

Framework for Effectiveness and Resilience of Small and Medium Irrigation in Nepal

RSAS 0017 Final Report

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Executive summary

Rationale

Agriculture is a mainstay of the economy of Nepal, providing about 30% of the GDP and supporting livelihoods for most of the population. It is very vulnerable due to the monsoon climate as well as to topography. Population growth and land fragmentation has made individual holdings so small that they are insufficient even for subsistence needs for most people. Off-farm employment and rural-urban migration are increasingly important, but agriculture remains a key part of livelihoods. There is a need both to improve agriculture and to make it more resilient to climate uncertainty and to change in general.

Three-quarters of agricultural land benefits from some form of irrigation. This is mostly long-established and is essential for ensuring a good crop. However, despite a long history of irrigation in the country, it is widely recognised that the sector is still not performing as well as it could and that climate change will only make the situation worse. Recent floods (such as in the Babai river in 2014) and droughts have raised concerns that climate is changing rapidly and that existing arrangements for irrigation design and management may no longer be appropriate.

Irrigation is a high priority and it is critical that investments are made wisely, taking appropriate account of climate change and other developments. However, existing policies and procedures for irrigation do not fully consider climate change. Climate change may also opportunity for facilitating transformational change to a more equitable and productive rural economy.

This study aims to help understand the impacts of climate change and to develop a framework for improving the resilience and effectiveness of small and medium scale irrigation systems – both existing and potential. It focuses on small and medium irrigation as this accounts for about 75% of the total irrigated area, and directly benefits about 40% of the total arable land area. Whilst the small number of about 20 large and major systems can be studied and planned individually, this is not possible for the vast number of medium and small schemes (probably more than 15,000, averaging less than 100 ha in size). There needs to be a good understanding and consistent approach across the sector, both for management of systems already in operation and those in the pipeline.

The objectives of the study are to improve the approach and methodology for planning, delivery, and management of efficient, effective, equitable and climate-resilient irrigation; to assess



processes, institutions and policy; and to prepare a framework to increase the climate resilience and effectiveness of small and medium scale irrigation systems, and to ensure that it is understood by relevant stakeholders.

Methodology

The study has been conducted in close coordination with the Department of Irrigation, with participation by other relevant stakeholders at national and sub-national levels. It began with a review of existing policies, strategies, policies programmes and studies. This formed a basis for a national overview of the irrigation sector in Nepal, covering infrastructure type, agriculture, socio-economy, governance and management arrangements.

The impact of climate change was assessed through analysis of existing climate data and literature, and projections of climate change for alternative emission scenarios and timescales from the Intergovernmental Panel on Climate Change (IPCC) and the Coupled Model Inter-comparison Project (CMIP5).

The study included a reconnaissance of 17 systems in various geographical and agro-ecological zones in 2015, and more detailed studies in two river basins in 2016. These studies included:

- Climate data collection and analysis (temperature and rainfall, including frequency and intensity of rainfall events)
- Observations and consultations on irrigation infrastructure and management arrangements, including historical trend analysis
- Consultations on inter-relationship between adjacent irrigation systems and water users within a single river basin catchment
- Measurements and data collection on irrigation performance (canal flows and agriculture)
- Focus group discussions and questionnaires with farmers and other stakeholders covering on perceptions, performance, needs and constraints in relation to irrigation.

Results

Climate: There is a sparse database for historical climate, making it difficult to identify many changes which may already have occurred – despite a local strong perception of change. Some warming trends in temperature can be seen and recent years have been relatively dry. The recent decline (since 2000) in annual rainfall may be a short-term phenomenon and it contrasts with the anticipated impacts of climate change which include increased total rainfall. Other observed changes include the timing and duration of the monsoon, number of days with very light or very intense rainfall, and the numbers of warm and cold days. All of these changes vary across the country but can be expected to influence crop choice and productivity in the future.

Impact of Climate on Irrigation: Irrigated agriculture is very dependent on rainfall and only provides partial protection against drought: any changes to rainfall patterns will affect both supply and demand for irrigation water. There are few irrigation systems which have access to a reliable and adequate supply of water for the entire command area even under the present climate, so any change in climate can be expected to have a direct impact.

Climate change potentially has four important effects for irrigated agriculture:

- Reduced runoff in rivers, due to changing rainfall patterns in the catchment,
- Increased flood flows due to more intense rainfall,
- Increased demand for water due to higher temperatures and more erratic rainfall, and
- Changes in crop suitability due to temperature changes

Other concurrent changes. Climate changes must be reviewed in the context of other changes which are affecting both supply and demand for irrigation water, and also influencing the importance of agriculture and its place in livelihoods and the economy. These include:

- increasing water uses upstream due to increasing population and the changing socio-economic situation, which greatly exceeds the impact of climate change,
- degradation or changing management of watershed, including mining of riverbed materials,
- declining interests in agriculture,
- urbanisation and migration,
- improvements in rural access,
- globalisation of agricultural markets.

This study has shown that these other changes are more important in the short term for most small and medium irrigation, with the possible exception of the impact of increased rainfall intensity on flood risk. In the longer term, climate impacts will become greater but there will also be uncertainty in other changes

Performance of Irrigation. Measurements, observations and consultations in the Girwari *khola* in Nawalparasi and Banganga *nadi* in Kapilvastu reveal several strengths and weaknesses of irrigation performance which highlight its vulnerability to changes in climate:

- Water is inadequate: demand is almost always greater than supply even allowing for rainfall and even in many parts of well-supplied systems. The situation deteriorates towards the tail of most systems, although return flows can result in excess water at a late stage.
- There have been substantial reductions (measured) in river and canal flows in dry season over the past 20 years, and reported increases in flood flows (anecdotal but supported by water level observations). These are believed to be mainly a consequence of changes in land and water use in the upper catchments which affect runoff.
- Canal flows follow rainfall: flows increase in response to rainfall, ie. they match supply in the river rather than crop water requirements; abstractions are not reduced at time of high rainfall, except in the case of extreme events and then sometimes because of flood damage rather than deliberate operation.
- Permanent weirs and intake structures prevent many problems with abstraction of water from the river and, combined with better control structures, can significantly improve water management within individual systems. However, this can influence downstream farmers/systems – particularly those reliant on direct return flows via drains, but also downstream systems taking water from the same river.
- Equitable management is very challenging, usually with pronounced head-tail variations in access to water, sometimes enshrined in water rights. Surface storage is only possible on a very small scale, and few people have access to tubewells. Large-scale conjunctive management of surface and groundwater would be needed to improve this situation.
- In many cases command areas are declining, partly due to shortage of water. Loss of agricultural land as a result of urban development and decreasing interest in subsistence agriculture in marginal areas appear to be more immediate reasons for the changes.

Despite these observations which might appear to indicate *ad hoc* and weak management, the systems are operated effectively given their current objectives and development history. The field studies indicate that irrigation performs well if the institutions are strong, water users involved effectively, and the infrastructure is appropriate.

Irrigation systems have responded partly to the profound changes in requirements in recent decades, but further attempts to optimise water use and productivity need to be planned with extreme sensitivity in the context of local livelihoods otherwise they will risk destroying long-established institutional arrangements.

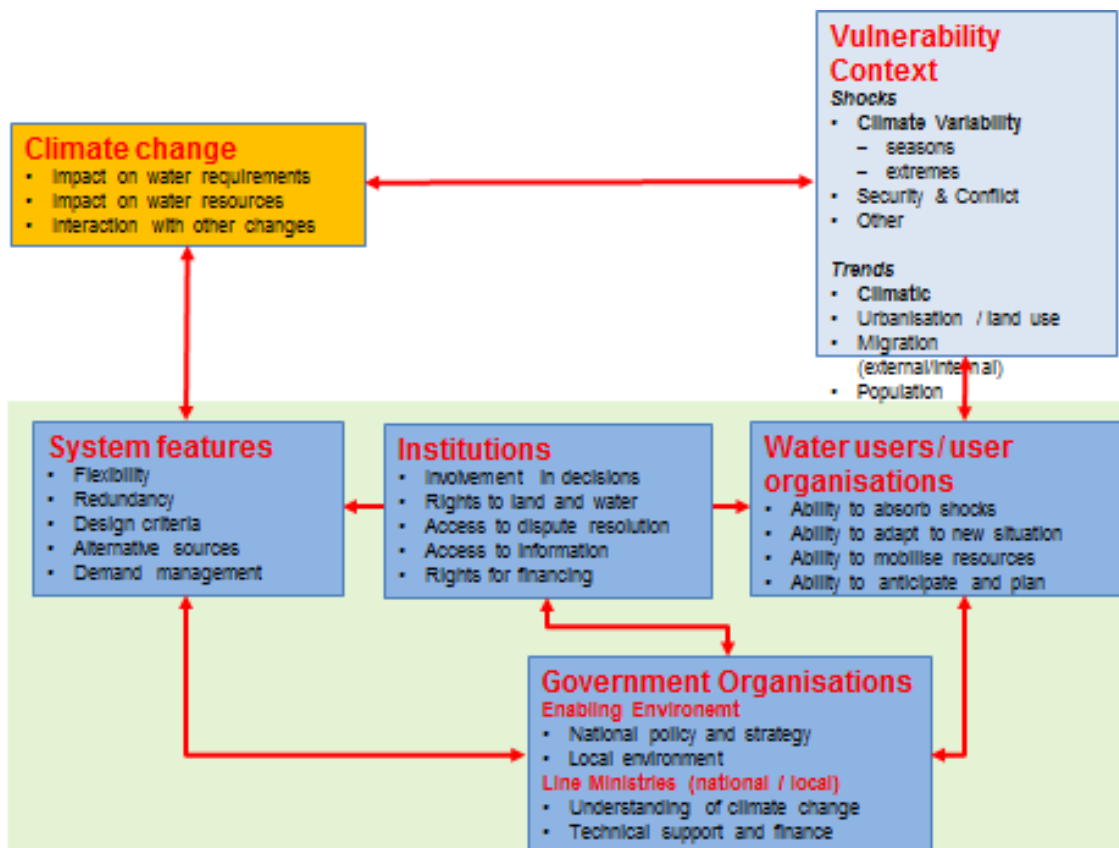
There is some evidence that improving physical infrastructure to improve water control or to reduce losses has had a detrimental impact on downstream farmers. It is important to evaluate all interventions in a river basin context: irrigation is widely reported to be inefficient, but most ‘lost’ water is reused immediately downstream. The greater uncertainty that will come as climate change becomes more severe will require greater sensitivity in management and, in particular, more coordinated operation of systems within a single catchment. High tech ‘water-saving’ irrigation is unlikely to reduce consumption of water and may reduce water availability to others further downstream

Framework for Resilience

Climate resilience is a new and unfamiliar concept to many local practitioners and planners, and it brings with it a new language and terminology, and new stakeholders - but the underlying issues are familiar. Good practice for promoting irrigation performance will address many of the issues, as well as the additional and growing risks caused by climate change.

The IPCC definition of resilience is “*the ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity of self-organization, and the capacity to adapt to stress and change*” (IPCC, 2014). Resilience also includes the ability to anticipate shocks, and to develop into a stronger state.

Figure S.1 Framework for Resilience



The framework set out above may appear complex, but it is an attempt to put many issues which are individually well understood into a logical structure. It aims to help understand how to build resilience and improve performance in response to all changes.

The first part of the framework covers the overall vulnerability of the system, and then the second part relates to the key features of resilience. Following the Drivers of Change framework, this, considers three components:

- Systems (infrastructure and river basins)
- Institutions (rules)
- Agents (actors/individuals/organisations)

Examples of actions in relation to these three main components are given in the table below. All three elements of the framework should be addressed together, and the responses should be designed on the basis of a good understanding of the vulnerability context (including climate extremes and trends as well as other facets of vulnerability). Infrastructure is part of the solution, but it is only of value if it is designed and operated well and fits with the local situation and requirements of the users and other stakeholders.

Systems (infrastructure):	Institutions (rules)	Agents (individuals, organisations)
Modified design criteria, particularly flood and dry season flood estimates.	Arrangements for cooperative management of natural resources, including river bed materials as well as water.	Farmer ability to absorb, adapt, anticipate change, in response to climate uncertainty and other non-climatic changes.
Design of structures and systems to be adaptable as the need changes	Water rights, across the river basin - to avoid causing adverse impacts, and taking account of traditional rights as well as new policy provisions.	Access to knowledge, willingness and resources to adapt or diversify agriculture, and livelihoods more widely.
Flood capacity – exclusion of peak floods, safe escape structures and fuse plugs, protection of vulnerable canal reaches.	Mechanisms for preventing /resolving conflicts.	
Control of water at low flows; impact on improved control other users.	Enhanced ability to raise finance.	
Development of new sources, with conjunctive management.	Markets and subsidies for crops, and support systems for agricultural development.	

Recommendations for Climate-Resilient Development

Climate is changing and this will get worse. Water is already scarce: river basins are stressed and need to be better managed to ensure that water is, overall, used in the best way possible. The smaller the basin the more sensitive it is to change, and most irrigation is dependent on small catchments. Adaptive management is essential – irrigation can be developed gradually as the situation changes. Climate finance also provides new opportunities for facilitating transformational change of agriculture and enabling a more resilient and prosperous society.

Irrigation is highly sensitive to climate, and actions to reduce this sensitivity are likely to be complex in terms of both infrastructure and institutions. Actions in one area may have negative impacts in other areas, so it is recommended that any changes are carefully monitored and introduced incrementally as they are needed. Sensitivity tests can be done to analyse and mitigate the risk of catastrophic damage in the short term. It is recommended that:

Systems:

- Climate stations are improved, at least for key parameters (min and max temperature, and daily rainfall), with river flow monitoring introduced in representative small basins.
- More reliable methods are derived for flood and low flow forecasting in ungauged catchments, and estimation of effective rainfall.
- Research is undertaken on the impact of soil and water conservation in upper catchments, including small-scale water harvesting as this can reduce availability further downstream.

- Risk-based approach to design is introduced, with improved procedures for
 - Design of diversions and intakes, particularly in flashy Siwalik rivers
 - Flood and sediment control at permanent intakes
 - Consideration of lift irrigation to reduce the need for long vulnerable canals in the hills
 - Management of low flows, diversified cropping, crop water requirements and delivery mechanisms for winter and spring cropping
- Evaluation of new approaches to infrastructure, including
 - Lift irrigation in hills and on river terraces (*tar*)
 - Provision and use of small-scale and on-farm storage.
 - Tubewells integrated into surface systems

Institutions:

- Water management is improved (at system level and on-farm), with development and use of appropriate operating rules.
- There is a value chain approach to agricultural development, linking producers to markets and addressing constraints at all levels.
- Support is provided for deep and shallow development to supplement surface irrigation, and for conjunctive management of surface and groundwater (covering arrangements for both development and management of tubewells)
- Institutional arrangements for river basin management are developed and strengthened (considering all water users, and actions in the river), with better understanding of the trade-offs between different users and optimal sharing of benefits.

Agents

- Actions are taken to promote understanding of climatic and other changes, their impacts, and coping mechanisms in the context of irrigated agriculture.
- Make better use of short term and seasonal forecasts on water availability and floods, and adapt crop and water management decisions accordingly.

1 Introduction

1.1 Study Objectives

The Government of Nepal has made investing in irrigation a high priority, but is concerned that climate change will affect the type of development needed, require new approaches, or at least change the design parameters. In addition, measures taken to adapt to climate change may be undertaken on a project by project basis rather than being mainstreamed into national policy and fully coordinated with other sectors.

The Government of Nepal requested support from the DFID-funded Climate Development and Knowledge Network (CDKN) to research these issues and develop a framework for improving the resilience and effectiveness of small and medium scale irrigation systems in Nepal, to:

- Improve the approach and methodology for planning and delivery of efficient, effective, equitable and climate-resilient irrigation systems.
- Assess processes, institutions and policy for irrigation development, management and resource governance.
- Provide framework to increase the climate resilience and effectiveness of small and medium scale irrigation systems.
- Ensure framework is well understood by the relevant governing and implementing parties.

1.2 Background

1.2.1 Irrigation in Nepal

Agriculture is a mainstay of the economy of Nepal, providing about 30% of the GDP, but it is very vulnerable due to the vagaries of the monsoon climate as well as the harsh topography. Population growth has led to land holdings so small that they are insufficient even for subsistence needs for most people, making off-farm employment and rural-urban migration increasingly important. Nevertheless, agriculture remains a very important part of livelihoods, and there is a need both to improve this and make it more resilient to climate change.

Much of the arable land in Nepal is at least partly irrigated - about 50% of the 2.6m ha of agricultural land is irrigated to some extent - and further improvement of agriculture depends on better and more sustainable irrigation and water management. Very little land has reliable perennial irrigation and quite large areas are not fully irrigated even during the monsoon season. There is a constraint due to water shortage but, despite a long history of irrigation in the country, it is also widely recognised that the sector is not performing as well as it could.

The Irrigation Policy splits irrigation into four size categories: major, large, medium and small. The focus of this study is on small (less than 10 ha in the hills and less than 100 ha in the tarai) and medium irrigation (10-500 ha in the hills and 100-2,000 ha in the tarai). DOI is the lead agency for all irrigation apart from small irrigation which falls under the purview of DOLIDAR.

There has been a large investment in irrigation over the past 50 years. Initially this was mainly on large-scale irrigation from the main rivers, but since the 1990s donor interest has shifted to rehabilitation, improvement and modernization small and medium-scale farmer managed

irrigation. The approach has been refined over the decades but there are still many difficulties in improving irrigation even before consideration of climate change. However, measures to improve performance under assumptions of a stationary climate will also be effective in improving resilience against a changing climate.

Rice, maize and wheat are the major grain crops in Nepal, but production is variable due to the diverse local climate and agro-ecology. The figure below shows three agro-ecological zones (belts) in Nepal - tarai, hills and mountains. There is a considerable area of irrigation in the hills – this is almost all on a relatively small scale (less than 100ha), but cumulatively amounts to a large area (175,000ha, or 15% of the total). This used to be where most people lived and where there is a good tradition of farmer-managed irrigation. The mountain region is sparsely populated and with little irrigation (50,000ha or 4% of the total) – mostly in low lying river valley parts of otherwise mountainous districts

The majority of irrigation is now in the lowland areas of the tarai (including inner tarai). This region has been developed over the past 50 years or so, with a large influx of population and development of major and minor irrigation. There is also a strong tradition of farmer-managed irrigation in the tarai, where there are several large schemes, particularly in the west, but most has been developed more recently with varying degrees of government support.

Figure 1: Agro-ecological zones in Nepal



1.2.2 Climate change and Irrigation in Nepal

There is a consensus that climate change will have adverse impacts on water resources and on agriculture both globally and in South Asia in particular (IPCC, 2014, Nelson et al, 2009). This has been confirmed for Nepal as well (Pradhan *et al*, 2015, IDS-Nepal et al, 2014). Most irrigation in Nepal is in small and medium irrigation schemes and draws water from small rainfed

tributaries of the major Himalayan rivers where there is no storage possible and where there is already a shortage of water. These streams are very vulnerable to climate change – there may be a slight increase in total runoff but it is likely that the distribution and intensity of rainfall will change resulting in greater shortages at some times or places. The projected increase in temperature will affect snow and glacier melt, but this is less relevant to small and medium irrigation which is predominantly rainfed. It will also increase crop water requirements and may affect crop choice and productivity. Thus, there are likely to be some significant adverse impacts and there are local perceptions that these impacts have already started. There may be some benefits as well as adverse impacts, such as higher yields due to higher temperatures and carbon fertilization.

Projections of future change are highly variable according to location, scenario and model. However, the purpose of this study is building resilience or adapting to climate change; it is not to model the precise impacts of climate change. Although many past studies (eg ADPC, 2013) have stressed the need for ever more precise modelling and downscaling of global models, the World Bank (2014) have suggested that such top-down approaches focused on climate change downscaling have generally been unhelpful. They recommend a bottom-up approach, with effort spent on identifying the future conditions that are problematic for the design under consideration, evaluating whether these future conditions are likely (using the best available information), and then assessing whether the vulnerabilities can be mitigated. Locally, Selvaraju (2014) also discusses the problems of model reliability and uncertainty in the Nepal context and recommends a community-centred and bottom-up approach.

Although Nepal is endowed with enormous water resources, of the order of 240 km³/yr, only a small proportion of this – less than 10 km³/yr is actually abstracted. Most of the balance is in major rivers which provide a potentially secure source of water for the major irrigation and hydropower systems, including further downstream in India. There is, however, little scope to use this on smaller irrigation systems, which are mostly dependent on small and medium rainfed rivers (including tributaries of the major rivers).

This report is concerned only with small and medium-scale irrigation (less than 100ha in the hills and less than 2,000 ha in the tarai), which accounts for about 75% of the irrigation in the country.

1.3 Climate-resilient Irrigation

A definition of Climate Resilience is “*the capacity of a system to absorb the stresses imposed by climate change and respond and evolve into a more desirable state that will improve the robustness of the system leaving it in a stronger state to withstand not only the increasing impacts from climate change but also other external shocks.*” (IPCC, 2014)

There is now an extensive literature on irrigation and climate change, notably by FAO (Turrall, 2011), and some of which is listed in Appendix G. The impact on water resources is complex and there is no simple clear trend – changes in magnitude, intensity and duration of precipitation are expected, with consequent impacts on river flow and requirements for irrigation. In Nepal, MOSTE (2014) anticipate that irrigation will need to cope with rainfall that is more erratic and intense, resulting in increases in peak river flows but changes in timing of flows; reduced dry season flows and an increase in the number of consecutive dry days; and shorter, warmer winters.

