas through the integration of all aspects of irrigated agriculture. CAD works include the implementation of intensive irrigation networks with proper water division structures, field channels, and drainage facilities. It also comprises land leveling and land shaping, including agriculture extension activities. The characteristics of irrigation development practices are detailed in Table 1 below.

Irrigation Development	Service Area from Irrigation	Serving Canals
Extensive Development (ED)	300-500 ha	Primary and Secondary
Intensive Development (ID)	30-50 ha	Primary, Secondary and Tertiary
Command Area Development (CAD)	3-5 ha	Primary, Secondary, Tertiary and Quaternary Canals

Source: Agrawal, 2001

Table 1: Practices of Irrigation Intensity Development

Water Distribution System

Water distribution system is the conveyance and delivery of irrigation water to the farmer's field in the controlled way. The main objective of water distribution is to deliver the required amount of water to the right place at the right time to meet the crop requirements. All the large irrigation systems in Nepal are run-of-river systems which withdraw water directly from medium and large rivers. By virtue of Himalayan topography and monsoon hydrology, flow variations are significant in these rivers with adequate supply during monsoon and a shortage of water during winter and spring seasons. Hence, planning and design of water distribution should cope with large flow variations and fulfill the requirements of the end users.

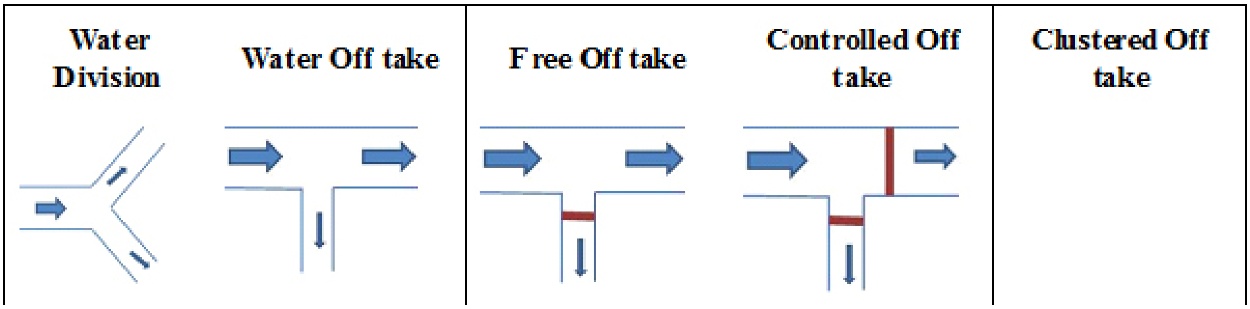
Water Division Structures

Water division structures divide and control the incoming flow of water into more than one system. These water division structures form the crucial component of an irrigation system. Their types and characteristics largely determine the operability and subsequent manageability of the system (Horst, 1998).Water division structures are broadly grouped into three types:

- Flow regulating structures such as cross regulators, head regulators and escapes;
- Flow division structures such as flow dividers, proportional dividers; and
- Off takes/outlets.

If a flow dividing structure divides more than 25 percent of the parent canal flow, it is referred to as division structure. If the structure divides flow less than 25 percent of the parent canal flow it is referred to as an off take or outlet structure. The flow regulating and flow division structures may be equipped with water control gates and flow measuring devices either upstream or downstream of the structure. Off take structures are also grouped into three based on the level of water control: free off take, controlled off take and clustered off take (Figure 1). The clustered off takes are economical and user-friendly in large irrigation systems. In SMIP, eight numbers of cross regulators regulate the water levels in 46 off taking canals (DFID, 2006).