However, the impacts may be very variable across the country and there is unlikely to be a consistent pattern. Trends and future projections for many climatic variables are described in

the next chapter, but the high degree of variability and uncertainty means that irrigation needs to be flexible and able to cope with a wide range of climatic conditions.

IFPRI (2009) forecast significant reductions in rice and wheat production in South Asia, and consequent reductions in average calorie availability. They recommend substantial expenditure on irrigation expansion and efficiency improvements. Greater variability in rainfall will also increase the need for water storage: surface storage is both expensive and disruptive, but groundwater aquifers provide a natural reservoir which can easily be tapped. Such changes are difficult to achieve but the improvements proposed to make irrigation more climate resilient are often the same measures which are needed under the present climate. Irrigation involves application of large volumes of water over extensive areas and can itself have an impact on climate, although the impact is small (Sacks et al 2009) and not significant in Nepal.

Although there have been many studies of small and medium irrigation, climate change, and adaptation in Nepal, there is little basis for quantifying the impact of climate change on the irrigation sector particularly as there are so many concurrent changes (see for example, Budathoki & Duncan, nd).

1.4 Other Changes Influencing Irrigated Agriculture

Agriculture in Nepal is in a state of transition. Although still accounting for a large proportion of GDP and is particularly important for the poor, the nature of agriculture is changing. It no longer accounts for the majority of most people's income and there are few farmers solely dependent on subsistence agriculture. Urbanisation has created many alternative local employment opportunities and migration to India, Malaysia and the Gulf provides further opportunities. These are often more profitable than agriculture but farming still remains important for many households, so agriculture must cope with the changing labour availability. Perversely this has led to reduced cropping intensity and even abandonment of land in some areas.

The environment in Nepal makes it difficult for small farmers to compete in a global market for traditional crops (rice, wheat and maize). There is scope for high value diversified agriculture, particularly for new urban markets which have opened up as a result of improved access, but not all farmers have the resources or ability for this. Such diversified agriculture has more stringent requirements for water management than traditional rice cultivation, and thus is more sensitive to climate change. In the short term these other changes are much more significant than climate change. For example:

- Urbanisation and off-farm employment;
- Longer-term international migration;
- Poor security and weak governance;
- Poor service delivery for agricultural support, inputs and advice;
- Land holding size and topography making profitable agriculture for cereal crops difficult;
- Low agricultural prices for main crops;
- Labour shortage for intensive high-value crops; and
- Very variable climate and limited scope for perennial irrigation

2 Climate Change in Nepal

2.1 Background

This analysis of observational climate is based on a review of existing data and studies from the Department of Hydrology and Meteorology in Nepal, as well as from scientific journals and the Fifth Assessment Reports of the IPCC (AR5 WGI 2013 and WGII 2014). For the analysis of future climate projections, results from experiments performed with climate models, most notably coupled ocean-atmosphere General Circulation Models (GCMs) that comprehensively simulate the coupled ocean-atmosphere-cryosphere-biosphere systems are used. The IPCC AR5 uses Representative Concentration Pathways (RCPs) as the standard set of scenarios for future projections and recommends that these supersede previous SRES scenarios. An overview of the different scenario sets is detailed in Box 1. In the IPCC AR5, RCP-based climate projections become available from a number of climate models under the Coupled Model Inter-comparison Project 5 (CMIP5).

Box 1. High-level description of RCPs scenarios

RCPs are based on factors that mainly drive anthropogenic GHG emissions, and describe four different 21st century pathways of GHG emissions and atmospheric concentrations, air pollutant emissions and land use:

- **RCP2.6** – a stringent mitigation scenario
- **RCP4.5** and **RCP6.0** – two intermediate scenarios
- **RCP8.5** – a scenario with very high GHG emissions (which is closest aligned with current emission pathways of relatively unabated carbon emissions).

Scenarios without additional efforts to constrain emissions ('baseline scenarios') lead to pathways ranging between RCP6.0 and RCP8.5.

2.2 Global and Regional Climatic Changes

2.2.1 Global

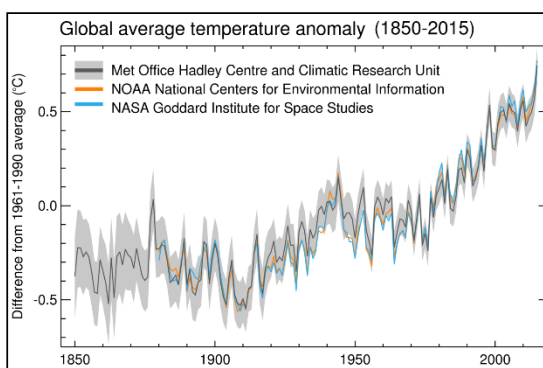
Data from the latest the IPCC WGI AR5 (2013) shows a global average warming over land and oceans of $0.65 \pm 1.06^\circ\text{C}$ over the period between 1880 and 2012. In 2015 the annual global surface temperature anomaly reached 1.2°C above pre-industrial levels, making it the warmest year on record (WMO, 2016). 2016 is likely to be even warmer still.

The CMIP5 simulations for all four RCP scenarios used in the IPCC AR5 project increases in temperature from 0.3°C to 0.7°C by 2035 relative to 1986–2005 baseline. Subsequent temperature increases vary considerably between emission scenarios. By the end of the 21st century (2081–2100), the increase over 1986–2005 is likely to range from 0.3°C to 4.8°C for all RCPs. Figure 2 below presents the 2015 annual global temperature anomaly from 1850-2015 whilst Figure 3 shows observed and projected future global annual average temperature relative to 1986–2005 and 1850-1900 (pre-industrial levels).

Precipitation trends are very variable spatially, with increasing and decreasing trends in different parts of the world. However, according to the IPCC AR5 it is virtually certain that, in the long term, global precipitation will increase as the global mean surface temperature increases. Total precipitation is likely to increase by 1 to 3% per degree rise in temperature apart from for RCP2.6 for which the increase is likely to be 0.5 to 4% per degree by the end of the 21st century.

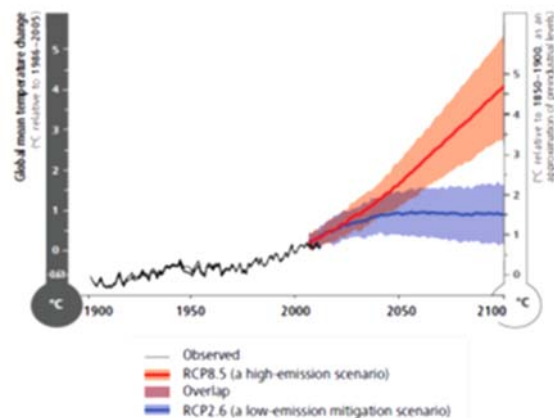
It is projected that global monsoon will strengthen in area and intensity while the monsoon circulation will weaken. Weakening of the monsoon will be balanced by increased atmospheric moisture content and hence more precipitation. In the CMIP5 models used in the IPCC WGII AR5 (2013), the global monsoon area (GMA), the global monsoon total precipitation (GMP) and the global monsoon precipitation intensity (GMI) are all projected to increase by the end of the 21st century under all RCP scenarios. Climate models project a 5% to 15% increase in GMP depending on the scenario. Monsoon onset dates are likely to become earlier or not to change much and monsoon retreat dates are likely to be delayed, resulting in lengthening of the monsoon season in many regions.

Figure 2: Observed global mean combined land and ocean surface temperature anomalies, from 1850 to 2012 from three data sets.



Source: WMO, 2016

Figure 3: Global observed and projected mean temperature change (°C relative to 1986-2005 and 1850-1900)



Source: IPCC AR5 2013

2.2.2 South Asia

IPCC AR5 (WGII, 2014) indicates that warming of up to 2°C has occurred in South Asia in some locations since the start of the 20th century. Records indicate that it is also likely that the numbers of cold days and nights have decreased, the numbers of warm days and nights have increased across most of Asia, and heat wave frequency has increased. By the end of the 21st century, based on the CMIP5 simulations under all RCPs, ensemble-mean changes in mean annual temperature in South Asia range between 2-6°C above the late-20th-century baseline across all RCPs.

Precipitation changes, including extremes, are highly variable according to location and season, with both increasing and decreasing trends observed in different places and seasons. According to the IPCC AR5 (WGII 2014), the seasonal mean precipitation in South Asia has been declining recently with more frequent deficit monsoons but there are large spatial variations in these changes. The frequency of heavy precipitation events is increasing, while light rain events are decreasing. Projections of future annual precipitation show increases are very likely in the northern part of South Asia, while it is likely that changes in the south will not substantially exceed natural variability.

The monsoon circulation systems dominate the climate of Nepal, and this is strongly influenced by the El Niño Southern Oscillation (ENSO)¹ which is widely accepted as an important player in influencing climate variability and precipitation in South Asia. The different phases of ENSO, El Niño and La Niña drive changes in circulation, winds, rainfall and ocean surface temperatures, often exacerbating drought and flood risk. There is a tendency for less Indian summer monsoon rainfall in El Niño years and above normal rainfall in La Niña years (IPCC AR4, 2007). According to the IPCC (WGII AR5, 2013), the Indian summer (south-west) monsoon is also known to have undergone abrupt shifts in the past millennium, giving rise to prolonged and intense droughts.

2.3 Observed Climatic Changes in Nepal

2.3.1 Temperature

According to the Government of Nepal in their Second National Communication (SNC) (MoSTE, 2014) to the UNFCCC, the temperature across most of Nepal has increased by up to 0.55°C per decade.² Other studies have indicated trends of 0.27°C per decade (1975-2006) (Sharma, 2010) and 0.4°C to 0.6°C per decade (1976-2005) (Practical Action, 2009). Despite these differences, all suggest that temperature in Nepal is increasing at a faster rate than the global rate of warming reported by the IPCC (WGI AR5 2013) of 0.12°C per decade from 1951-2012. Both studies indicate a higher rate of increase in maximum temperature compared to minimum temperature. It must be noted, however, that this trend is not uniform across the year or across the country (see 2.3.3 for regional variations).

More subtle indicators than annual average temperature are more important for agriculture, and several studies (e.g. McSweeney et al., 2010; ADPC, 2013) indicate an increasing trend in the number of warm days and nights and decreasing trend in the number of cold days and nights, particularly in the hills³.

2.3.2 Precipitation and monsoon

Studies on precipitation do not yet reveal clear or consistent trends: some studies indicate a decrease and others suggest an increasing trend in mean annual precipitation but none of these are statistically significant. McSweeney et al. (2010) report a decreasing trend of an average 3.7 mm per month (-3.2%) per decade (1960-2006) whilst the Ministry of Population and Environment (MoPE) in their Initial National Communication (INC) to the UNFCCC (2004) indicates that the precipitation over Nepal is decreasing at the rate of 9.8 mm per decade on annual basis based on the 1981-1998 baseline period. However, Sharma (2010) reports an increasing trend over the period 1977-2006 in annual precipitation of 9.9mm/decade (largely [9.0mm/decade] during the monsoon). The SNC (2014) to the UNFCCC reports that the annual precipitation in most of the country shows a positive trend with a maximum increase of about 15% of the annual amount per decade.

According to records maintained by the DHM in Nepal, the normal date of the onset of the South-west monsoon is 12th June (Sharma, 2014). Whilst there is no significant trend in the monsoon arrival, several studies show that the monsoon duration is increasing and the withdrawal date is becoming later (see, for example, Sharma, 2010; Gautam et al., 2013).

¹ The ENSO phenomena consist of two oceanic phases including the warm El Niño phase and the cold La Niña phase that are connected to the atmosphere through a sea-saw atmospheric pressure fluctuation in the South Pacific called the Southern Oscillation

² This is based on data from the Department of Hydrology and Meteorology (DHM) that analysed temperature (both maximum and minimum) based on a thirty-year time series data prior to 2010 observed at 110 stations.

³ Days with an average temperature below 12°C are considered as cold days, and warm days are the days with average daily temperature exceeding 24°C.

Recent observations in Nepal suggest that drought is becoming more frequent, particularly during the winter months and in the western tarai (which is generally drier than eastern Nepal) (see World Bank Knowledge Portal).

In terms of precipitation extremes, Saraju et al. (2008) found an increasing trend in the number of extreme precipitation days (particularly for stations below 1500 metres) and highlighted the implications this has for landslides, flash floods and inundation. There is also some evidence that the number of consecutive dry days or length of dry spells is increasing whereas the number consecutive wet days or maximum length of wet spells is decreasing (ADPC, 2013). Such erratic rainfall events with no decrease in total annual precipitation increase the possibility of climatic extremes like irregular or delayed monsoon patterns, droughts and floods.

2.3.3 Regional Variation within Nepal

Nepal's diverse topography and range of ecological zones means the overall impact of climate change is likely to differ spatially across the country.

Whilst both maximum and minimum daily temperatures predominately show increasing trends during all seasons, there are high variations in the spatial distributions of temperature trends. These trends, in general, are found higher (i.e. increasing more rapidly) in maximum than in minimum temperature with warming being observed more in the north than in the south of the country. A trend analysis of air temperature for the period of 1971-2012, found the mean annual maximum temperature trend to be higher in the mid-high altitude region and lower in low lying tarai, while the trend pattern in mean annual minimum temperature is reversed with greater changes in the tarai and Siwalik areas and smaller changes in high altitude region (Nepal Hydrological and Meteorological Research Center (2015) (Table 1).

The only exception to the increasing trend in maximum temperature is in parts of the tarai region during winter, which is associated with fog. Foggy conditions during December and January have become more prominent and persistent in recent years, but this is also inconsistent as fog free periods have resulted in an increase in the number of cold days.

A trend analysis for precipitation for the same period (1971-2012), found a decreasing trend in mean annual precipitation in the tarai and middle mountain region and an increasing trend in the high Himalaya region (see also Table 1).

The effect of monsoon is prominent across all of Nepal, except the Trans-Himalayan region (mostly in the west and mid-western region). The south-west monsoon is weaker in the west resulting in a generally drier climate. The winter (DJF) precipitation is influenced by the north-east monsoon which is strongest in the far west.

Table 1: Regional trends of annual precipitation and maximum and minimum temperature

Region	Max. Temperature Trend (°C/year)			Min. Temperature Trend (°C/year)			Precipitation Trend (mm/year)		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Terai	-0.02	0.05	0.02	-0.01	0.04	0.02	-14.9	19.8	-1.3
Siwalik	-0.02	0.07	0.02	-0.03	0.05	0.01	-16.3	26.8	0.6
Middle Mountain	-0.01	0.11	0.04	-0.04	0.05	0.01	-35.0	28.7	-2.3
High Mountain	0.02	0.07	0.05	-0.03	0.05	0.01	-42.5	31.1	0.2
High Himalaya	0.04	0.06	0.05	-0.01	0.02	0.01	-6.1	17.2	6.6
Country	-0.02	0.11	0.04	-0.04	0.05	0.01	-23.0	24.7	0.7

Source: Nepal Hydrological and Meteorological Research Centre and Consultancy, 2015

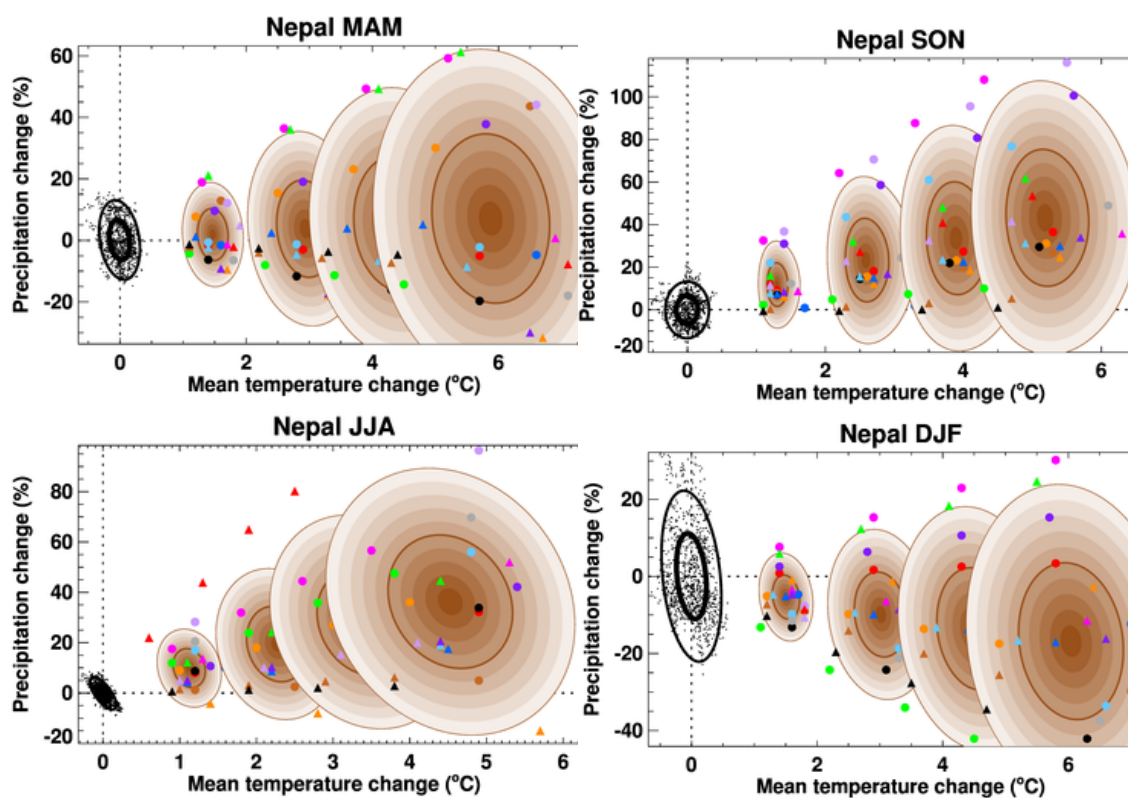
2.4 Climate projections

2.4.1 Temperature and Precipitation

To provide a frame for changes in future climate, Figure 4 below shows the range of uncertainty and overall changes in precipitation and mean temperature for Nepal that are likely to happen from the full range of CMIP5 (AR5) models and forcing scenarios. Projections of national average climate change are provided in Figure 4 for specific levels of global warming using climate scenarios from the RCP and SRES groups which result in warming of up to 4 °C above the 1961-1990 baseline depending on the scenario and timescale.

Whilst it is currently difficult to get a clear picture of precipitation change due to large model uncertainties, the scatter plots indicate that the annual precipitation change will be in the range of -30 to +30% in MAM, -10 to +50% in JJA, -20 to +60% in SON, and -30 to +10% in DJF for a 2 °C temperature rise which is appropriate for the time horizon for small and medium irrigation. Increases in rainfall intensity are expected to be of the same order as increases in magnitude of precipitation.

Figure 4: Changes in seasonal precipitation and mean temperature for Nepal using CMIP5 models



Source: Osborn et al., 2015

The changes in national average temperature (x-axis) are the difference between the future climate and the 1961-1990 mean. The national average precipitation (y-axis) is expressed as a percentage change from the 1961-1990 mean.

Changes are given for 21 CMIP5 climate models with scenarios which result in global warmings of approximately 1, 2, 3 and 4°C. The spread in the projections from these four multi-model ensembles is visualized by the shaded ellipses. The outer ellipse line marks the +/-2 standard deviation range of the models in each ensemble, while the inner ellipse line marks the +/-1 standard deviation range.

The small black dots (and associated ellipses) provide an estimate of the natural variability inherent in our climate, with each one representing a 30-year average of national average precipitation and temperature calculated from a 1000-year "control run" simulation with the CMIP3/CMIP5 HadCM3 climate model. We do not have long enough climate observation records to estimate this variability for the real world, so this is only an indicative, model-based estimate of this variability. Further, the variability of individual years is much greater than the variability of 30-year "climate averages."

2.4.2 Monsoon projections

Based on CMIP5 simulations it is likely that the area encompassed by monsoon systems will increase and monsoon precipitation is likely to intensify. For the Indian monsoon, CMIP5 models project an increase in mean precipitation as well as its inter-annual variability and extremes throughout the 21st century under all RCP scenarios. All models project an increase in heavy precipitation events but disagree on consecutive dry days (CDD) changes. Regarding seasonality, model agreement is high on an earlier onset and later retreat, and hence longer duration. This projected lengthening of the monsoon is consistent with current observations in Nepal, although recent data suggests that the date of onset has been slightly delayed in recent years.

Although IPCC report moderate confidence that monsoon precipitation will increase, a number of recent studies (see, for example, Ogata et al., 2014; Soorai et al., 2014; Ma and Yu, 2014) based on CMIP5 simulations have indicated a significant weakening of the South Asian summer monsoon circulation, resulting in a decrease in precipitation. This implies that we are likely to see more extreme rainfall events together with a decrease in light rain events and an increase in the number of dry days during the monsoon period and drier winter months. This could result in more frequent monsoon floods and winter droughts.

In a suite of models used in the IPCC AR5 (WGI 2013) that realistically simulate ENSO – monsoon relationships, normal Indian monsoon years are likely to become less frequent in the future, but there is no clear consensus about the occurrence of extreme monsoon years. Whilst there is high confidence that ENSO will remain the dominant mode of inter-annual variability with global influences in the 21st century, how ENSO will change in the future – and how its effects on monsoon will change – remains uncertain. However, the projected overall increase in monsoon rainfall indicates a corresponding increase in the risk of extreme rain events.

3 Irrigation and Irrigated Agriculture

3.1 Introduction to the Irrigation Sector

About 1,766,000 ha of the country's cultivated land is irrigable, of which about 75% (1,227,000 ha) has been provided with some irrigation infrastructure and about two thirds of that is actually irrigated during the monsoon season (CERD, 2007). About 30% can be irrigated during the winter season and only about 18 % of the total cultivated land receives year-round irrigation.

Until the mid-1950s, irrigation development in Nepal was largely a result of farmers' own initiative and investment in irrigation. Such systems are based on indigenous technology and some are reported to be as old as 400 years. They still make a substantial contribution to the national economy and account for about half of the irrigated area.

The government's direct involvement in irrigation development and management started during the first five-year plan in 1957 with the construction of medium and large surface irrigation systems in the tarai, later with considerable donor assistance. However, performance was not considered very good and from the mid-1980s the government and donor agencies shifted their attention to the rehabilitation and improvement of farmer-managed systems, together with programmes to transfer of management of the larger systems to farmer (or joint) management. Extensive groundwater development started around the same time and now accounts for a quarter of the total area. There have also been some recent developments on micro-irrigation (drip/sprinkler) often termed as non-conventional.

About 51% of irrigated land is in farmer-managed surface irrigation schemes (620,000 ha), 23% in groundwater irrigation (280,000ha almost entirely farmer managed), and 26% (315,000ha) in agency-managed or joint-managed surface schemes⁴. Shallow groundwater use has developed rapidly over the past 25 years, and provides a reliable form of small-scale perennial irrigation but it still only covers 25% of the irrigated area and all of this is in the tarai. Most irrigation (80% of the total area) is in the tarai and about 60% of the surface irrigation in the tarai is supplied from small rainfed rivers with large seasonal variations. Only major schemes are able to make use of the main rivers⁵ and there have been major financial, institutional and technical difficulties in developing and managing this effectively.

Agency-managed irrigation systems (AMIS), ranging up to 60,000 ha were designed to the conventional engineering principles in common use at the time (and influenced by the donors or consultants involved). They set out to irrigate large areas which could not be done by traditional methods, and often were in newly-developed land. They are structurally robust and hydraulically sound, with designs based on a certain level of anticipated hydrological variability. Most AMISs are designed with 80% reliability of service, and would fail to deliver water as designed if low flows occur more frequently. They are also vulnerable to flood damage as it has increasingly been found that the design assumptions major weirs have been exceeded (for example, Bagmati in 1993, Babai in 2013) causing significant damage.

⁴ Data is limited and definitions of irrigated areas are contentious. These figures are from the 2007 database which is being updated now

⁵ Major systems have been built on all the main rivers in the tarai except the Karnali (ie. on the Mahakali, Babai, Rapti, Gandaki, Bagmati, Kamala, Koshi and Kankai rivers) although these are not all fully complete yet. These irrigate around 200,000 ha (15% of the total irrigated area) and draw water from large perennial rivers, but the lack of diversion structures in most cases can limit the dry season flows, and complexities of management of large scale supplementary irrigation have limited their performance.

These systems were planned to be managed by DOI, with their field staff adjusting control structures and delivering water to farmers on a pre-determined schedule. However, this proved to be very demanding in terms of DOI resources so systems of joint management have emerged both informally and on a planned basis. In all cases farmers undertake more than was envisaged in the original design, and are now increasingly organised into Water Users' Associations to make this process more effective and large scale. Thus most small AMIS, and large parts of most medium and large AMIS are actually farmer-managed in practice, but they differ from traditional irrigation in their design – the types of control structures, the capacities of canals, scale of systems and so on may be quite different – and this has implications for their management.

Farmer-Managed Irrigation (FMIS) by contrast has emerged informally over several centuries, from a traditional heritage of irrigation exemplified by large schemes in the tarai, such as Chattis Mauja (Rupandehi District), Rajapur (Bardiya District) or Rani/Jamara/Kulariya (Kailali District), as well as many smaller ones in the hills. Most are small or medium – very few exceed 5,000ha, but there are large numbers of smaller schemes which have been developed. About half have had some form of government assistance at some stage whether for initial construction or subsequent rehabilitation, improvement or extension. Traditionally they had simple but effective methods of sharing water although many have been modernized in ways which changes the traditional arrangements.

They may not follow standard engineering and agronomic principles, and their designs are also strongly influenced by many institutional, managerial, social and ecological considerations. The infrastructure is designed to provide a coping strategy for extreme events, using concepts of “design to fail”, “oversized canals” and “flexibility in management”. However, with the potential change in climate, even these responses may no longer be viable. For example, the labour requirements for maintenance – which are already hard to meet because of migration – may become excessive if the flood frequency becomes much higher. Replacing high maintenance ‘fail-safe’ weirs with low maintenance permanent structures will solve one problem but may transfer the risk downstream rather than fully resolve it.

Although there is still potential to improve FMIS, there is an emerging trend to move the emphasis back to larger infrastructural solutions – particularly new large-scale irrigation on medium to large rivers, where there is now seen as greater potential⁶. The government has initiated development of large scale tarai irrigation systems including the Sikta Irrigation Project (35,000 ha) in the West Rapti Basin and the Mahakali Irrigation phase III (34,000 ha) in the Mahakali Basin. In addition, inter-basin transfers are now being implemented. The first major example is the Bheri-Babai diversion which will augment the Babai irrigation scheme to over 60,000 ha (DOI, 2014). These will enable new large-scale irrigation as well as augment flows to numerous smaller traditional systems. However, such transfer canals are expensive, contentious (socially and environmentally) and may have trans-boundary implications. The first contracts have been awarded for the Bheri-Babai link, the Sun Kosi-Marin diversion is being studied now, and there is a successful precedent from hydropower.

A parallel development has been the rapid growth of shallow tubewell irrigation. Low cost Chinese diesel pumps have made this an affordable and reliable source of irrigation in the tarai where it has replaced or augmented irrigation from poor quality surface schemes. Further technological developments, such as solar pumps should encourage this development further. This has been supported by DOI, but many other institutional stakeholders are involved. The

⁶ Global poor performance of irrigation infrastructure by the 1990s encouraged donors to focus on institutions rather than yet more infrastructure. However, this led to unrealistic demands being placed on weak WUAs to take on responsibility for incomplete or poor quality infrastructure. A more nuanced approach is emerging, recognising that good infrastructure is needed as well as the organisations to manage it

most effective surface irrigation in the tarai is now in the northern part of the tarai, where groundwater is less accessible and surface runoff more reliable, with groundwater irrigation being more dominant further south. The southern part of the tarai has less direct access to runoff from the hills and is more dependent on drainage and return flows from upstream systems. Improvement of these upstream systems, though construction of permanent intakes and canal lining combined with more intensive agriculture can reduce return flows significantly and thus increase vulnerability downstream – even before any consideration of climate change. The spread of groundwater irrigation is thus a very positive development; the utilisation of groundwater is still well below the annual recharge (estimates being typically of the order of 10%) so there is little resource constraint and little vulnerability to climate change.

Water governance is generally weak and there is little coordinated management of resources across river basins, although there are now plans to establish river basin organisations for the main rivers (starting with Bagmati). Institutional innovations such as conjunctive management of surface and groundwater have been proposed but are not easy to implement.

3.2 Agricultural Development

3.2.1 Current Status and Trends

The agriculture sector plays a vital role in the Nepalese economy; it provides significant employment opportunities to large numbers of rural farmers and it contributes to national and local food security. The sector provides almost one third of GDP and employs about two thirds of the population. It has received top priority in investment since the Fifth Five-Year Development Plan but progress in the improving the livelihoods of agricultural communities remains weak, with limited achievements in diversification and enhancing overall agricultural production and productivity in comparison to many developing countries.

In terms of both production volume and value, food crops (notably paddy, maize and wheat) are the most important group. Paddy provides the largest share of production (52%) followed by maize (23%), wheat (22%), and millet (3%). The production trend shows that there has been little improvement in the production volume of any agricultural products apart from vegetables and to a lesser extent potato. Although the largest component, annual production of paddy has varied considerably, with a strong influence on the overall agriculture sector component of GDP. The largest increases in production have been in fruits and vegetables, but these are still relatively minor crops.

Table 2: Production of Selected Agricultural Commodities in Nepal ('000 Mt)

Crop	04/05	05/06	06/07	07/08	08/09	09/10	10/11	11/12	12/13	13/14*	14/15	15/16
Paddy	4,290	4,209	3,681	4,299	4,524	4,024	4,460	5,072	4,504	5,047	4,789	4,299
Maize	1,716	1,734	1,820	1,879	1,931	1,855	2,067	2,179	1,999	2,283	2,145	2,232
Wheat	1,442	1,394	1,515	1,572	1,344	1,556	1,746	1,846	1,882	1,883	1,976	1,812
Sugarcane	2,376	2,463	2,600	2,485	2,354	2,495	2,718	2,869	2,930	3,020	3,063	3,149
Oil Seeds	142	139	136	134	135	155	176	181	183	184	195	199
Potato	1,739	1,975	1,943	2,055	2,424	2,518	2,508	2,682	2,753	2,818	2,842	2,875
Pulses	271	267	274	270	255	262	318	327	357	352	354	352
Fruits	548	535	575	631	686	707	832	886	1,087	965	992	1,097
Vegetable	2,082	2,190	2,299	2,539	2,754	3,004	3,203	3,401	3,410	3,421	3,629	3,701

Source: Economic Survey,, MOF, Government of Nepal

3.2.2 Opportunities and Constraints for Agricultural Development

Agricultural development is constrained by numerous factors, which result in its share of GDP declining despite the overall importance of the sector:

- Unreliability of water supply: limited irrigation facilities, untimely rainfall, periodic drought and flood make crop production risky and seasonally very variable;
- Poor availability and quality of agricultural inputs and improved technology, and hence poor uptake;
- The structural transformation of labour gradually moving from agriculture to secondary processing and manufacturing industries and tertiary services industries;
- Low level of agricultural commercialization and continued reliance on subsistence economy, with two thirds of the population either directly engaged in or dependent on agriculture for sustenance, yet there is inadequate labour to diversify effectively;
- Weak policy and institutional support for agriculture, limited access to finance and competition with more heavily subsidised Indian agriculture.

However, there is scope for commercialization in the agricultural sector and development of agribusiness through value crops such as off-season vegetables, fruits, spices, medicinal plants, tea, coffee, honey and mushrooms for sale in local urban markets and export.

The Agricultural Development Strategy (ADS – MOAD, 2014) aims increase food and nutrition security; reduce poverty and improve equity of income in rural households; increase agricultural trade competitiveness; and strengthen farmers' rights. This will be increase resilience against climatic and other shocks and trends and will be achieved through four strategic components related to governance, productivity, profitable commercialization, and competitiveness. Commercial agricultural in Nepal will remain primarily a smallholder activity (with holdings smaller than 2 ha of land). The ADS will accelerate the process of commercialization, improving both the income of small commercial farmers and the livelihoods of the subsistence farmers, while generating growth and employment in the non-farm sector.

There is also potential to increase the productivity of cereal crops; this is comparable to other countries in the region but low compared to China. Small land holdings averaging about 0.7ha per household, with majority having barely 0.25 ha, are insufficient to generate an income above the poverty level and hence most households depend on off-farm income. Although overall land productivity, as measured by agricultural GDP per ha of arable land is about \$500 higher than in India, land holdings are considerably lower. By contrast, Nepal has about the same arable land per capita as China, but much lower cereal yields due to lower use of inputs, irrigation and mechanization.

Table 3: Land Productivity Comparison by Country

Country	Arable Land/capita (ha)	Cereal yield (kg per ha)	Ag GDP per ha of arable land (PPP\$/ha)
Bangladesh	0.054	4,191	2,734
China	0.082	5,706	5,299
India	0.139	2,883	2,139
Pakistan	0.122	2,718	2,219
Nepal	0.082	2,481	2,651

Source: Adapted from ADS Final Report, September 2014, MOAD.

3.2.3 Impact of climate and climate change on agriculture

Agriculture is highly dependent on the vagaries of the climate. Even where irrigation is available, the reliability and especially access to irrigation in the dry season is usually strongly correlated with rainfall (see Chapter 5). Given the huge range of agro-climatic conditions in Nepal, agriculture is very diverse and changes in climate will influence what can be grown in a particular location – this particularly affects high value crops which have the best potential for export and income generation. Although the climate data does not yet give a clear indication of trends in any parameters other than temperature, there are indications of changes in the locations where citrus, apples and other fruits can be grown.

There have been very large changes in agriculture in recent decades, with new varieties (often with shorter time to maturity), greater mechanisation, rapid improvements in road access, migration of adult males (and consequent feminization of agriculture) and so on. Few of the changes have been driven by climatic factors yet, and some of the changes will help increase resilience in the face of future climate change. Better access to markets, inputs and information will facilitate diversification to higher value, climate-smart agriculture. Such improvements and diversification are needed regardless of the climate, and climate change may introduce further constraints to it – but equally climate change could provide a driver for the more far-reaching reforms which are needed to improve the sector.

Analysis of the future impacts of climate change on the agricultural sector (Pokhrel, et al., 2014) showed a strongly differentiated pattern over time and across the country, with potentially high long-term impacts in the Terai (especially for rice and wheat production), but a varied pattern in the hills and mountains that include some potential benefits.

The impacts of climate change in the short to medium term were assessed to be smaller, with even the potential for an overall net increase in production. However, the yields of some key crops are projected to decrease by 10–20% by the 2070s, with an overall decrease in crop productivity and impacts on vulnerable groups, and possibly high distributional effects. This analysis also did not fully recognise the impact of increased flooding, increased soil erosion and the changing range and prevalence of pests and diseases.

3.3 Water resources and demands

3.3.1 Water resources

It has been estimated that about 225 billion cubic meter of surface water flow through Nepal annually, which amounts to an average annual flows of 7,125 m³/sec (WECS, 2003). This is equivalent to almost 8,000 m³ of water per person on an annual basis, and makes Nepal a very water-rich country (compared for example to China 2,100 m³/capita and India 1,100 m³/capita). However, although Nepal has abundant water resources in total, there is a remarkable temporal and spatial variation in their availability.

- Four major river basins (Kosi, Narayani, Karnali and Mahakali) account for 78% of water resources and irrigate 30-40% of the total area. This is either in major systems outside the scope of this report t⁷, or in small rainfed sub-basins which have a much lower per capita runoff and are generally water-short
- Five medium rivers (Kankai, Kamala, Bagmati, West Rapti, and Babai) discharge about 10% of country's surface waters and irrigate about 10% of the tarai surface irrigated area (plus small areas in the hills)

⁷ The major systems (Sunsari-Morang, West Gandak, Mahakali etc) in the tarai take a small proportion of the total flow in those rivers, and are constrained by factors other than absolute water availability in the rivers

- 75 much smaller and highly seasonal rivers discharge 12% of water resources and supply about 50% of the total surface irrigation

All rivers are trans-boundary, draining into the Ganges river system in India and some are subject to international arrangements and agreements which currently restrict development.

Table 4: Water Availability in each River Basin

River	Drainage Area (km ²)		Population 2001	Flow	Per capita	% Total	
	Total	Within Nepal	('000)	(m ³ /s)	m ³	Flow	Population
Mahakali	15,260	5,410	444	698	24,761	9.8	1.9
Karnali	44,000	41,890	2,166	1,441	20,981	20.2	9.4
Narayani	34,960	28,090	4,377	1,753	12,632	24.6	18.9
Koshi	60,400	31,940	2,816	1,658	18,568	23.3	12.2
Babai	3,400	3,400	489	103	6,636	1.5	2.1
W. Rapti	6,500	6,500	1,046	224	6,738	3.1	4.5
Bagmati	3,700	3,700	1,935	178	2,900	2.5	8.4
Kamala	2,100	2,100	336	100	9,397	1.4	1.5
Kankai	1,330	1,330	266	68	8,055	1.0	1.2
Southern	22,821	22,821	9,274	901	3,065	12.7	40.1
Total	194,471	147,181	23,151	7,125	9,705	100	100

Figure 5: River Basins



About 80% of rainfall occurs during the four months (June to September) of the summer monsoon and the hydrology follows the same pattern: about 75% of total annual flow occurs between June and September, with 25% in the month of August alone and just 1-2 per cent in

the month of February. All the medium and southern rivers and most tributaries of the major rivers in the middle hills already have deficit in water supply, especially during dry months. This means that there is little scope for new small or medium scale irrigation from surface water; new surface irrigation is likely to depend on the medium and major rivers (or transfers from these rivers) and will be large scale.

Surface runoff in small basins is declining although there is little or no quantitative data on past and present river flows or on the relationship between rainfall and runoff. For example, flows in the Kaila and Banganga rivers in the tarai have declined significantly and this believed to be mainly due to changes in land use, more intensive agriculture and abstractions in the head reach of the catchment. This is supported by spot measurements in 1980 (Pradhan, 1996) and this study.

By contrast, the ground water resource is relatively abundant but this is only available in the tarai and in some valleys in the hills. The annual estimated groundwater recharge in the tarai is about 12,000 Mm³ – much more than ten times the annual abstraction of 685 Mm³ (Kansakar, 1996) although there is very little data on actual abstraction. Thus, considering the low utilization of the present rechargeable reserve⁸, ground water is an ample resource for irrigation in much of the tarai and is resilient since it is stored in an aquifer and can be pumped when required rather than being subject to seasonal variation.

3.3.2 Water uses

Irrigation is the main consumer of water. Its requirements vary according to season, location, cropping patterns etc. Urban and rural domestic water use is a much smaller demand but is required with a much greater reliability and uniformity through the year. Traditionally, irrigation had first priority but domestic uses are now accorded to priority by the Water Policy. There is competition between these uses in some areas, but often urban use draws on deep groundwater which is uneconomic for irrigation.

Hydropower has a very large potential, much of which is unutilised at present. Much of this is on the major rivers which are less used for irrigation, but there are many smaller and medium-sized projects which may overlap with irrigation uses – notably Kulekhani in the Bagmati basin. Although hydropower is a non-consumptive use, it does affect the availability of water which may even be discharged in a different river basin – the small Jhimruk plant for example takes water from the Jhimruk khola and discharges it into the Mari Khola with impacts on irrigation further downstream on the Jhimruk. Such projects are increasingly being developed and may well create complications for irrigation.

Environmental flows have been neglected in the past since traditional irrigation offtakes were made of simple materials and were highly permeable, and irrigation was inefficient with large return flows. Thus much water made its way back to the river systems. Nevertheless, large numbers of small systems on small rivers did cumulatively deplete flows and such rivers often dry up in the downstream end in the dry season. The problem may be exacerbated by construction of permanent intakes which enable diversion of the entire flow, and by canal lining which reduces canal losses. This causes negative impacts on downstream users which are increasingly significant. The physical improvements needed to compensate for declining water availability (for whatever reason) in most river basins may thus have an adverse impact on

⁸ The situation in the Kathmandu valley is an exception to this pattern, as the annual estimated groundwater recharge is about 0.027 Mm³, while the abstraction is about 0.05 Mm³ resulting in ground water levels dropping at about 2.5 m/year (MHPP, 1994). Given the scarcity of water in the valley, the resources are increasingly being diverted from irrigation to drinking water, although there is scope for improved irrigation from urban wastewater and from shallow groundwater which is of too poor quality to be used for potable purposes

downstream environmental conditions. Ironically, such improvements are being justified on the grounds of climate resilience.

3.3.3 Water balance

The major rivers all have an adequate resource overall, but this cannot be used in the hills because the land is at a much higher level. It can be used in the tarai but the constraint is on abstraction of water from the rivers as few have a weir (which would be prohibitively expensive). Utilisation is also dependent on large scale irrigation via long canals, which have proved problematic for management. Such major irrigation is outside the scope of this study.

The five medium rivers have considerable potential. All have now been provided with weirs making reliable abstraction of water possible. The downstream networks have not been fully developed and in some cases (Babai and West Rapti) there are disagreements with India over water rights. However, even these medium rivers will also have a deficit water supply during the dry months between November and May.

Small and medium surface irrigation is almost entirely dependent on small tributaries of the major rivers in the hills and the small southern rivers in the tarai. The water balance of these rivers is negative in almost all cases during the dry months.

3.4 Irrigation Systems

3.4.1 Overview of Irrigated Areas

A database of irrigation was prepared in 2007 by CERD, and this is in the process of being updated so that a new masterplan can be prepared. As there are many thousand small schemes (WECS estimate 1,800 in the tarai and 15,000 in the hills), with a total area of over 1.2m ha and many with ill-defined command areas it is not easy to quantify the area and performance of irrigation. About 25% of the irrigated area is under major and large schemes, with the remaining 900,000ha in small and medium schemes (less than 500 ha in the hills and less than 2,000 ha in the tarai). Most of the large schemes are in the east and central tarai, with a small proportion in the rest of the country (Table 5).