Initially almost all Agency Managed Irrigation Systems (AMIS) in Nepal were designed as continuous supply with gated control structures up to the farm fields. All these gated structures were adjustable vertical lift gates with broad crested weirs. These



Source: Derived from Horst, 1998

Figure 1: Type of Water Divisions and off takes

Water distribution systems are comprised of two parts: conveyance and water division. The conveyance is comprised of canals and conveyance structures such as drops cross drainage structures, and escapes. The water division consists of the structures which divide, regulate and measure the flow and termed as water division structures.

systems are Mahakali-I, Banganga, West Gandak, Chitwan Lift, Bagmati, Koshi Pump, Chandra Nahar, and Kankai Irrigation Systems. Recognizing the low water use efficiency and operational problems in equitable water distribution, these gated systems have adopted rotational water supply in block basis. These gated systems are referred as unstructured systems. Some irrigation systems in the 1990s were designed on rotational water supply system with proportional division structures at the service area. These ungated systems are referred as structured systems. Sunsari Morang-II, Mahakali-II and Sunsari Morang-III are the examples of structured system. In addition, the World Bank assisted Mahakali stage-I and SMIP stage-I have shifted from gated to ungated water control systems just after few years of operation. Hence, there are both structured and unstructured irrigation systems operating in Nepal. To date, however, there is no design standard of CAD works in the Department of Irrigation (DoI) and different irrigation projects adopt their own design principles suggested by various consulting professionals. Oftentimes, these decisions are not made appropriately.

Water Distribution Methods

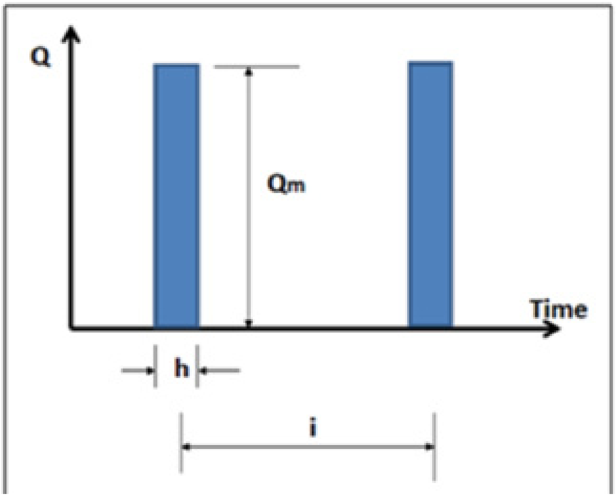
The actual distribution of water has different characteristics depending on the water distribution method to be adopted. The main water distribution methods are:

- Continuous water delivery;
- Rotational water delivery; and
- Delivery on demand.

In continuous water delivery, each canal receives its fixed share of water as an uninterrupted flow. The share of water is based on the area of each canal unit. In rotational water delivery, water is moved from one field canal or group of canals to the next canal or group. Each farmer receives a fixed amount of water over a predetermined interval of time. In demand based delivery, water is delivered as per the request of the farmer. Water is available to the farmer at any time that the intake is opened. Therefore the amounts to be used are not limited.

The choice of water distribution method is based on the type of irrigation system, availability of water, type of water distribution structure, and the organization to operate and manage the system. During the planning and design stage, the water distribution method shall be determined for the particular irrigation system. In most Nepali irrigation systems, the rotational water distribution method has been adopted. However, during the monsoon period when water is abundant, continuous water delivery method is also used in some systems. Rotational water distribution is a highly efficient system from the operational point of view and socially equitable since it gives an equal share to each farmer. In rotational systems, options are flexible in terms of flow rate, irrigation interval and delivery times (Figure 2). The Quantitative analysis of Rotational water Distribution system has been explained as follows:

Qm = unit flow (l/s),
h= farm delivery time (hours),
i= irrigation interval (days)



Source: Derived from Horst, 1998

Figure 2: Definition Sketch of Rotational Water Distribution

The changing irrigation requirements during the crop growing season can be met by changing one or more of the above three variables: Qm, h or i. However, from a practical operational point of view, it is advised to change only one variable to meet changing irrigation requirements.