Most small and medium irrigation is long-established and farmer managed. Some has been developed or improved in accordance with conventional engineering and agronomic principles, but the designs are also strongly influenced by other (institutional, social, ecological etc) considerations. Water rights may not be proportional to area, and infrastructure is usually designed to supplement rainfall and provides a partial coping mechanism for extreme events. Critical parts of the system may be designed to fail to prevent more serious and widespread damage; canals may be oversized to carry flood flows affecting performance in the dry season; and labour resources for maintenance are a critical constraint.

Irrigation performance is not easy to quantify – simple indicators such as kg rice per m³ water diverted can be proposed, but these cannot readily be measured on small traditional schemes and they may not be directly related to the performance of the system. Food security, saving of time (to enable off-farm activities), or reduction in local conflict may be more important locally. Some systems remain intensively cultivated while others may be managed on a 'low input' basis just to protect local food supplies with the main source of income coming from elsewhere.

Accurate data on actual irrigation areas, as opposed to design command areas is always difficult to obtain and they may vary substantially from year to year. As FAO point out "*Although rapid improvements are being made in land-use classification from remote sensing, obtaining an accurate assessment of rainfed and irrigated areas and production will remain a continual*

challenge resulting from the relatively rapid short-term market-driven responses in crop choice. In the end, an analysis of the sensitivity of agriculture water management to climate change only makes sense within a systemic context – the river basin and its related aquifers” (Turrall, 2011).

Table 5: Overview of Irrigation Systems

AEZ	Total Irrigable Area	Major & Large Surface Irrigation			Total Small and Medium (AMIS+FMIS incl. GW)	TOTAL Irrigated Area (ha)	Est Population (in 2006)
		FMIS	AMIS	Total			
Tarai	1,337,581	36,300	280,933	317,233	677,764	994,997	12,265,579
Hills	368,541	2,630	2,910	5,540	176,774	182,314	10,822,559
Mountain	59,718				50,042	50,042	1,734,826
Sub-total	1,765,840	38,930	283,843	322,773	904,580	1,227,353	24,822,964
% total irrigated area		3%	23%	26%	74%	100%	

Source: CERD (2007)

3.4.2 DOI Inventory of Small and Medium-scale Irrigation

A summary of the small and medium schemes (900,000ha) from the inventory is presented in Table 3.7. This indicates that virtually the whole of this area is under farmer management – 64% in surface irrigation and 31% in groundwater. About half of the FMIS has received some assistance from the government in recent years.

Those systems which are difficult to manage or under-performing under present climate are likely to be most vulnerable to climate change. However, climate change may increase the vulnerability to some factors which are not strongly related to current performance, such as flood damage of intakes or supply channels. Climate change may also stimulate innovations in implementation or management of systems which are not climate-vulnerable but which are underperforming – for example deep tubewells. Further information on this is given in Section 5.

Types of Systems

The type of systems is significant for their resilience:

- About 625,000 ha (70% of the total area) is irrigated from surface water, of which 410,000 ha is in the tarai and 320,000 ha from the small ‘southern basins’ (see Section 3.3). These are small rivers draining the Siwalik hills, with small catchments and rapid runoff resulting in high floods, prolonged dry seasons and thus low resilience.
- The sources for surface irrigation are subject to large seasonal fluctuations – activities to abstract dry season flows are at risk of being damaged by flood flows
- About 275,000 ha is from groundwater. This is resilient to climate change, particularly as abstraction is so much less than annual recharge, but sustainable management of the larger deep tubewells is not easy: many are underperforming as well as being expensive to operate. They may be located with surface irrigation commands but are still managed independently
- Shallow tubewells are mostly privately financed although they were often subsidised in the past. They have generally been more successful as they are lower cost (both for initial construction and for operation) and can more easily be managed by farmer groups.
- Less than 5% of the area is agency-managed, and even this is likely to have a substantial involvement by farmers in management. Management of AMIS – particularly small and medium systems - has often been problematic, but measures to improve this generally entail enhancing the community role in management

- Commercial private sector involvement in irrigation management has not yet been introduced in Nepal, although it has been considered in the Bagmati Basin (Lahmeyer, 2016) and is also being evaluated in the context of solar-powered pumping of groundwater.

Location of systems

The largest single group of systems are those in the 'southern basins'. These have just 12.5% of the country's water resources in total but with a greater than average seasonal variation in flows. They account for 50% of surface irrigation, benefiting 40% of irrigation farmers. There are very varies degrees of development in the catchments: the smaller the catchment, the more sensitive they are to reduction of dry season flows due to upstream land use patterns. Changes in land use in both catchments and command areas are changing more rapidly than in more remote parts of the country. Intensification of land use in command area (affecting water resources) and urbanisation of command areas (reducing irrigable areas) are particularly significant from the perspective of resilience.

Hill irrigation is an important part of the total (about 30%), although there is much less than in the tarai. Systems are smaller and face additional challenges due to the topography. These also mostly draw water from small, seasonally variable tributaries, but there are some which tap larger rivers. There are some systems in the mountain districts, but mostly in southern parts which are similar to the hill districts, and thus these are considered together with the hill irrigation. There are very small areas in 'mountain' locations.

The AMIS in the hills are mainly in the Kathmandu and Pokhara valleys, where they are being gradually lost to urbanisation, although the remaining area can be used for high value agriculture if there is still access to the source.

3.4.3 Small-scale Irrigation

Although the current policy indicates that medium irrigation is the responsibility of DOI and small-scale irrigation comes under DOLIDAR, the distinction is not always clear in practice. In addition, there are numerous other agencies implementing a range of activities related to small-scale irrigation and watershed management. Some of this is linked to climate change programmes such as the NAPA and LAPAs which have highlighted the importance of village-level improvements in water management. Small scale irrigation includes:

- Small surface diversion and earthen canals
- Plastic ponds,
- Micro irrigation (drip and sprinkler),
- Low-lift treadle
- Rower pumps
- Multiple-use systems (MUS)
- Shallow tube wells
- Solar-powered lift systems
- Rainwater harvesting.

Small surface diversion and earthen canals account for a large majority small irrigated areas and are most vulnerable to climate change. These are commonly found in the hills, especially in upper watersheds. Because of mountainous terrain, land areas in hills are heavily dissected by natural drains and gullies. As a result, a village or an irrigated area would contain several patches of terraces with independent earthen canal that receive water from adjoining seasonal streams whose discharge depends closely on the rainfall. In the past, these seasonal streams

used to supply a fair amount of water to their respective earthen canals, but they are now reported to be drying up and they are not very climate resilient. Traditionally they were used for paddy cultivation, particularly to enable timely planting and to protect against dry periods during the monsoon. They still provide some protection but probably less so than in the past. Operation of these small systems is equally vulnerable to the range of other changes in livelihoods, population growth and governance highlighted earlier.

In recent years there have been many interventions to improve their performance, including diversification of water sources, provision of irrigation ponds integrated with watershed management, and measures to make more efficient use of water. Plastic-lined ponds, as promoted by the Local Infrastructure for Livelihood Improvement Project (LILI) have become well-accepted and this is recognized as a milestone in the development of small irrigation in mid Hills. These ponds receive water from local springs, and the storage increases climate resilience. However, they are small and thus depend on complementary activities to diversify crops to high-value varieties on small areas. They are also vulnerable to springs drying up over the medium to long term, so they need to be integrated into programs for watershed management to improve land cover, maintain soil moisture, and facilitate aquifer recharge.

Micro-irrigation (particularly drip), combined with small-scale storage is a valuable development for high-value crops, particularly horticulture. It still depends on a reliable source of water, but it enables farmers to gain a good income from smaller areas of land and less water than is the case with traditional field crops. It is usually combined with small tanks, ponds on lift systems (including treadle and rower pumps as well as slightly larger tubewells and innovations such as solar lift systems and hydraulic rams). Systems dependent on groundwater are generally more resilient than surface systems but these are only common in the tarai.

Traditional irrigation is inefficient at a system level, with leaky earth canals. However, adjacent farmers are often able to tap some of the losses, so some measures – such as canal lining - to increase efficiency may have adverse impacts. Such activities need to be combined with programmes to increase productivity of water (such as diversification into vegetable crops on smaller areas) so that farmers are able to get an adequate livelihood without consuming more water. The distinction between abstraction and consumption of water is important in this context.

The term non-conventional irrigation technology (NCIT) is now used in Nepal to cover all irrigation technologies part from traditional surface irrigation. These are more resilient than conventional open canals, if farmers use them to divert less water from the source. The NAPA has stressed scaling up of the NCIT options to minimize the likely impact of climate change in food production, but this must be done in the context of water use at watershed level.

There have been several studies on small-scale and non-conventional irrigation recently. Sijapati (2013) recommended small-scale storage as a simple technology which marginal farmers could adopt and implement quickly at relatively low cost. Sugden et al (2014), however, highlight that while small-scale storage may be crucial from a livelihoods perspective, it is unlikely to have a significant impact on water balance at a basin or sub-basin scale. They stressed the need for integrated watershed management with initiatives to improve land cover, and maintain soil moisture, and facilitate aquifer recharge. IWMI (2015) came to a similar conclusion in relation multiple water use systems (MUS). These were found to be generally more sustainable than single-use domestic water supply systems in Nepal, but they are only resilient if there are no conflicting demands on the sources. Such systems should be based on a Water User Master Plan at sub basin or watershed level.

A National Seminar on Small Scale Irrigation (Dixit et al 2013) also highlighted the risks of climate change as well as urbanization and other change processes which are threatening local

food security and livelihoods. Finally, Selvaraju (2014) suggested that resource conservation is pivotal to promote adaptation and resilience in agriculture. This includes rainwater harvesting and soil moisture conservation; improvement of degraded land; protection from riverbank cutting and inundation; slope stabilization and management; conservation of biodiversity and traditional crops; promotion of conservation agriculture in rice–wheat systems, improved crops and cropping systems, multi-storey cropping and agroforestry systems; sustainable use of forest resources through community forest user groups; and alternative energy sources for households. Improved small scale and no-conventional irrigation can play an important role in this context.

		total Population	FMIS (Surface)				AMIS Surface	Total Surface	Groundwater			Non-conv- entional	TOTAL
			new	rehab	non- assisted	total FMIS			STW	DTW	Total		
<i>Tarai</i>	East	3,558,881	6,881	43,861	69,625	120,367	4,240	124,607	89,113	1,250	90,363	2,017	216,987
	Central	4,320,799	6,162	50,580	58,595	115,337	1,700	117,037	77,924	5,656	83,580	1,854	202,471
	West	1,924,453	543	23,904	43,069	67,516	2,530	70,046	23,791	23,669	47,460	323	117,829
	Mid-west	1,350,671	192	28,538	15,425	44,155	4,795	48,950	18,856	4,655	23,511	760	73,221
	Far west	1,110,777	103	14,448	17,958	32,509	1,500	34,009	29,643	2,870	32,513	735	67,257
	Total		12,265,581	13,881	161,331	204,672	379,884	14,765	394,649	239,327	38,100	277,427	5,689
Hills	East	1,622,297	8,065	14,179	22,184	44,428	630	45,058	674	-	674	2,748	48,480
	Central	3,987,273	9,099	21,591	13,563	44,253	6,337	50,590	57	-	57	1,083	51,730
	West	2,802,158	1,185	25,625	7,046	33,856	4,490	38,346	1	-	1	1,960	40,307
	Mid-west	1,580,260	739	10,877	11,506	23,122	727	23,849	-	-	-	284	24,133
	Far west	830,573	170	8,172	1,653	9,995	1,869	11,864	-	-	-	260	12,124
	Total		10,822,561	19,258	80,444	55,952	155,654	14,053	169,707	732	76,200	732	6,335
Mountain	East	396,838	1,857	4,308	11,116	17,281		17,281				696	17,977
	Central	536,236	3,500	4,892	6,055	14,447	175	14,622				216	14,838
	West	22,279	55	1,363	263	1,681	51	1,732				2	1,734
	Mid-west	348,899	77	3,415	2,527	6,019	-	6,019				45	6,064
	Far west	430,574	22	3,982	3,763	7,767	1,634	9,401				28	9,429
	Total		1,734,826	5,511	17,960	23,724	47,195	1,634	49,055				987
Total			38,650	259,735	284,348	582,733	30,452	613,411	240,058	114,100	278,158	13,011	904,580

Source: CERD (2007)

4 Institutions

4.1 Government Organisations

4.1.1 Overall structure

The major government institution currently involved in the water resources and irrigation sector is the Ministry of Irrigation (MOI), which is responsible for the utilization and management of water resources. It prepares plans and policies and their implementation regarding irrigation development. The MOI includes the Department of Water Induced Disaster Prevention (DWIDP) and the Department of Irrigation (DOI).

Other institutions with direct links to the irrigation sector are:

- DOLIDAR of Ministry of Federal Affairs and Local Development also looks after the construction and rehabilitation of small schemes less than 10 hectares
- Water and Energy Commission Secretariat (WECS): is a Government consultative body;
- Department of Hydrology and Meteorology of the Ministry of Environment.
- Ministry of Agriculture Development (MOAD): responsible for the formulation and implementation of agricultural development policies and plans, agricultural research, training of farmers, transfer of modern technology, and activities to develop youth and women farmers;
- National Planning Commission (NPC): prepares plans for all sectors including irrigation;
- Ministry of Finance for allocation of financial resources
- Agriculture Development Bank of Nepal (ADB/N): provides concessional loans and channels government subsidies for rural projects; and the

The institutional arrangements for small and medium irrigation are relatively straightforward with few complex linkages. DOI under MOI is the key organisation, but this needs to collaborate particularly with DOA in relation to agricultural support services. The size of these projects is such that they are implemented and managed at divisional level. However, such projects are almost entirely FMIS so the role of DOI is limited and focused on rehabilitation and critical aspects of maintenance: it does not have a permanent or continuous role.

4.1.2 Constitutional Reform

A new constitution was promulgated in 2015 which will change institutional arrangements significantly. This has made provision for a federal government system with a three-tiered administrative system

- Federal Government at the centre,
- Seven Provincial Governments, and
- Local Government bodies comprising 719 villages or municipalities, which will be rather larger than existing VDCs; the districts will retain a coordinating role⁹

⁹ The boundary of local government is still to be confirmed.

There are many issues around management of water resources at a whole which will need clarification and, as Shrestha (2010) suggests, federalism will have many impacts on water resource management – particularly in relation to large-scale hydropower and water storage. There may be many trans-provincial boundary issues, concerns over sharing of benefits and impacts, and so on – in addition to the long-standing and largely unresolved international transboundary issues. However, these should have little impact on small and medium scale irrigation which will be essentially a provincial and local level concern.

The Government is now formulating a new Federal Integrated Water Resources Policy and modernizing the Water Act, and deciding on restructuring in terms of organizational structure, human resources, financial systems and inter-linkages. A draft policy has been prepared with both the policy and water act expected to be approved by mid-2017. A taskforce has prepared a functional analysis of the existing organizations in water sector, and the plan for administrative restructuring is also likely to be complete by mid-2017.

The current and proposed sharing of responsibility is tabulated below.

Table 6: Responsibilities for Irrigation

Existing Structure / Responsibilities

Level	Irrigation Development	Irrigation Management
Central	All projects (development and management) funded by the government (AMIS and FMIS) is the responsibility of centre (small irrigation is under DOLIDAR and all other projects are under DOI).	
Region	Regional offices (both DOI and DOLIDAR) only have financial authority and execute projects on behalf of the central government	
District	DDC - All projects funded by district funds	WUA
VDC	VDC - All projects funded by VDC funds	WUA
Community	WUA – self-financed FMIS	WUA Lower part of joint managed AMIS, All AMIS transferred to WUA, All FMIS

Future Structure (After new constitution)

Level	Irrigation Development	Irrigation Management
Federal	(a) All major projects covering more than one province (b) All projects funded by donors (IWRMP, CMIASP etc)	None – responsibility for management transferred to province concurrently with local level governments
Province	All projects (other than donor funded) within the provinces (examples are Medium irrigation projects, all O&M projects, all central level projects funded by government like Sikta, Mahakali III, Babai, etc	O&M of all AMIS (except components handed over to WUAs)
(District Coordination Office)	Still vague. In the short term probably similar to present day DDC operation	WUA
Village (group of VDCs?)	Unclear, similar to present but with villages operating at a slightly higher level	WUA
Community	Same as present	Same as present

If the new constitution is implemented fully, most of the present day role of the government on irrigation development and management will be shifted to provincial government. The federal government role will be limited to policy, regulation and monitoring, as well donor-funded projects. DOI at central level will have a very small role, and some question whether it will need to exist as its functions could be transferred to a wing of the Ministry.

At a local level, and particularly for small and medium irrigation arrangements will be simplified as there will be a single body in place of Districts and VDCs, although the Districts are expected to retain some role in the short term due to limited capacity at lower levels. Role of WUA will remain the same.

4.1.3 Principal Departments involved in Irrigation

4.1.3.1 Department of Irrigation (DOI)

The Department of Irrigation (DOI) was established in 1952 and remains the principal government institution responsible for the planning, design, development and management of irrigation. The DOI now has 2,148 staff across the country (DOI, 2016). It has undergone organizational reforms several times since 1952, and presently has following four divisions each of which is headed by Deputy Director General.

- Programme, Monitoring and Evaluation Division (PMED)
- Planning Division (PD)
- Surface Irrigation and Machinery Management Division (SIMMD)
- Irrigation Management Division (IMD), and
- Ground Water Division (GWD).

DOI has a network of offices throughout the country. It has five regional irrigation directorates (RID), located in Biratnagar, Kathmandu, Pokhara, Nepalgunj, and Dhangadi, with a mandate to oversee the division and sub-division offices in the respective region. There are a total of 57 irrigation development division offices and 20 subdivision offices. In addition to reporting to the respective RID, these are also linked directly to the project coordinators' offices in SSIMMD in Kathmandu for donor-funded sector projects

There is also an Irrigation Management Division in Chitwan, with a similar role to the RIDs but focused solely on (surface) irrigation management rather than development. This supervises the management of existing agency and joint-managed irrigation systems, through 13 irrigation management divisions or sub-divisions. This differs from the role of IMD Kathmandu which has a high level role for policy, planning, and programming. The distinction between irrigation development and management divisions can have an impact at a local level, as was found in Banganga (see Section 5.2.2).

Groundwater Irrigation is supervised by the Underground Water Irrigation Directorate, Chitwan which has 11 field offices, known as Underground Water Irrigation Development Divisions (UWIDD), which look after development and management of underground water for irrigation. In the same way as for surface water GWD in Kathmandu again focuses on policy, planning and programming, and there is also ground water development board (GWDB)

A Social Environmental and Climate Change Section (SECCS) was established under SIMMD in 2014 but then sub-divided in 2015 into a gender/social section under SIMMD and an environment and climate change section under PMED. These sections are responsible for social safeguards, environmental and climate change aspects of irrigation development.

4.1.3.2 Department of Hydrology and Meteorology

The Department of Hydrology and Meteorology (DHM) is located under the Ministry of Environment and has been collecting hydrological and meteorological data since 1962. There are three river basin offices: Karnali (Nepalgunj), Narayani (Narayanghat) and Kosi (Biratnagar), and three regional meteorological offices (Surkhet, Pokhara and Dharan). DHM has a mandate to monitor all hydrological and meteorological activities in Nepal, including river hydrology, climate, agro-meteorology, sediment, air quality, water quality, limnology, snow hydrology, glaciology, and wind and solar energy.

As a member of the World Meteorological Organisation (WMO), DHM contributes to the global exchange of meteorological data and is a focal point for the Intergovernmental Panel on Climate Change (IPCC).

4.1.3.3 Department of Agriculture

The Department of Agriculture under the Ministry of Agriculture Development (MOAD) aims to contribute to food security and poverty alleviation through diversification and commercialization of agriculture with objectives to:

- increase agricultural production and support food security
- increase the production of raw material for agro-industry
- support production with comparative market advantage
- increase availability of off-farm employment by supporting small industries and enterprises.
- support export promotion and import substitution of agriculture.
- alleviate poverty through employment opportunities for small, marginal and women farmers.

4.1.3.4 Department of Local Infrastructure Development and Agricultural Roads (DOLIDAR)

DOLIDAR was established with the objective of planning and undertaking infrastructure development in accordance with decentralization policies, and making the local authorities (DDC/VDC) technically capable and ensuring their accountable participation. It works in co-ordination with the concerned line departments (such as the Department of Irrigation, Roads, Rural Water Supply, Agriculture) and in accordance with national policies and guidelines.

4.1.3.5 Department of Soil Conservation and Watershed Management (DSCWM)

The Department of Soil Conservation and Watershed Management (DSCWM) was established in 1974 under the Ministry of Forests. The department has two divisions namely the watershed management division and technology development & extension division. It provides soil conservation and watershed management services to 73 out of the 75 districts through 56 District Soil Conservation Offices and 640 staff. It implements several land and watershed management programs / projects, which may also include a component of small irrigation.

4.2 Irrigation development plans and policies

Irrigation is the most prominent water use sector in Nepal, and affects the lives of the many people involved in agriculture. It is important for maintaining food security and crop diversity, and is by far the largest sector in terms of consumptive use of water. Given the importance of irrigation and the large investment required, the efficiency and effectiveness of water delivery is of primary concern. The vision for the sector is to provide sustainable and year-round irrigation service to all the agricultural land and to help increase agricultural productivity.