Layout Plan for Water Distribution Networks

The layout plan in an irrigation system is the arrangement of canals, drains and structures required to achieve water conveyance and distribution, including removal of excess water from irrigation fields. The layout planning establishes the optimal arrangements, positions, levels of canals, and structures. It also considers physical, technical, and social constraints of the specific site. Generally two types of canal layouts exist: bifurcating layout and hierarchical layout: In a bifurcating system, water is divided among two or three large group of canals, subdivided into two or three small group of canals and so on. This type of layout system exists in community managed systems in valleys and plains. In hierarchical layout system water is divided into large blocks and subsequently sub-divided into smaller units. This type of layout is planned and designed in large irrigation systems. Most large irrigation systems in Nepal follow the hierarchical layout with varying levels of hierarchy. The number of hierarchy levels depends upon the size and complexity of the scheme (DoI, 1990) and in most cases they vary from three to six hierarchies. Smaller the hierarchy, simpler and efficient is the operation and management. The existing hierarchy of some large irrigation systems is presented in Table 2 below:

Design of Structured System

The structured system in an irrigation project is the management of water distribution with regulated flow at the upper canal networks and a proportional division of water at the lower level canals based on a systematic operational plan. According to this principle, upper level canals would run with continuous flow while lower level canals would run with intermittent supply. The irrigation water flow in lower level canals is maintained either at full supply level or at no flow condition for fixed days on a rotating interval. The system is equipped with water control gates at the upper canal networks up to the service area (Albinson and Perry, 2002). The best example of a structured system in Nepal is the Sunsari Morang Irrigation Project (SMIP) stage-II and stage-III. In SMIP, the main and secondary canals constitute the upper canal network, while the sub-secondary and or tertiary canals down to the watercourse form the service area of the structured irrigation system (Figure 3). The interfaces between the upper and lower sections are equipped with adjustable gated structures. The underlying assumption of structured irrigation system is to distribute water equitably according to the command areas. One of the advantages of a structured system is its transparency and simplicity in water entitlement (Albinson and Perry, 2002). Moreover, a structured system assures reliability of water supply and easier management through ungated regulating structures. It is equally important to understand the hydraulic characteristics of water division structures by all the concerned stakeholders and to craft faithful rules and regulations for maintaining equity (Shanan, 1986).

Irrigation System	Kankai (7,000 ha)	SMIP-II (9,700 ha)	Narayani (28,700 ha)	Banganga (6,200 ha)
Hierarchy of canals	Main canal Secondary canals (17) Tertiary canals Field channels	Main canal (CMC[2]) Secondary canal (SC) Sub-secondary canal (SSC) Tertiary canal (TC) Watercourses Field channels	Main canal (NEC[3]) Main secondary canal (MSC) Branch secondary canal (BSC) Sub-secondary canal (SSC) Tertiary canal (TC) Field channels	Main canal Branch canal/ Distributary canal[4] Tertiary canal Field channels

Table 2: Canal Hierarchy of Large Irrigation Systems

The key parameters in designing the structured system are the system water requirement per unit area (l/s/ha), the structured level or interface below which the system is unregulated (ungated), the size of the service area within which farmers share the water proportionately according to their land holdings, and the size and capacity of the tertiary canal (modular discharge).

Unit Water Requirement

The water requirement for the system is already calculated during the project planning and design stage based on the total water availability at the source, agro-climatic parameters, and average and maximum crop water requirements.