The Water Resources Strategy, 2002 set the following targets for 2027:

- Provide irrigation services to 90% of irrigable lands;
- Increase cropping intensity to over 250 percent;
- Increase irrigation system efficiency of large surface irrigation schemes to 60 percent;
- Establish and strengthen WUAs to manage irrigation on 5,000 ha;
- Provide year-round irrigation to two thirds of irrigated areas;

Some of the key policy principles to be adopted were:

- Participatory and demand-driven approach of irrigation development
- Delivery of year-round irrigation services
- Sustainable financial arrangements
- Focus on service delivery rather than provision of infrastructure
- Implement the concept of river basin planning and management
- Encourage farmers to consolidate land to maximise irrigation and agricultural efficiency.

However, although the strategy and subsequent National Water Plan still prevail, these are hardly implemented in a systematic manner and they appear to be very optimistic targets given the constraints of water resources. As a result, they are not effective any more, and their outcomes have not been analysed. It is not clear to what extent they would be achievable even without considering climate change, and there are many constraints.

The first irrigation policy was issued in 1992 and focused on rehabilitation and improvement of existing irrigation systems with short gestation period, mostly FMISs. This was a change from the previous focus on construction of new irrigation systems giving very little attention on their management. The policy has been revised four times, most recently in 2013 (BS 2070). Participatory development and management has been a cornerstone of these policies, both for farmer and government-managed systems. These policies also recognized the need to account for environmental considerations and for conjunctive use of ground and surface water. The 2003 policy introduced an emphasis on perennial irrigation and on decentralization. This led to a greater role for local bodies (VDCs and DDCs) in the development and management of small irrigation systems. As a result of this policy provision, DOLIDAR is now implementing small scale surface irrigation development programs.

The 2013 irrigation policy recognized the need to consider the anticipated impact of climate change in the design and management of irrigation system through the introduction of appropriate adaptation and mitigation measures. It lists climate change as one of the threats to irrigation development in the future and states the need for resilience through a *“Study of adverse effect caused by population increase, immigration, climate change, and water induced disaster to the water sources and their use in irrigation and implementation of suitable resilience programmes.”*

According to the policy, the responsibility for management, maintenance and operation and rehabilitation of small and medium-scale irrigation system should be given to the Water Users’ Associations (WUAs). The Department of Irrigation shall provide technical assistance to local bodies as required, but with close inter-agency corporation between *“the district, regional and national level offices of Department of Irrigation (DOI), Department of Agriculture (DOA), and Department of Local Infrastructure Development and Agricultural Roads (DOLIDAR) to integrate irrigation development, expansion and management programme with agriculture programme starting from identification and selection activities to implementation, monitoring and evaluation activities of the project.”*

4.3 Water Users' Associations

All effective irrigation requires some form of organization to take on management responsibilities. Even small-scale irrigation is complex to manage and expensive to maintain, and the critical value of water for agriculture means that access is often contested. Traditionally, there were a wide range of informal arrangements, but since the formulation of the irrigation policy and more standardized form of Water Users' Association has been developed. These are legal entities, able to open bank accounts and manage finances as well as access Government assistance.

WUAs have been formed entirely anew on most agency-managed systems, with varying degrees of success, but have generally built on traditional arrangements on FMIS. In practice, the traditional arrangements may remain dominant even after formation of a WUA, but they may lack the skills or resources for maintaining complex modern structures – particularly if separate schemes are combined or sophisticated headworks built. Traditional irrigation was rarely democratic or equitable and attempts to change this through formalization of WUAs are not often effective.

Village Development Committees (VDCs) are often involved directly or indirectly in management of FMIS and have greater legal powers than WUAs. Their formal role changed with the enactment of the Local Self-Governance Act, but this was not fully implemented since the local bodies were dissolved in 2002 and no election will occur before 2017.

WUAs, or equivalent traditional arrangements, are likely to remain the key organizations for management and resilience of small and medium irrigation. In the medium term the new local bodies may take on a greater role, particularly as they are larger and irrigation systems are more likely to fall within the purview of a single entity which is important for ensuring coherent management. However, improved arrangements for coordination across the entire sub-basin will be essential and this is likely to rely mainly on cooperation between WUAs.

5 Lessons from Case Studies

5.1 Reconnaissance Studies

5.1.1 Location

The characteristics of the systems visited are presented in Table 7 with further details in Appendix C, including perceptions of the main categories of climatic and non-climatic changes and a vulnerability assessment. In general, non-climatic threats – such as population growth, changes in the rural economy, off-farm employment, migration, poor irrigation management, upstream land and water use changes, and urbanisation – are regarded as greater challenges. However, measures to build resilience will take account of all of these threats.

Table 7: Sites for Reconnaissance Studies

System	District	latest intervention	Area (ha)	Institution	Intake	Zone	Crop
Nepane	Sindhuli	1998	210	weak	Temporary	Hill	Cereal
Kauchhe	Sindhuli	none	24	Good / informal	Temporary	Hill	300% mixed, mostly cereal
Bardautaar	Sindhuli	before 1997	70	Good	Temporary	Hill	Predominantly cereal
Chandadevi	Sindhuli		25		Permanent	Hill	Mixed (300%), esp. ginger
Gadkhar	Nuwakot	2014	105	weak	Permanent	Hill	mixed (300%)
Ratanpur	Rupandehi		400	new/weak	DTW	tarai	cereal (150%), cash (60%)
Belwaha	Rupandehi	2000	25	new/good	STW	tarai	vegetable (180%) cereal (10%)
Lausi Khola	Rupandehi	2000	400	weak	Permanent	tarai	cereal (145%), cash (50%)
Char Tapah	Rupandehi	2010	1,200	strong	Permanent	tarai	cereal (170%), cash 35%
Singhi Ghat	Kapilvastu	2005	2,500	strong	Permanent (11 newly-linked systems)	tarai	cereal (155%), cash (30%)
Mahendrakot	Kapilvastu	2001	430	OK	Permanent	tarai	cereal (155%), cash (45%)
Girwari (6 systems of which Julphe is one)	Nawalparasi	2003	1,000 (total, of which 200ha in Julphe)	strong	Temporary	tarai	cereal (128%, 70%)
Tanting	Jhapa	2010	200	OK	Permanent plus temporary diversion	tarai	maize, rice, mustard, wheat, with some cash crops (betel)
Biring (4 systems)	Jhapa	ongoing repairs	1000	strong	Temporary	tarai	maize, wheat, mustard, betel

Source: This study

5.1.2 Types of Irrigation

Medium/Large Rivers in Hills – valley bottom irrigation

These are typified by the Nepane and Kauchhe systems which take water from the Kamala river as it flows through a wide gravel flood plain, to irrigate adjacent terraces (Figure 6). These are very vulnerable to changes in the river course as it is not possible to build permanent weirs and offtakes in such large rivers/floodplains. In addition, floods can destroy temporary intakes at a time when it is not easy to repair them. They have an inherent vulnerability, and traditionally rely

on heavy manual maintenance for construction of temporary weirs and approach channels. Climate change is a relatively small but significant additional threat.

Figure 6: Nepane Irrigation Intake



Figure 7: Bardeutar Irrigation System



Small/Medium Rivers in Hills – hill terrace irrigation

These are typified by the Gadkhar system in Nuwakot, a relatively large system, and the much smaller Bardeutar (Figure 7) and Chandadevi in Sindhuli. These face problems of low flows in the dry season – which is exacerbated by low rainfall due to climate change. A more serious problem can be landslides which can destroy canals or cause major maintenance needs. Intense rainfall increases the risk, which was made worse by major earthquakes in April and May 2015. Strong institutional arrangements and good participation can help reduce the risks and make the systems resilient under both present and future climate.

Tarai – Rivers emerging from Churia

This is the largest single group of irrigation systems. These can be subdivided into: the smaller rivers which can be provided with permanent weirs and intakes; and those which are in large river valleys and cannot be economically provided with permanent structures.

Char Tapaha, Mahendrakot and Singeghat (Figure 8) fall into the first category and have good infrastructure. This is not sufficient as they also require strong management. In many cases several smaller traditional systems are combined and supplied from a single weir. This disrupts traditional management arrangements, which need to be adapted. Climate or other changes can provide the stimulus to make the necessary management changes, but in other cases management remains weak.

Girwari (5 systems – Figure 9), Tanting and Biring (4 systems) fall into the second category. They draw water from very wide rivers through floodplains in the boulder phase and face very similar to the problems for valley irrigation described above. They are even more vulnerable as the rivers are very flashy and very wide. Tanting is fortunate in have a secondary source which is smaller but sufficient for the monsoon season. As they are already vulnerable and difficult to manage, there is a trend towards combining them and making better intake arrangements – however these are still vulnerable. The quest for greater reliability needs to be balanced against the risk of more systems being dependent on a single imperfect intake, plus the risk of traditional management being disrupted. Coordinated management of multiple systems along a single river is thus a critical challenge and one which climate change is bringing to the fore.

Figure 8: Singheghat Main Canal**Figure 9: Julphe Canal Intake****Tarai – small rivers further downstream, relying on return flows**

These are very vulnerable and in many cases have diversified to the extent that there is little interest in maintaining them. One example is the Lausi khola, which depends entirely on drainage water from upstream systems and rainfall – there is no natural catchment. However, groundwater provides an alternative and more reliable albeit more expensive source for these. Farmers in the Lausi khola system can now benefit from urbanisation in the Butwal Bhairahawa corridor, and those who wish to continue farming can tap groundwater. Although good infrastructure has been provided, there is little local interest in managing this and the system is not at all resilient even before consideration of climate change

Tarai – ground water irrigation

There is no significant impact of climate change on groundwater resources, and given the low percentage abstraction this is reasonable. Changes in temperature will affect crop water requirements but the change is too small to be observable so far. Groundwater irrigation is only viable if it is used for high value crops rather than traditional cereal crops, and these can be selected to suit the current climate. Crop change is driven by economics rather than climate, and this is true for both deep and shallow groundwater.

5.1.3 Climate

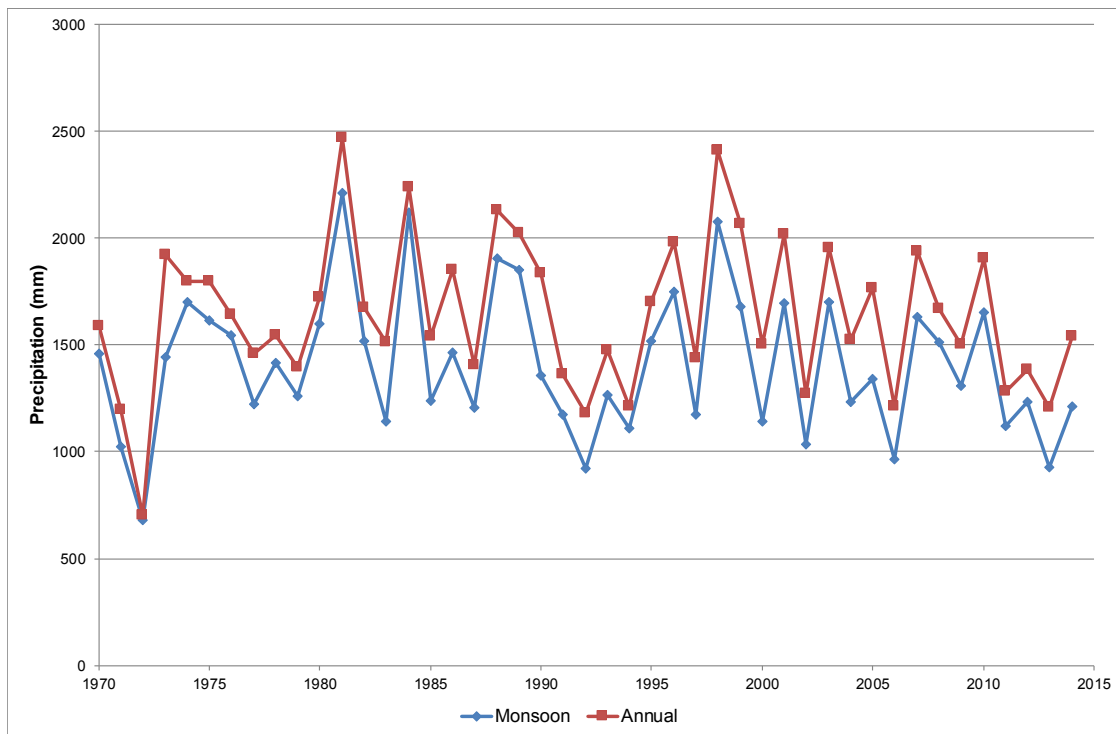
The project watersheds and basins in this study cover the Biring khola, Gadyauli watershed, Kamala River Basin, Likhu Khola Basin, Girwari Khola Basin and Banganga River Basin. To assess climate trends in temperature and precipitation in the project areas, data was analysed from the nearest DHM stations within the vicinity. For temperature, Kathmandu, Okhaldhunga, Simara, Janakpur and Bhairahawa show increasing trends in maximum temperature during the period 1976-2014.

Except the records of Sindhulgadi, which had statistically significant decrease in annual and monsoon precipitation, none of the trends are significant. Furthermore, Sindhulgadi, Bhairahawa and Patharkot stations show decreasing tendencies of precipitation whereas the other three stations show increasing precipitation. In terms of daily extreme precipitation, none of the daily precipitation as well as dry season precipitation indicated a statistically significant trend. Three stations (Kathmandu, Beluwa-Girwari and Patharkot) indicated increased annual extreme of daily precipitation and the other three indicated decreases (Sindhulgadi, Tulsi and Bhairahawa). Four stations (Kathmandu, Bhairahawa, Beluwa-Girwari and Patharkot) had increasing trends of dry season precipitation.

Trends in precipitation threshold indicate decreasing number of days with low precipitation (≤ 1 mm). Precipitation greater than 50mm in a day and precipitation greater than 100 mm in a day were increasing in all cases but one (Bhairahawa). It demonstrates the increasing variability of rainfall with time on long-term basis. None of the trends are statistically significant.

Data on these catchments are presented in Appendix A.

Figure 10: Rainfall in Bhairahawa



Source: DHM data

5.2 Detailed Studies

5.2.1 Girwari khola, Nawalparasi

Background

Irrigation in this area dates back about 100 years and was initiated by zamindars who could mobilize their tenants to maintain the system. Water rights were linked to land, and paddy was the only crop grown. The cultivated area remained low until rapid migration from the Hills started in the 1960s, when much was cleared and cropped. There are now five separate but adjacent systems irrigating about 1,000 ha on the left bank of the Girwari khola after it emerges from the Hills and as far as the East west highway (plus one small one on the right bank). A further 10 systems irrigate the southern part of the sub-basin as far as the confluence with the Narayani river, as shown on the map below. The upper five systems abstract all surface water from the river at critical times, but water re-emerges 5-10km further downstream and can be abstracted to irrigate the southern area. The catchment upstream of the irrigation systems is about 50 km², with only small areas of cultivation. The total cultivable area downstream of the intakes is about 2,000 ha (20 km²) and thus a shortage of surface water is inevitable in the dry season.

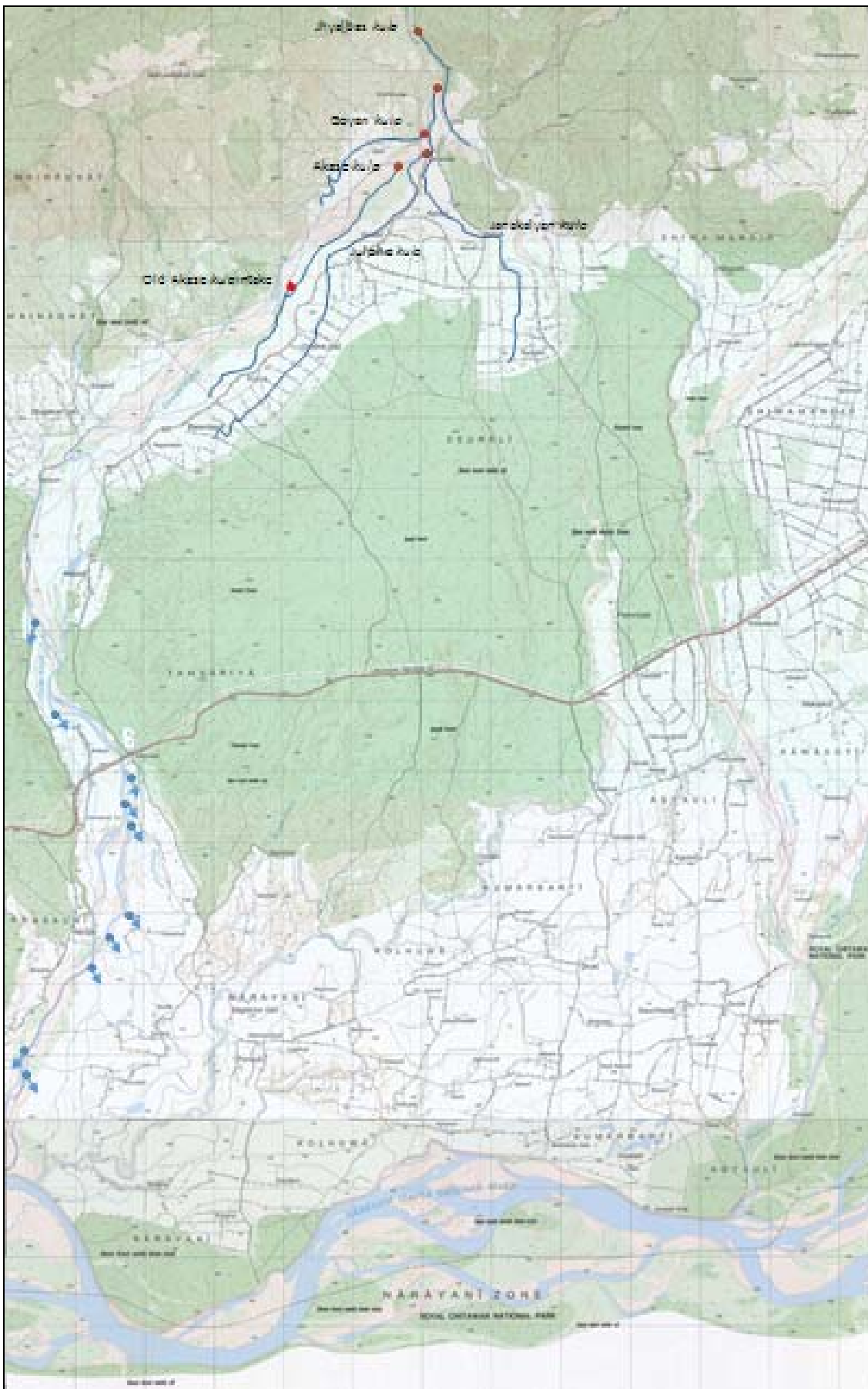
These six systems are separate but still interdependent and require a degree of cooperation in management. The southernmost intake (for Akase kulo) has gradually been moved northwards because of problems with diverting water from the wide river bed, until it is almost at the same location as the Julphe kulo; there is now ongoing discussion about formally combining the two systems which already share water during the dry season.

The Julphe kulo is the largest system and is the focus of this study, but relations between systems and overall management of the sub-basin are increasingly important because of the growing demands for, and declining supply of, water. Since the 1970s, cultivation has become increasingly intense, reaching up to 300% in places with water being a major constraint. A lack of surface water can be offset by using groundwater although the depth to the water table is quite great in this northern area, making pumping difficult and expensive.

The system was rehabilitated in the 1970s, extending the Julphe systems so there are now three command areas (Julphe, Koliya and Basantapur) which receive proportionate shares of the main canal flow. These function as independent sub-systems with their own organizational and institutional arrangements, and water rights are no longer linked to land area. These water rights are now unequal in comparison to land area and this makes it difficult to formalise the water-sharing arrangements with the Akase kulo.

There have been several studies of this catchment focusing on irrigation and on the impact of climate change (eg Duncan and Budathoki, nd). Found that water resources are declining and hence identified a need for improved agricultural practices. However, they also identified that the reduction was due to changes in upstream land use practices rather than in rainfall.





Climate data

The Beluwa meteorological station is located close to Julphe and has data extending back to 1958. Although a straight line regression shows a slight (but significant) increasing trend this is very small compared to the annual variation. Extreme daily rainfall is also highly variable and has also not changed significantly over this period, nor the number of days with more than 10mm rainfall. By contrast local perceptions are that rainfall is decreasing significantly – this may be a consequence of a marked decline since 2001 and four increasingly dry years from 2012 to 2015, with the rainfall in 2015 being barely half of the long term average. The timing of rainfall was also adverse in these years, with prolonged dry periods in the critical month of September. 2016 has been a much wetter year, but this has included several unusually intense events which caused flood damage to irrigation infrastructure rather than alleviate water shortages for crops.