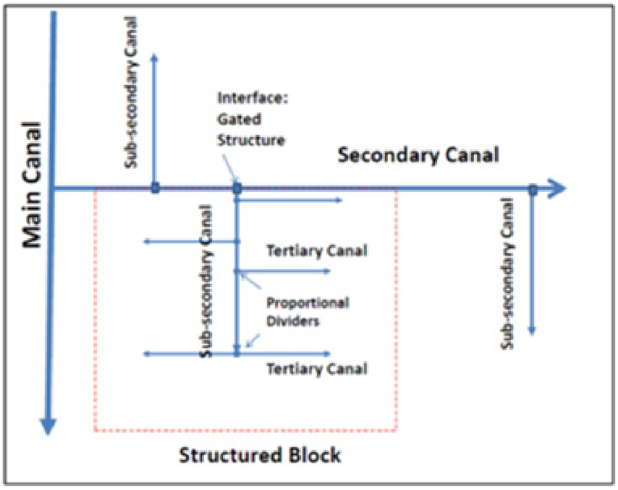


Figure 3: Definition Sketch of Structured Block at SMIP

Service Area and Structured Level

Determination of the service area and structured level are related to each other. The structural level is the point downstream at which the canal system is ungated (Plusquellec, 2002) and above which the canals are regulated with gates. Below the structured system, canal is unregulated and water distribution is proportional. In principle the size of service area and the structured level are determined based on the type of soils, response to rainfall, established water rights, time to fill and empty rotational units, the capacity of WUA to operate the system and socio-political environment. During the feasibility design of the command area works, the service area and structured level need to be determined in the layout plan of the irrigation system. The basic concept of a structured system is that it is easier to operate in rotational basis to meet the limited water availability and variation in water demands. The lower the structural level, the more gates need to regulate water while higher structural levels dictate easier management of gates. In addition, the larger size of structured area will have longer response time, the time taken to start irrigation on the farthest portion of the block. The response time must not be longer than 15 percent of the irrigation cycle (Shanan, 1986) of the whole irrigation system. In Nepal, there is no standard of service area and proper structured system. The operational characteristics of SMIP along with the size of the service area are presented in Table 3 which shows the varying service area of SMIP from 200 ha to 1500 ha.

Capacity of Tertiary Canal (Modular Discharge)

The capacity of the tertiary canal is one of the most significant parameters in command area development works. Typically, a farm stream of 30 l/s is manageable with a range from 20 to 100 l/s depending on soil characteristics, slopes, and other factors such as labor availability (Albinson, 2002). In addition, tertiary

Location	Hydraulics	Command Area (ha)	Operational Responsibility	Water Distribution
Main Canal (CMC)	Regulated	64,000 ha	Project Office	Continuous flow
Secondary canals	Regulated	5000-8000 ha	Project Office	Continuous flow
Interface (sub-secondary canal)	Regulated	200-1500 ha	Project Office	Rotation
Tertiary canal	Proportionate Distribution	140-150 ha	Farmers	Rotation
Watercourse[5]	APM	28 ha	Farmers	Rotation
Field Channels	Open cut	4 ha	Farmers	Rotation

Source: Field Survey, 2004

Table 3: Operational Characteristics of Structured System in SMIP

discharge ranges from 20 to 40 l/s which are considered a reasonable flow for individual farmers to handle (DoI, 1990). Tertiary units are sized to fulfill crop water requirements by tertiary discharge, taking into account the socio-cultural environment. Initially tertiary units were grouped based on topography and administrative boundaries of the locality. With the promulgation of Irrigation Policy 1992, tertiary groupings have started to include farm boundaries and these procedures have been successfully implemented at Mahakali-II (Adhikari et. al., 1998).

Selection of Outlets

The structure through which water is released from the distributing canal to the tertiary canal or watercourse is termed as outlet structure. According to IS Code of Practice[6] of India, the discharge of an outlet should be less than 85 l/s. The outlet should be designed soundly to work efficiently with varying heads in the parent canals. It should also be economical and farmer friendly in operation. There are three types of outlets being used in developing countries including Nepal: non-modular, semi-modular and modular outlets. The non-modular outlets are piped outlets whose discharge varies with the change in either water levels of distributing canals or in tertiary canals or watercourses. The discharge of the semi-modular outlets is independent of water level in the tertiary canal or watercourse up to minimum working head and depends only on the water levels in the distributing canal. Pipe outlets, venture flumes, Adjustable Proportional Module (APM) and orifice semi modules are the examples of semi-module outlets. The discharge of modular outlets is independent of the water levels of either in the distributing canal or in the tertiary canal or water courses. Modular outlets do not exist in the irrigation systems of Nepal. The types of outlets that exist in large irrigation systems of Nepal are presented in Table 4 below:

Based on the structured system principle, the upper level canals such as main and secondary canals run with continuous flow while lower level canals-sub-secondary and tertiary-would run with intermittent supply. The irrigation water flow in sub-secondary and tertiary canals is maintained either at full supply level or no flow condition for fixed days of rotation interval. The size of sub-secondary canals may vary from 90 ha to 150 ha having 3 to 5 numbers of tertiary canals irrigating about 25 to 30 ha of land. Each tertiary canal shall have 7 numbers of field outlets each serving 4 ha field chak[7] through field channels constructed by the farmers. All sub-secondary canals shall be equipped with Proportional Dividing structures (PD) at their head while tertiary canals shall have semi-modular outlet structures.

Irrigation system	SMIP-II	Chandra Nahar	Bagmati	Narayani	Marchawar Lift	Mahalai-II
Type of outlet	Piped APM (Semi-modular)	Orifice semi modular	Adjustable open gated (Non-modular)	Gated piped outlet (Semi-modular)	On/off shutter gate (Non-modular)	Precast block with piped outlet (Semi-modular)

Table 4: Types of Irrigation Outlets in Large Irrigation Systems

Discussion

From operational point of view unstructured systems (gated) are flexible to respond variety of water demands related to their crops. However, gated systems are not operated as designed and equity in water distribution is seldom maintained. All the FMIS in Nepal demonstrate better water distribution performance with proportional water divisions and ungated control systems (structured system). These proportional divisions are simple in technology, transparent in water distribution and equity in management. Among large irrigation systems Kankai, Bagmati, West Gandak, Marchawar, and Banganga have gated water distribution systems while ungated systems are operational in SMIP, Chandra Canal and Mahakali-II. Mahakali-I has both gated and ungated systems (block-1 and block-2 have gated outlets while block-3 and block-4 has ungated outlets). In most of the systems the capacity of tertiary canals lies between 30 l/s to 40 l/s with an idle size of command area of 25 ha to 40 ha. The size of service area managing by WUA in all large irrigation systems varies from 600 ha to 1500 ha.

Most of the large irrigation systems have been designed by foreign consultants in various time periods and hence their design standards do not match each other. In Narayani Lift System duckbill weirs exist while in Babai irrigation crump weirs exist for cross regulators. In addition, Babai irrigation has undershot gated piped regulators with and without water measuring devices while in SMIP-III open overshot head regulators exist with downstream water measuring devices. The command area development works designed by DoI engineers and implemented under National Contractors also possesses several dissimilarities due to frequent transfer of experienced engineers.

Sikta Irrigation Project (SIP) is one of the largest irrigation projects of Nepal which is being implemented under national Pride Projects of the Government. The main objective of the project is to provide assured irrigation facilities to about 43,000 ha of cultivated lands and increase rural incomes with the help of increased agricultural production. The project has completed its barrage at Agaiya and the construction of 35 km long main canal is at the final stage. The detailed planning, engineering design of branch canals and command area development works are just initiated and it is high time to adopt structured system for sustainable water distribution.

Conclusions

Despite the issues and concerns of operation and management of large irrigation systems, there are no studies on appropriateness of irrigation system layout and design in Nepal. The planning and design of on-going large irrigation projects are being implemented without in-depth study and research. The Department of Irrigation has no design standard on water distribution design and practice for large scale irrigation nor does it has code of practice for system operation and maintenance. In this context, structured system of water distribution is more appropriate which has demonstrated significant positive results in SMIP-II, SMIP-III and Mahakali-II. Sikta Irrigation Project, Babai Irrigation Project and Mahakali Irrigation Project stage-III are at the stages of planning and design of CAD works and it is high time to prepare standard design principles for CAD works of these large irrigation systems based on structured principles. The main benefits of structured system are equity in water distribution, transparent water division, farmer-friendly design, less efforts in canal operation, less possibility of vandalism, reliability of water at the tail end and high efficiency of water use.

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Footnotes

1. Irrigation Policy 2070 classifies large irrigation system with command area of more than 2,000 ha in Terai and more than 500 ha in the hills
2. CMC refers to Chatra Main Canal
3. NEC refers to Nepal Eastern Canal
4. Both branch and distributary canals take off from main canal. In addition tertiary canals also take off directly from the main canal (Pradhan, 1996).
5. In SMIP tertiary canals are named as watercourses and tertiary canals are higher level canals
6. IS Code of Practice 7986-1976
7. Chak is the area of a field outlet

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