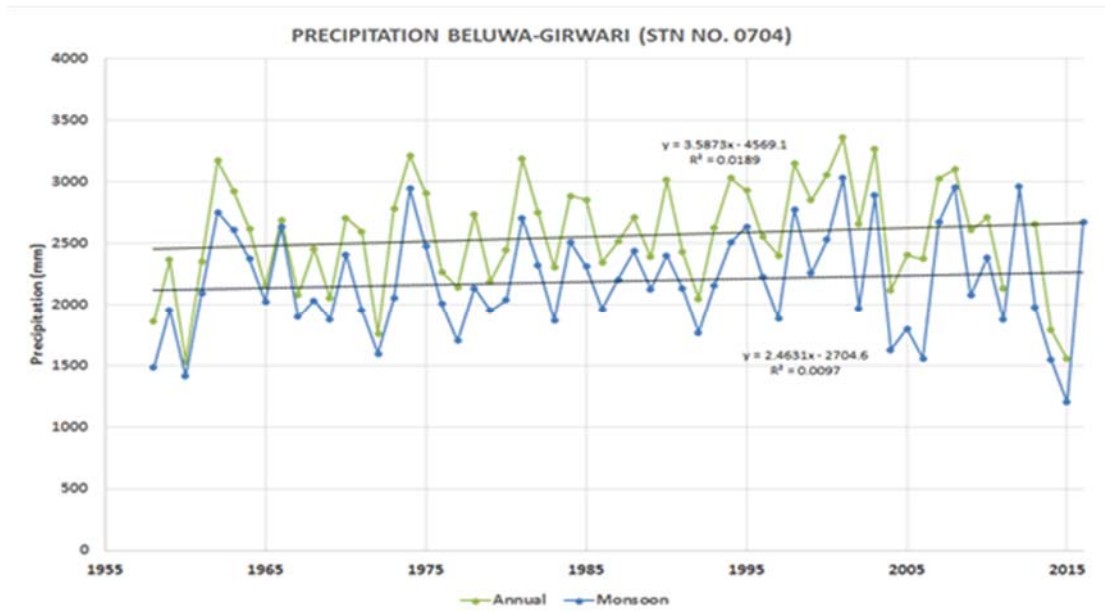
System management

The six systems are operated independently but various coordination arrangements have been set up, especially for the spring season resulting in each system receiving water in turn with about a 10-day cycle, and then with a further rotation with the system. During the monsoon systems can be operated continuously, with ad hoc arrangements at times of intermittent rainfall. As irrigation is supplementary to rainfall, such dry periods both create additional demands and reduce the availability in the river.

Water supply appears to be decreasing, although this is based on very limited data. The minimum flow recorded in April/May 1982 was 310 l/sec (East Consult, 1982), whereas a flow of 90 l/sec was observed in April 2016. The natural minimum river flow is estimated to be 400 l/sec at the intake to the first system, whereas the minimum measure was 90 l/sec meaning that almost 80% of the potential runoff was used in the upper catchment. The corresponding for upstream water use in 1980 would have been just 20%

Floods also appear to be increasing, with intense rainfall recorded in 22 July, 26 August and 1st September, 2016. These cause high sediment inflows to the canals, and also washed out the weir which supplied water to the Akase kulo. However, such damage is not only related to flood flows: there is extensive quarrying of construction materials in the river bed which has significantly lowered the bed making it difficult to raise the water level and divert water. The river has a cobble bed about 50 – 200 m wide with very erodible banks: measures to divert water attract the flows to the bank and can cause bank erosion which exacerbates the flood damage problem. Such quarrying is locally recognised to cause significant problems, but is an important source of revenue for the DDC. Much of the quarrying is believed to be illicit and there is no data on the quantities removed.

Figure 11: Rainfall trends in Girwari



Source: DHM Data

Figure 12: Small-scale quarrying in river



Figure 13: Large quarry



Irrigation Management

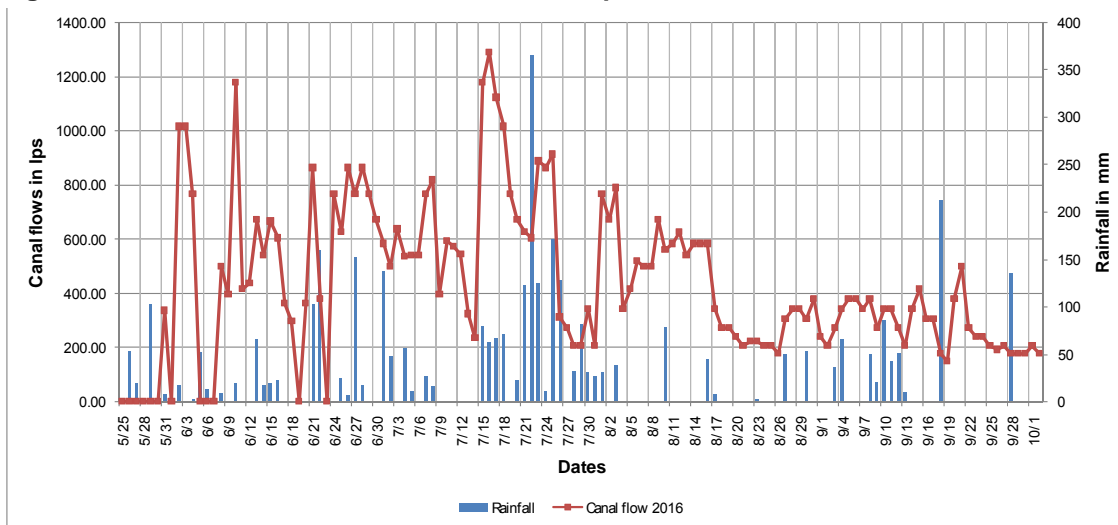
The three sub-systems of Julphe operate continuously during the monsoon and winter seasons, but only the head (Julphe sub-system) operates during the spring season, as seepage losses from the smaller dry season flows would be too great to deliver sufficient water to the tail. Within these constraints distribution to the tertiary canals appears to be equitable, and the management arrangements have not changed in the last decade.

At lower levels of the system, management has been improved recently to formalise a rotational schedule for transplanting since the previous *ad hoc* arrangements had led to increasing conflict. During the crop growth stages much of the water to most fields in some areas comes from runoff and seepage from upper areas. Such reuse is reported to have declined because of

construction of roads which divert drainage water and due to improvement of the canal networks which reduces seepage losses. Other areas are unable to tap drainage water and rely entirely on the canals system; in these places canals are operated to deliver water on a uniform basis according to area. In addition, some tube wells have been installed – six were dug in 2011 but only four are operational and each irrigated 10-12 ha so most land relies entirely on the canal system plus direct rainfall.

The decrease in river flow is primarily due to changes in land use in the upstream, as indicated above although there will be other factors which have had a smaller effect. Figure 7 and 8 present relationships between rainfall in the respective command areas and flows in their main canals.

Figure 14: Rainfall and canal flow at head of Julphe

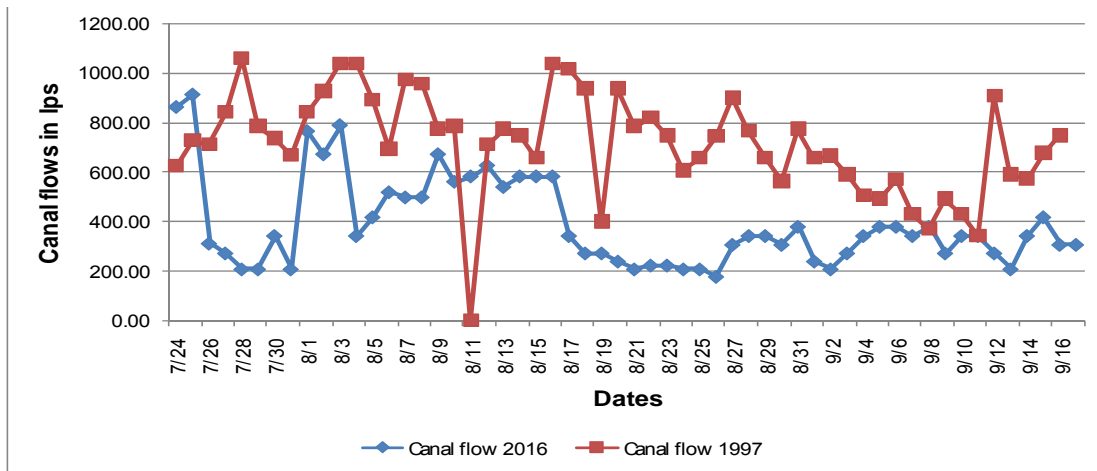


Source: This study

Main canal flows were measured upstream of the main (or first) proportioning weir at the end of feeder (or main) canal and at several locations further downstream. It can be seen that there is a close relationship between rainfall and canal flows (with canal flows rising as it rains, rather than being curtailed due to less demand).

- Rapid decrease in the main canal flows from 9th to 15th July, 17-26th August, and 19-29th September as a result of dry spells in those periods
- Almost continuous rainfalls between 15th July and 2nd August resulted in larger canal flows in that period, but these also decreased rapidly due to flood damage at the intake

Canal flows measured during the field study in 2016 at the three proportioning weirs were compared with flows measured in 1997 at the same locations (one shown in Figure E, others in Appendix D). Over the season the flow is about half that recorded in 1997 – but this is consistent down the main canal suggesting that management remains strong, and that farmers have been able to cope with the deteriorating situation.

Figure 15: Canal flow at Julphe upstream of main proportioning weir

Local perceptions

The population is predominantly Magar (48%) with a sizeable minority of Brahmin and Chettri (34%), with 11% Dalit and 8% others. Overall, 85% of household income is reported to be from agriculture (95% in the head and 75% in the tail), with balance from local non-farm activities and from migration/remittances in roughly equal proportions.

There is a general consensus that it has got hotter particularly in the monsoon. There is also a weak perception that extreme cold has increased due a reduction of winter fog. Perceptions are slightly stronger amongst poorer farmers. Rainfall is strongly believed to be less, more erratic and delayed – particularly in the monsoon This perception is influenced by recent exceptionally dry years as much as any long-term trend. River flow is seen to be getting less, and the new infrastructure only partly alleviates the impact of this. Better infrastructure however enables better control of water and more reliable rotations during times of shortage. Groundwater development helps some farmers but only about 5% are able to access this.

Monsoon rice used to be the main crop, but the area has gone down due to urbanisation and house building. Improved varieties have enabled better yields but this is offset in dry years if the monsoon is delayed. The irrigation system only provides partial protection against a late monsoon as river flows only rise after the rains start (and subject to upstream abstractions and water use which also peaks at this time). Spring rice is entirely dependent on irrigation and is not widely grown.

Wheat has declined, partly due to unreliable winter rainfall and temperature changes, but mainly due to economic factors which make potato preferable (subject to labour availability and timing of rice harvest). Potato has increased markedly in importance due to good markets, but maize has declined apart from among richer farmers with good access to water. Oilseeds and summer vegetables are less important than in the past, although there is less change in winter vegetables and pulses. Availability of new short-maturing varieties, labour shortages and market conditions are seen as the primary determinants of changes in crop choice and productivity.

Livestock are kept for commercial reasons (mainly for milk) rather than for draught power, and thus numbers have declined. Remittances and off-farm local have increased from almost zero but are still less than 20%.



Climate resilience

The Girwari systems have been adapting to change over the past 50 years, largely because of the strong institutional arrangements supported to by limited investment in infrastructure. However, they are increasingly water-stressed and riverbed quarries are making it more difficult to abstract the limited water from the river. The cost of permanent solutions would make them uneconomic, but some improvements to infrastructure may be possible and necessary. Water rights are not uniform, and must be carefully considered when planning any changes to the system.

The resilience of the Girwari systems at present can be summarised in terms of the infrastructure, the rules governing its management, and the individuals and organisations involved. In general, they can be assessed as resilient and not threatened by climate change, but this is partly because of diversification of livelihoods and those who rely mainly on agriculture are most vulnerable. There are many concurrent changes which are more significant than climate change: it is the ability to respond to these changes which is determining resilience to climate change.

Systems (infrastructure)

The infrastructure has been developed incrementally over the past 50 years in response to changes in the needs of the farmers and the environment they are operating in. Intensification of agricultural land use has affected both resources and demands for water, stimulating improved methods for capturing and distributing water. It has never been possible to mitigate fully the effects of variable climate, and exceptional droughts or floods have had some adverse impacts. The system was a traditional farmer-built system so there were no formal design parameters, but it has performed satisfactorily in this context.

The most critical threat that the system now faces is due to flood damage to the Akase kulo intake. This was caused by two very severe rainfall events in July and September 2016 – the first was very intense (365mm in 24 hours); the second was smaller but more prolonged and did more damage. Storms of such intensity are unusual and are consistent with the predictions for climate change. It should be noted, however, that the damage was much greater than would be expected and farmers less able to cope because of other external factors. Extensive gravel quarrying has lowered the river bed and attacked the banks, making the intakes more vulnerable.

Water shortage is an important issue. Incremental damage to intakes that is characteristic of such traditional systems has made capture of water more difficult. Physical constraints are exacerbated by reduction in labour availability for maintenance of intakes, and more intense land use in the command areas makes it difficult to move intakes upstream to more stable locations. Groundwater development can alleviate some of the shortages, but the cost of development and management in a location where the water table is deep makes this an unaffordable solution for most people.

Institutions (rules)

The development history of the Girwari systems has resulted in strong resilient institutions within the framework that they were planned for, and they have been able to adapt as the situation has changed. Two problems have been serious challenges to their capacity. The first related to the development of a domestic water supply for Tribhuwantar from the same source and which benefited a geographically, ethnically and politically distinct group of people. This led to conflict, which took time to resolve. The second issue is the rapid increase in unregulated gravel extraction from the river bed. Although this may be largely undertaken by people outside the WUA, the construction industry is important in the local economy. This is the primary cause of the damage to the intakes highlighted above and makes the systems more vulnerable to climate change. Better control of quarrying and enforcement of measures to protect the environment is needed and this will require actions at District level.

Agents (individuals, organisations)

Organisations are adapting to cope with the changing situation: informal cooperation between WUAs for individual systems are emerging, leading to measures for water sharing. These changes do not extend to cooperation with upstream farmers in the catchment where land use changes are having an impact on water resources, nor is it easy to envisage how such arrangements might be developed: in practice, irrigation farmers will need to adapt to the declining water resources. They also do not extend control of river bed quarries, where there may be a conflict of interest between those local people who extract materials and those who rely on a stable river bed.

Farmers have adapted their practices substantially over the years, changing from single-cropping of rice to more intense and diverse cropping. Rice is still dominant but new varieties and farming practices have enabled increased production; some of these varieties are better adapted to the climate, but increasing variability in the timing and intensity of monsoon rainfall remains a threat. Sources of information are also more diverse: personal contacts, mass media, private sector providers, and a range of projects all augment formal government extension services. Diversification of livelihoods brings both challenges and opportunities; those who are able to gain off-farm employment are most resilient to change

Modified design criteria, particularly flood and dry season flood estimates.	Arrangements for cooperative management of natural resources, including river bed materials as well as water.	Farmer ability to absorb, adapt, anticipate change, in response to climate uncertainty and other non-climatic changes.
Design of structures and systems to be adaptable as the need changes	Water rights, across the river basin - to avoid causing adverse impacts, and taking account of traditional rights as well as new policy provisions.	Access to knowledge, willingness and resources to adapt or diversify agriculture, and livelihoods more widely.
Flood capacity – exclusion of peak floods, safe escape structures and fuse plugs, protection of vulnerable canal reaches.	Mechanisms for preventing /resolving conflicts.	
Control of water at low flows; impact on improved control other users.	Enhanced ability to raise finance.	
Development of new sources, with conjunctive management.	Markets and subsidies for crops, and support systems for agricultural development.	

5.2.2 Singeghat, Kapilvastu

Background

The Singeghat Irrigation System (SIS) covers the right and left banks of the Banganga River as it emerges from the hills to just south of the East-West Highway. Irrigation dates back centuries, with the areas under the present irrigation system divided into 11 *mauja*, each with an independent canal and water diversion weir at the Banganga River. Irrigation in each *mauja* used to be managed by a water manager (*Badghar*) who was elected or selected each year and was in charge of local public work activities including irrigation and water management.

Each canal used to divert water from the Banganga River independently, but there were rules on how much water each could abstract. During times of water scarcity, the length of weir permitted in the river was proportional to the water right. All the diversion weirs were temporary, made of boulders and brushwood, and were frequently washed away by floods. Each *mauja* had to mobilize huge labour resources¹⁰ for their repeated maintenance. Changing river morphology, and declining availability of labour and brushwood made it increasingly difficult for farmers to build and maintain the weirs.

A joint committee of all 11 canals was formed in 1972 to manage the river water more systematically. This was later registered with the District Water Resource Committee (DWRC)¹¹ and lobbied the government to build a common permanent weir for all 11 canals. This was built in 1999-2006, and included a concrete weir and a new main canal 4.5 km long to feed the old branch canals via six proportional dividers in accordance with their traditional water shares.

The intake to this system is located about 10km upstream of the large Banganga Irrigation System and the command area extends almost as far as that system. There is a small FMIS between the two systems – Pragati kulo – which did not join with the other 11 systems as it believed it would have a more reliable water supply directly from the river. However, it has suffered from water shortage in recent years, mainly as a result of quarrying of river bed materials to feed the local construction industry. There are some disagreements between the three systems, which systems fall under different divisions (irrigation development and management) in DOI, which needed resolution level under the auspices of the Chief District Officer.

¹⁰ Farmers report that on average about 120,000 person day of labour was required each year for construction and repair of temporary diversion weirs for the 11 canals.

¹¹ The Sangha Sanstha Darta Ain came into existence in 2035 BS. WUAs could then be registered in the CDO office. After Water Resources Act 1992, District Water Resources Committee (DWRC) started registration of WUA to establish water rights. After approval of Irrigation Regulation under Water Resources Act of 1992, DOI also started to register WUAs

Figure 16: Singeghat Weir**Table 8: Details of the Singeghat Irrigation System**

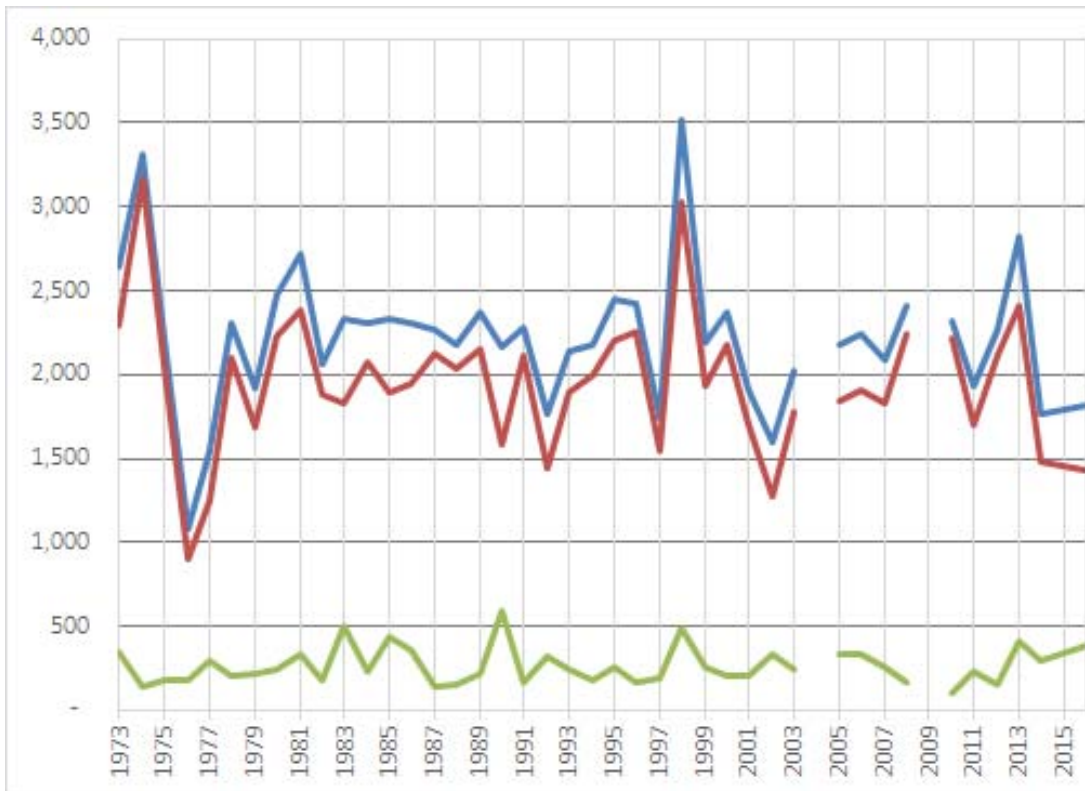
Right bank canals					Left bank canals.				
Total water shares 4 Aana (16 paisa) that corresponds to 25% of the incoming water					Total water shares 12 Aana (48 paisa) that corresponds to 75% of the incoming water				
SN	Existing canals / mauja	Water shares (Paisa)	Irrigated areas (ha)	HH	SN	Existing canals / maujas	Water shares (paisa)	Irrigated areas (ha)	HH
1	Motipur	10	674	1565	1	Baijalpur	2	107	273
2	Madhuban	6	274	795	2	Tinaiya	2	196	490
					3	Pipara	6	283	1072
					4	Rajpur	3	92	275
					5	Bathanpur	3	217	415
					6	Gaieda	14	363	1050
					7	Jeetpur	2	137	547
					8	Jhanda	8	343	940
					9	Dugaha	8	430	1085
	Total (Paisa)	16	948	2360		Total (Paisa)	48	2168	6147

Source: Feasibility Study

Climate Data

Rainfall is recorded at the nearby Patharkot station (Figure 9), which suggests little change compared to annual variation. Unlike Julphe, rainfall appears to be increasing since 2001, apart from very dry years in 2014 and 2015. However, these trends are not significant and likely to represent short term fluctuations rather than climate change.

Figure 17: Rainfall at Patharkot (mm - annual, monsoon and dry season)



Source: DHM data

Farmers perceive a more severe decline than this data suggests, but this may reflect an overall shortage of water as the irrigation system only provides part of their needs and any short term change in rainfall will have a direct impact on their crops.

Although rainfall intensity can be expected to increase, and thus the proportion of total rainfall that is effective, there is little sign that this has happened so far (Figure 10)

Singheghat Location Map on Banganga River

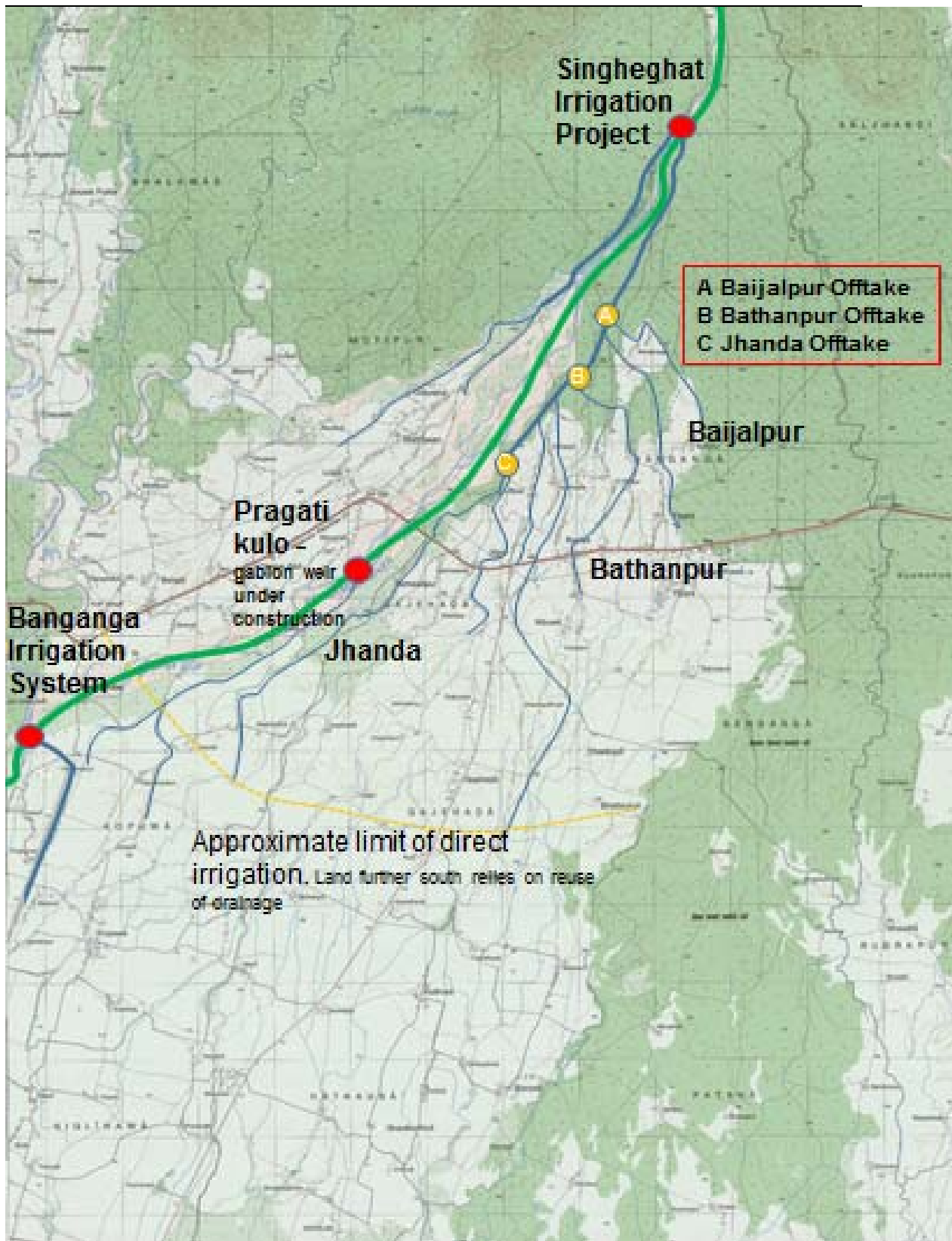
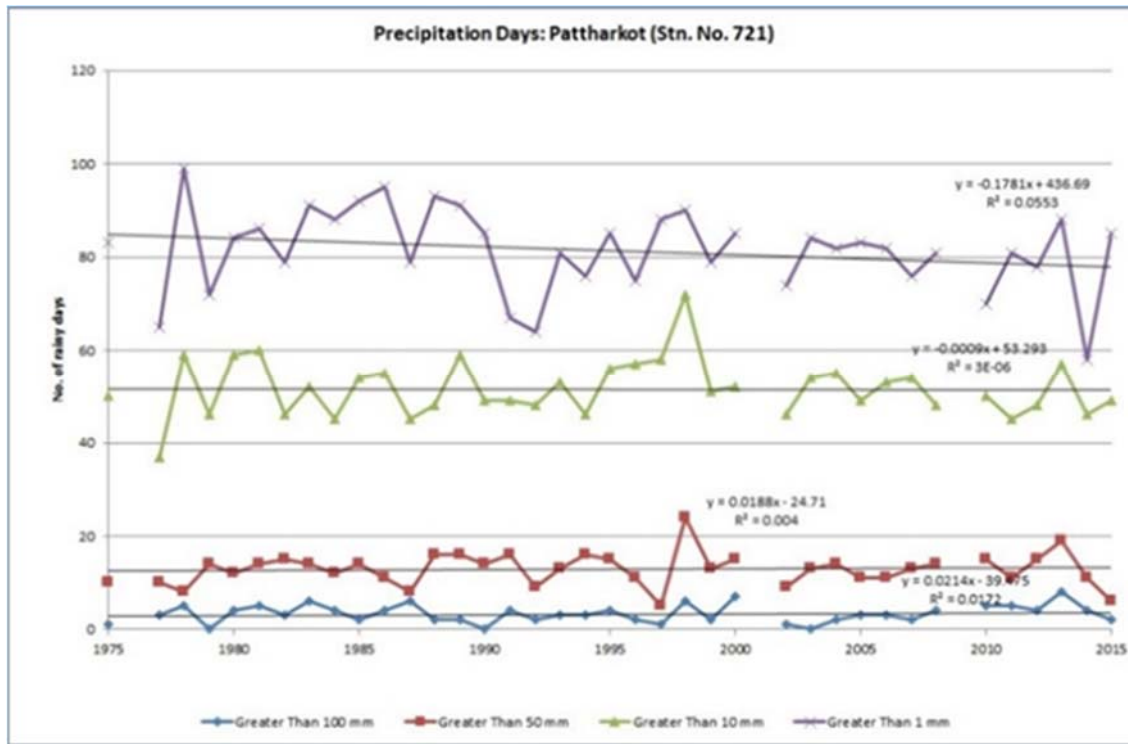


Figure 18: Rainfall Characteristics at Patharkot

Source: DHM Data

Water Available for the System

There is a general consensus that the availability of water in the river, especially during the dry season, has decreased significantly in recent past. The flow in the Banganga River was measured in May 2016 as 240 l/sec given in Table 6. However, the natural flow, calculated according to the WECS/DHM method is 1.47 m³/sec, meaning that 1.23 m³/sec is used in the upper catchment. Small changes in the upstream will thus have a profound impact.

Most of the flow for the Banganga project is contributed by the Kaila Nadi (165 l/sec) as there is much less agriculture in the catchment. The remainder of the flow is from subsurface flow which re-emerges between the highway and the barrage, since all of the surface flow in the Banganga nadi is diverted by SIS. This is about 50% of the flow measured in the dry season in 1980 (Pradhan TMS, 1996).

There is a consensus among the farmers that the availability of water is not adequate. There is less water in the source river, but less water in total is diverted as a result of the integration of the 11 systems. Water is now abstracted from one point at the head of the system, whereas previously there were multiple diversion points which meant that return flows downstream of the first weir were re-diverted by downstream weirs

Table 9: River Flows for Singeghat

Date	Location	Flow area (M2)	Adjusted velocity (m/sec)	Flow (lps)	Remarks
04 May 2016	Singeghat left main canal (head)	0.6	0.3	180	
04 May 2016	Singeghat right main canal (head)	0.35	0.18	60	
	Total water in the river (at Singeghat weir)			240	All incoming waters were diverted to the Singeghat canals
04 May 2016	Banganga River at highway bridge			0.00	River bed was dry
04 May 2016	Kaila Nadi (at highway)	0.416	0.402	165	
03 May 2016	Banganga River upstream of the Banganga barrage of the Jagdishpur reservoir	0.744		310	

Source: This study

System Management

Although there is less water available, the improved infrastructural control has improved both the reliability of water delivery and efficiency of system operation. It is also possible to manage very low flows in ways which would not have been possible before. This is a valuable lesson for coping with water shortage more widely.

There is, however, a negative impact on users further downstream, outside the formal (water rights) boundaries of the Singeghat canals, who used to benefit from the uncontrolled flows which passed into and through the system.

- Water is delivered in accordance with local water allocation norms and principles, but not proportional to area, varying according to season.
- During the monsoon season, the main and branch canals receive water continuously (albeit generally less than demand as indicated by the figure below, even after allowing for rainfall) basis, while during the dry season the branch canals at the head receive water on timed rotation. It is not physically possible to transport small volumes to the tail given the nature of the canals
- The water deficit observed at the head of the main canal is matched by similar levels of deficit in the branch canals. Despite the declining availability and significant shortage of water no land has been abandoned for this reason.
- There has not been any major change in irrigation management since construction of the weir. The new main committee is able to manage the main canal, and the long-established branch canal committees continue with their traditional arrangements.

The flow in the canals is usually well below the demand for water, even allowing for rainfall. As a result, the flow in the canal increases with rainfall until the demand is met in mid-July. However, the canals are not then actively managed and continue to respond more to rainfall than the need for irrigation. If the canals were closed when water is no longer needed for irrigation, this would enable water to be made available for others and it would also mean that flood flows could be excluded from the canal. In the event, a major flood in late July caused considerable damage and sediment entry into the canals.

Figure 19: Singhghat canal structures



Figure 20: Rainfall and Main Canal Flows

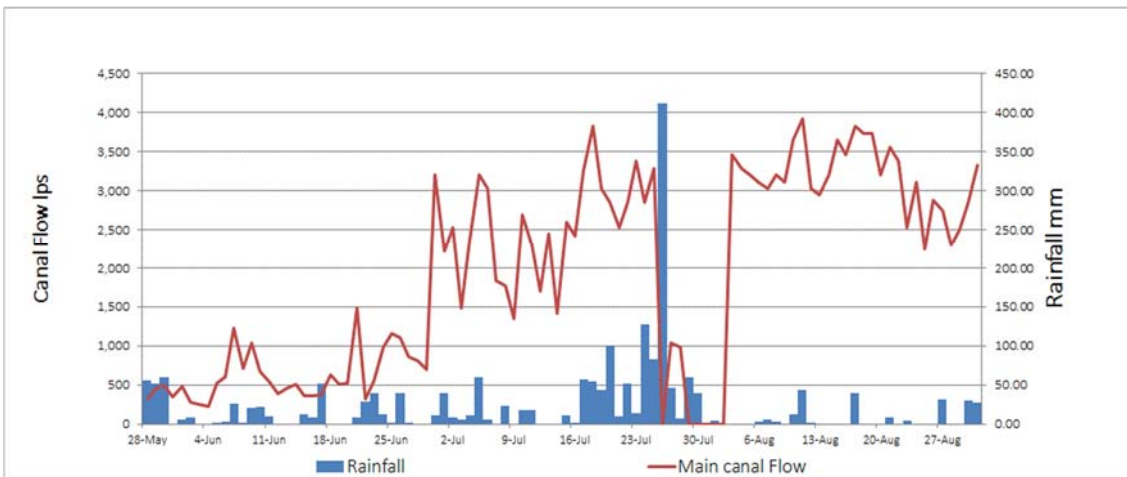
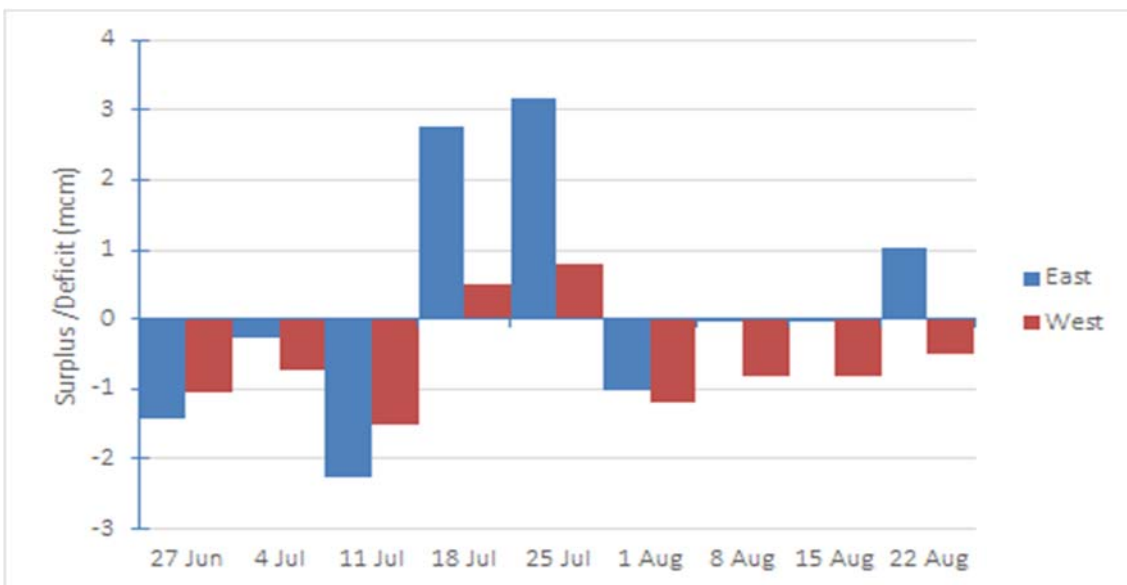


Figure 21: Surplus/Deficit of Water in East and West Main Canals



The weir and canal system thus withstood a flood of 20 % more than the design flood, and it should also be noted that the abutments and canal head regulator appear to have been built significantly lower than the required level. A flood of over 470m³/sec (85% of the actual design flood) would exceed the safe design level for the head regulator with 50cm freeboard.

As the flood overtopped the structure it was not possible to operate the gates at the peak of the flood, but considerable damage would have been avoided if the canal gates had been closed as the flood was rising. This incident highlights the need to ensure that designs are carefully detailed with adequate safety factors / freeboard, and to ensure that there are appropriate operating rules and that the structure is operable under peak design conditions. Automation or electrification of such small structures is unlikely to be feasible in the short to medium term, but operators need to have a good understanding of the operating rules and be able to apply them.

Local perceptions

The population is predominantly Brahmin and Chettri (52%), with 30% Tharu and 18% others (Magar, Gurung, Newar and Dalit). Overall, 60% of household income is reported to be from agriculture (down from 95% previously), with 20% from local non-farm activities and 20% from migration/remittances. The west bank which has a worse water supply is much less dependent on agriculture (just 10% of income as compared to 75% on the east)

Perceptions of climate are very similar as in Girwari and responses are similar. Rice is equally dominant, and the same decline in wheat and increase in potato is evident. Remittances and off-farm local have increased from almost zero but are still less than 20%.



Climate resilience

The Singeghat systems have also been adapting to change over the past 50 years, with water availability dropping to much less than 50% of the natural flow due to upstream water use. This response has been achieved through a combination of strong institutional arrangements

supported by limited investment in infrastructure. The provision of a weir has protected it from the impact of riverbed quarries, but downstream systems are still vulnerable and this is being addressed by construction of a new gabion weir.

As in the case of the Girwari systems, the resilience at present can be summarised in terms of the infrastructure, the rules governing its management, and the individuals and organisations involved (section 5.2.1). This system itself may be more resilient as a result of improvements to the infrastructure, combined with the ability of the institutions to adapt to the new requirements. These physical changes have, however, had a negative impact on some downstream users. Nevertheless, they are all less threatened by climate change than they are by the many concurrent changes which are more significant than climate change: it is the ability to respond to these changes which is determining resilience.

Systems (infrastructure)

The infrastructure was developed incrementally over several decades in response to changes in the needs of the farmers and the environment they are operating in, but the potential for significant improvement in the infrastructure was recognised 20 years or so ago. Like Girwari there were several successive intakes along the river. There was a good location for a weir and land available for a link canal. Improvements to the distribution system were made at the same time, enabling better control of water within subsystems. This was a very beneficial action and removed the problem of abstracting water from the river for the official command area. Although expensive the cost could be justified because of the relatively large area after the systems were combined. It had had two significant impacts:

- reduced return flows, which may have influenced downstream areas which are dependent on direct reuse of drainage water;
- increase capture of water at the weir site, but fewer opportunities for diverting water from the river as there is only one intake rather than eleven, and thus less overall reduction in river flow further downstream. This is beneficial for downstream systems in terms of availability of water in the river for them, although this is masked by changes in overall water resources and the impact of large-scale river quarries.

Like Girwari, there was a severe flood in 2016 (411mm in 24 hours), which was reported to be the most severe since the weir was completed. It exceeded the design flood and overtopped the structure, but did no significant damage apart from allow excess sediment into the canal. Even this minor impact could have been avoided had there been better operating rules.

This demonstrated the physical resilience against the main climate-related threat. Storms of such intensity are clearly unusual but are consistent with the predictions for climate change.

Water shortage is an important and growing issue. The weir has made capture of water easy, but resources are declining largely due to changes in upstream land use, so better system management is necessary. However, this does not help those downstream farmers dependent on drainage reuse and may even make their situation worse. Better water management and choice of crops and varieties which minimise consumption of water is also needed.

Groundwater development has alleviated some of the shortages, but the cost of development and management in a location where the water table is deep has made this an unaffordable solution for most people.

Institutions (rules)

The development history of the Singeghat systems led to strong institutions within the framework that they were planned for. They were able to adapt to the new situation after unification of the system, which was achieved with little change to the operating rules. Water

rights were unchanged – this was important for sustainability although it should be noted that it is not equitable and formalises rights which are not area-based but give greater water to the head of the system. Two subsystems downstream of the eleven merged systems elected to remain independent, but have subsequently suffered from excessive quarrying on a large commercial scale. This is an important source of revenue for the District but requires mitigation measures (a new, low cost weir) to avoid disrupting irrigation activities. However, interestingly, these new measures have been funded from central resources rather than from the revenue stream arising from the quarry.

Agents (individuals, organisations)

A new organisation emerged to manage the new link/main canal. The previous WUAs for individual systems continued to function largely as in the past. As in Girwari, there is no cooperation with upstream farmers in the catchment where land use changes are having an impact on water resources, nor is it easy to envisage how such arrangements might be developed.

Again, like Girwari, farmers have adapted their practices substantially over the years, changing from single-cropping of rice to more intense and diverse cropping. Rice is still dominant but new varieties and farming practices have enabled increased production; some of these varieties are better adapted to the climate, but increasing variability in the timing and intensity of monsoon rainfall remains a threat. Sources of information are also more diverse: personal contacts, mass media, private sector providers, and a range of projects all augment formal government extension services. Diversification of livelihoods brings both challenges and opportunities; those who are able to gain off-farm employment are most resilient to change

6 Climate-Resilient Development

6.1 Climate change in context of other changes

Climate change adds complexity and uncertainty to a situation where population is expected to grow by 50% by 2050, but supported by an even greater growth in GDP linked to diversification away from subsistence agriculture. Climate, however, potentially threatens the viability of irrigated agriculture. This has already been underperforming, and is increasingly under threat as new, higher value demands for water emerge.

The need to improve irrigation has been recognised for a long time and the recommendations of the [international] Comprehensive Assessment of Water Management in Agriculture (Molden et al., 2007) on how to achieve sustainable water management for agriculture remain largely valid:

- investment should focus on enhancing the productivity of existing systems through upgrading infrastructure and reforming management;
- Diversification from staples to fruits or vegetables is needed to cope with globalization, urbanization and rising living standards;
- Performance should be monitored against the full range of benefits and costs, including alternative uses of water and not only against commodity production.
- Water governance must improve, with more direct involvement of farmers.

Climate change will reinforce these existing requirements as well as add further considerations. Although irrigation is in itself designed to protect against an unreliable climate, there has long been insufficient consideration of the variability of climate. Irrigation is usually designed to protect against a 1 in 5 year drought, which means that it fails to meet demands for 20% of the time and this is just the time when it is needed most. Irrigation programmes have, however, tended to focus on requirements for management under average conditions even though poor performance in dry years can undermine the entire management system. A focus on climate change ensures that coping with climatic variability, trends and extremes is brought to the centre of attention in irrigation programmes.

“Climate change poses significant challenges for investments in the water sector, particularly due to the long life-span and large upfront costs associated with many water projects. While water practitioners have long contended with variability and uncertainty in hydrology, the circumstances surrounding climate change and the inability to derive probabilities of future scenarios require a major shift in thinking, planning, and designing water investments of the future. At the same time, adaptation to climate change must continue to build on conventional interventions while also addressing immediate challenges and needs, such as disaster management, ecological restoration, and poverty alleviation. Investment decisions must place the climate change dimension in the context of other factors, such as population growth, land management, and economic markets, which in some cases may be far more significant and critical than that of climate change in some parts of the world.” (World Bank 2014)

6.1.1 Climate Stresses

There is good evidence that temperature is rising, with impacts most strongly felt in the mountains, to a lesser extent in the middle hills and least in the tarai. There is much less evidence of changes in rainfall, and the limited data does not give much support to the widely-

(albeit inconsistently-) held perceptions on timing, intensity and magnitude of rainfall events. This does not mean that changes are not occurring but simply that they are small compared to existing climate variability, and that sufficiently accurate and detailed data is lacking. Change is accelerating and the impacts are likely to become much readily observable in the short to medium term.

It is not only the magnitude of the projected changes that is important, but also the timing and intensity. There have already been several floods exceeding the design capacity of major weirs (for example, Bagmati in 1993, Babai in 2013) which have caused significant damage. This raises questions about what parameters should be used, what risks are acceptable (and the consequences of failure), and whether fail-safe mechanisms should be built in to cope with more extreme events. These decisions will differ for new projects and for retrofitting existing projects (Table 10)

Unfortunately, we cannot predict the magnitude, nature or even the direction of many of the changes, and there will be large local variations. Some changes may be beneficial, but the overall impact can be expected to be negative: greater variability of rainfall will produce deeper droughts and more intense floods, and higher temperatures will increase demands. There may also be secondary impacts – more intense rainfall may increase landslides and sediment loads (both affecting irrigation performance and maintenance requirements).

Table 10: Impacts of Climate on Existing and Planned Irrigation

Impact	Existing irrigation systems	Future irrigation systems
Low Flows (lower average flows and greater variability)	Reduced river flows, leading to reduction in irrigated areas, in some years / seasons. This cannot yet be quantified and will change with time.	Command area may have to be less than would have been the case under previous climate scenario, or greater risk of failure may have to be accepted (eg 1 in 4 year instead of 1 in 5 year).
	Change in crop types which can be reliably grown	Command area or crop recommendations may need to be different from previous assumptions
	Reduced crop areas, and hence some areas reverting to partially rainfed conditions or need deficit irrigation	More intensive irrigation over smaller areas
	Impact on local livelihood and food security	Social acceptability and/or economic returns may be reduced, limiting scope to develop new irrigation or requiring alternative management arrangements
	Environmental damage (reduced downstream flows)	Designs for more efficient irrigation under climate change scenarios may lead to reduced return flows in comparison to previous assumptions
	Conflict due to reduced water availability and failure of allocation systems to respond	
High flows (higher peak flows)	Flood damage to infrastructure – potential need for retrofitting improvements or fail-safe) mechanisms	New design criteria, with higher design floods - hence higher cost and reduced rate of return. Undertake sensitivity analysis for more extreme events
	Flood damage to crops: drainage systems may be inadequate	New design criteria with greater drainage rates
	Increased sedimentation in canals due soil erosion as a result of more intense rainfall	Need for sediment exclusion arrangements which may reduce the amount of water available
Higher temperatures	Crop suitability and productivity changes	Crop water requirement estimates need to be revised
	Crop water requirements may increase	Timing and magnitude of runoff on glacier and snow-fed rivers will change

Source: This study

6.1.2 Non-climate Stressors

There has been remarkable population growth, urbanisation, increasing demands for water, changes in government systems, international migration and globalization, improved rural access and telecommunications, commercialisation of agriculture and market improvements, technological changes in agriculture and so on in recent decades. Such changes were rarely allowed for in the original design, but they have a profound impact on the requirements for irrigation and how it is managed.

Some systems have adapted accordingly and become very productive; some have retained a traditional focus, serving the needs of local food security within a changing external environment; but many others struggle on in an under-performing way. Increasing pressures on water resources and the unprofitability of traditional agriculture mean that irrigation urgently needs to evolve and adapt more rapidly. Whilst most of the immediate stressors may be non-climatic, climate change can still be an important driver for reform and improvement of irrigation.

6.2 Classification of Systems according to Vulnerability to Climate

Vulnerability to change and the ability to adapt to it is dependent on the local context and thus any study about the resilience of irrigation needs to be firmly grounded in an understanding of the local situation: the importance of irrigated agriculture in the local economy; the nature of alternative livelihood strategies; and the anticipated changes in climate as well as the physical, social and institutional characteristics of the system itself. The irrigation sector has been extensively studied in Nepal from a variety of perspectives with much grey and published literature available (Appendix G).

A simple irrigation typology has been developed in the context of the locally perceived benefits, risks and performance of the systems (Table 6.2). Vulnerability and then recommendations for enhancing resilience within each category can then be proposed.

Table 11: Classification of Small and Medium Irrigation Systems

Categorization	Irrigation type	Description / Examples	Vulnerability to climate change	
			Flood	Low flow
Water source	Surface	Gravity irrigation systems that receive water from rivers, streams or springs	Increased risk of damage	Increased risk of shortage
	Ground water	Deep & shallow tube wells, treadle pumps	Low impact	Low impact
Water availability	Perennial	System with perennial supply of irrigation waters (tube wells, lift irrigation, some surface gravity systems),	Low risk for GW irrigation, high for surface irrigation	Low/Medium (SW) Low (GW)
	Seasonal	System that operate only during the monsoon season for irrigating paddy	Medium risk	Medium/high risk
Infrastructure	Complete / permanent	Complete system, including weir / intake and canal system; good condition	Risk of physical damage; mitigate by improved design	Risk of shortage, mitigate by improved management
	Partial / temporary	Incomplete system, no permanent arrangements for river abstraction	Increased difficulty with abstraction	Reduced command
Management	Strong	Effective WUA for individual system, good arrangements for coordination between systems along single river	Risk of flood damage	Innovative water sharing systems and rotations to mitigate impact

Categorization	Irrigation type	Description / Examples	Vulnerability to climate change	
			Flood	Low flow
	Weak	Incomplete / <i>ad hoc</i> arrangements for individual system; limited coordination with other systems	Risk of physical damage	High risk of shortage
Topography	Hills	Hill terrace, valley bottom, river terrace systems. Long canals unstable terrain	Landslide damage to canals, flood risk to intakes	Reliant on small rivers, high seepage losses
	Tarai	Flat topography, poor drainage, possible reliance on upstream return flows	Flashy rivers in foothills, high maintenance	Increasing difficulty to capture water,

Source: This study

6.3 Potential Impacts and Coping Strategies

The case studies and review of other literature and other programmes indicate a range of potential impacts from climate change. The extent to which these will occur and be caused by climate change will vary according to location, but all of those listed in the table below are climate related.

Table 12: Potential Impacts of Climate

SN	Threat	Impacts
1	Flooding and flash floods	Physical damage of infrastructure Inundation, and sedimentation in canals Erosion, landslides blocking canals or damaging related infrastructure such as roads
2	Change in seasonal water availability	Reduced water availability in rivers during winter (November –March) leading to long dry spell and drought Fluctuating water availability in rivers during the monsoon season leading to intermediate dry spell and drought Possible Increased water availability (but mainly in snow-fed rivers) during pre-monsoon (May June)
3	Change in temperature	Increase in crop water requirements
4	Change in rainfall patterns	More intense, intermittent rainfall resulting in less effective rainfall and greater demand for irrigation water
5	Storms, hail and lightening	Physical damage to crops and possible influence to the viability of some crops in some areas
6	Heat waves (Mainly in tarai and inner tarai during summer)	Change in crop types, Crop losses, forest fires, increased evapotranspiration, and hence crop water requirements
7	Low temperatures, frosts, cold waves (Mainly during winter)	Change in crop types, Crop losses
8	Crop pests and diseases as a result of temperature changes	Crop losses, increased cultivation costs; possible change in crop type

Source: This Study

There are many coping strategies, some of which have been practiced for a long time, as they are mechanisms for coping with current climate variability. They may sometimes fail in the future climate if the water availability decreases too much or other changes are too great, and additional support may be needed. In addition to the threats, some opportunities may emerge with scope for different fruits and vegetables to be grown at any given altitude.

In this context, there are many win-win, no-regret, low-cost options available (which are similar or identical to current good practice) and which should be encouraged or adopted immediately

or in the short term. These should not be seen specifically as climate adaptation measures, but as an integral part of climate compatible development. Adaptation should not be seen as an additional activity to be identified, developed separately and then mainstreamed: it is part of normal development and mainstreaming should be planned from the outset.

In the longer term, additional measures may become possible or desirable. These include major new infrastructure such as storage reservoirs or inter-basin transfers, as well as 'softer' measures such as flood and drought forecasting, and crop insurance which are rapidly developing concepts. New methods and technologies are emerging all the time with, for example, innovations in remote sensing and communications technology. Some of these are already being used on experimental basis in some places (remote sensing of evapotranspiration in China) but there will be others which have not yet even been developed. Adaptability will be of critical importance: irrigation systems should no longer be designed on the assumption that the world will be an unchanged place in 50 years' time: it will change in ways we cannot predict as well as some which we can anticipate.

6.4 Climate Compatible Development

It is no longer possible to prevent climate change, but it is still possible to protect our societies and economies from its impacts. Adaptation is the process by which this can be achieved, but it is important to recognise what is commonly referred to as an 'adaptation deficit' – the fact that developing countries are not well-adapted even to the present climate.

Although there is a growing awareness of the strong connection between adaptation and development, it is still often treated separately. Fankhauser (2011) reports, *"in much of the policy discourse adaptation is still treated as a stand-alone issue with little or no links to other development challenges. This artificial distinction is particularly apparent in discussions of adaptation costs and the related debate on adaptation funding, which are both central to a post-2012 climate change regime. All too often analyses of adaptation needs treat adaptation as an incremental activity that is bolted onto a "business as usual" development path.*

Similarly, the practical instruments to advance adaptation planning in Least Developed Countries under the UNFCCC – the National Adaptation Plans of Action (NAPAs) and NAPs – are generally developed in parallel to national development strategies, poverty reduction strategies and associated medium-term expenditure frameworks (MTEFs) that form the basis for providing and programming international development assistance. All too often competing interests within governments champion mean adaptation is seen as an "environmental" issue to be kept separate from financing for "development".

The separation is not surprising as the need for climate change 'adaptation' emerged separately and with many different stakeholders from 'development'. There has also been a separation of funding streams, with development and adaption often financed from different sources.

A critical feature of irrigation is that it is in itself an adaptation to an uncertain and variable climate, but one that is not expected to mitigate all impacts even of current climate variability: it is usually supplementary to rainfall, and is generally only designed to provide full protection against a one in five-year drought. Most irrigation in Nepal was originally developed for subsistence crops in the monsoon (mostly rice). The priority is now for intensive, year-round irrigation, and now partly for market as well as subsistence, and there is a growing emphasis on high value crops.

Irrigation systems have been subject to more change (both climatic and non-climatic) than they were designed for, and future changes cannot be predicted with any precision. Measures to improve performance and resilience should thus focus increasing the flexibility and ability to

cope with uncertainty. Building in redundancy (such as additional sources of water to cope with shortage) and 'fail-safe' mechanisms (so that extreme floods do not cause extreme damage) are important.

Although irrigation systems are often considered as individual projects, the boundaries may not be clearly defined, nor are they likely to be constant across seasons: some farmers will have well-defined rights to draw water from the canals, but others will depend indirectly on the canal system via return flows to drains. Some of these farmers will use these drainage flows to supplement their formal rights, others will depend entirely on them. Some entire systems may be dependent on return flows from upstream systems, even if they have a formal internal system of water rights (as in the case of Lausi *khola* in Rupandehi which relies on return flows from the Chattis Mauja system). Enabling formal right holders to maintain their access to water even if the overall availability or timing changes may have an adverse influence on access by others further downstream. Upstream land use changes (such as agricultural intensification or de/afforestation) may also influence river flows by changing rainfall-runoff relations even without changes to actual abstractions from the river

Irrigation resilience must therefore be considered in the context of river basins as a whole, and also take account of other water uses which are growing as a result of urbanisation and population growth: it is no longer possible to consider rural agricultural water users in relative isolation. It should take full account of livelihood strategies of the irrigation users and the local agro-ecological context.

Small and medium irrigation in Nepal has been developed incrementally in response to a change in demand, and thus in turn on the activities and relationships of 'actors' who include the water users, and the community and Government organisations. Irrigation has been developed on the basis of a predictable climate, albeit within a broad band of uncertainty.

Some irrigation systems have performed well in this changing environment – for example the series of small systems along the Girwari *khola* in Nawalparasi district (*tara*) or along the Kamala *nadi* in Sindhuli (hills), and much can be learned from this successful experience. Others have fared less well: the Lausi *khola* system in Rupandehi, for example, has been undermined by growing urbanisation, which has created many more profitable employment opportunities and consequently reduced interest in irrigated agriculture. It has also suffered from increasing demand for water for more intensive agriculture by upstream water users. It continues to function, however, but at a low level of intensity and contributes to local food security. The main direct beneficiaries may also have changed since the relatively well-off farmers who used to farm the command area have been best able to capture the new opportunities from local urbanisation. Poorer tenant or sharecropping farmers may now farm the land, but they may lack the influence or connections needed to adapt the irrigation systems to the new context.

7 Framework for Resilience

7.1 Introduction

Climate resilience is a new and unfamiliar concept to many local practitioners and planners, and it brings with it a new language and terminology, and new stakeholders - but the underlying issues are familiar. Good practice for promoting irrigation performance will address many of the issues, as well as the additional and growing risks as a result of climate change.

The conventional approach to adaptation draws on a vulnerability assessment to identify the threats, the exposure and sensitivity of the systems to these threats and the local adaptive capacity to absorb or adapt to them. Then specific adaptation measures can be identified and implemented (DOI & MOSTE, 2016).

However, there are limitations to this approach – particularly for very small projects of the nature covered by this study. There is a lack of data and resources for detailed studies of such small projects, even though they have a large aggregate areas and importance. It is not possible to quantify all risks to irrigated agriculture, or their likelihood and impacts. Furthermore, as Tyler and Moench (2012) highlight for urban systems *“by focusing on adaptation interventions that respond to specific climate impacts, this approach may neglect indirect effects, systemic weaknesses or institutional constraints.”* It also risks neglecting the fact that climate change may not be the only or even the major threat to such projects in the short term, as highlighted in earlier chapters.

A focus on resilience, by contrast, makes it possible to build capacity to withstand climatic and other shocks and trends which may not yet be predictable. Some changes can be quantified (such as flood peaks), albeit with a considerable degree of uncertainty, but other changes may not even be anticipated at this stage. Rather than attempt to identify individual impacts and mitigation actions, this study therefore aimed to identify the main factors which influence resilience in small and medium irrigation, such as:

- Strength of local institutions
- Adaptive capacity of farmers and irrigation managers
- Relationship between systems and water users in the river basin
- Type of river and intake
- Reliability of water supply
- Type and quality of infrastructure
- Crop types and market penetration
- Urbanisation and off-farm employment

The two broad methods for assessing the effects of climate change on water resources use data tools differently and begin the impact and vulnerability assessment from different directions.

Traditional methods to assess climate risk and vulnerability take a top-down approach, by downscaling a necessarily limited selection of individual projections from GCMs to identify snapshots of potential climate impacts. The water system’s vulnerability to those particular scenarios is then assessed by forcing hydrological and water systems models with each scenario’s climate information.

Bottom-up approaches reverse this assessment process by first identifying system vulnerabilities to a very wide range of future climates (beyond that projected by GCMs) and then determining the plausibility of particular climate impacts using the best available and most credible climate information”.

....

“Water resource managers are primarily concerned with planning and design at the local and regional scale, yet precipitation (and to a lesser extent temperature) output from GCMs is only considered spatially credible at coarse resolution grid cells (100s of km) and temporally credible at a monthly time step.

Perhaps the most critical weakness of climate projections is that they are less reliable in regard to the variables that are most important for water resources projects, such as hydrologic extremes (e.g., flood and drought). Those extreme events are located at the tails of distributions of climate variables and percentage-wise will change more rapidly than the mean in a changing climate”

Beyond Downscaling: a bottom-up approach to climate adaptation for water resources management, World Bank, 2014

7.2 Framework for Resilience

The framework needs to address performance and resilience together, since actions to strengthen resilience to change will improve performance under current, ‘normal’, conditions. Equally, there is little prospect of improving resilience of an under-performing system unless the existing underlying weaknesses are resolved.

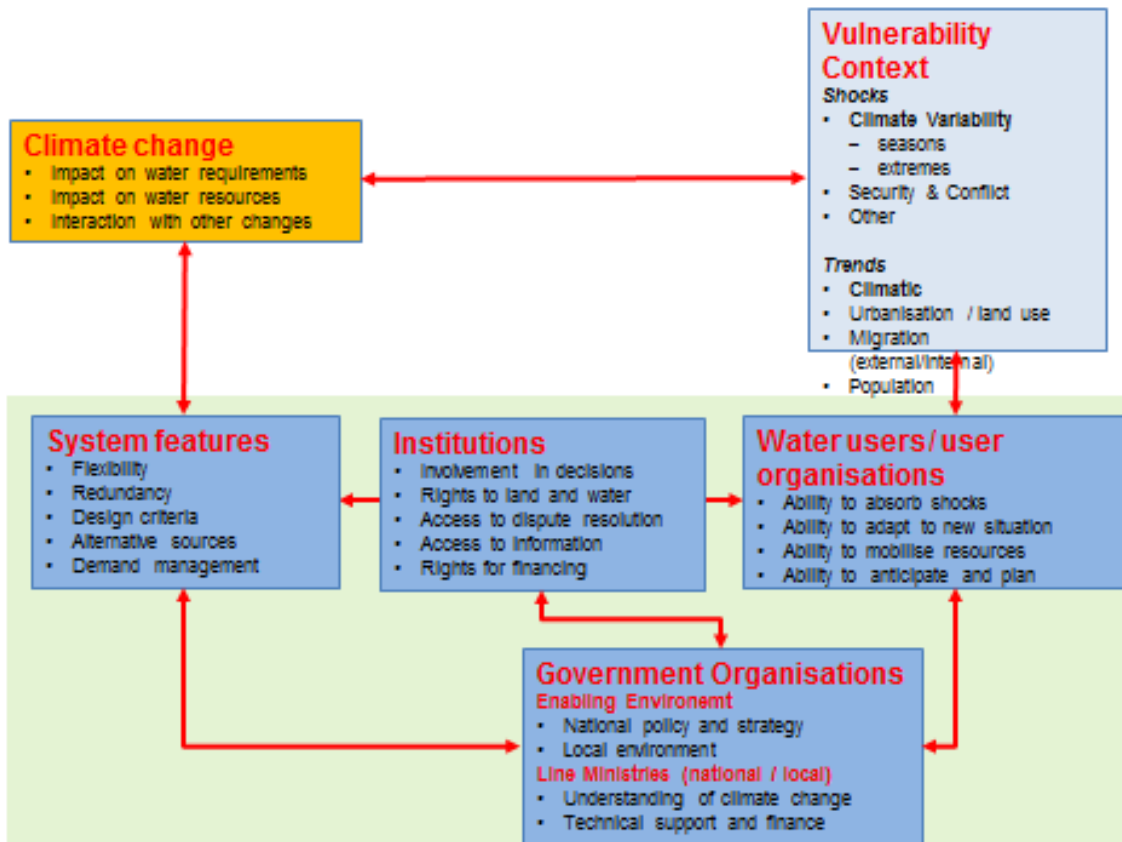
The framework thus draws on earlier work for improving the performance of irrigation in Nepal and in particular the methods presented in an earlier study conducted with DOI under DFID funding (Mott MacDonald, 2006). This used the Sustainable Livelihoods Framework to organise thinking about the assets that groups and individuals have available to pursue their livelihoods, the vulnerability context and the strategies they adopt for management of irrigation. This, however, gives relatively little attention to the institutional context that individuals operate in - a weakness is recognised in New Institutional Economics which gives a greater emphasis to the role of information, relationships, incentives and motivation to promote collaborative outcomes, (or to create conditions for opportunism) in social interactions. This was combined with a Drivers of Change perspective which emphasises the roles of:

- the ‘systems’ (in this context, essentially meaning the physical irrigation systems),
- the agents or actors (individuals or organisations) who are stakeholders in the systems, and
- the rules (‘institutions’) which guide the way the systems are managed by the actors.

This provides a good basis for a framework for improving the performance and resilience of irrigation. This draws on the findings of the case studies and other aspects of this projects, but generalise the findings so that they can be applied more widely. It takes account of the design and condition of the systems; the rules which influence how irrigation is managed; and the positions of agents/actors and influences on them. It also allows for consideration of the full range of observed and potential future changes and vulnerabilities, including those due to climate change. These approaches should in turn take account.

This leads to a framework for resilience as presented in the figure below.

Figure 22: Framework for Resilience



7.3 Application of the framework.

The framework set out above may appear complex, but it is simply an attempt to put many issues which are individually well understood into a logical structure. This is needed as it is important both to consider the impacts of all potential changes and the likelihood of them happening, and to recognise that there will be trade-offs – investment in one aspect of one system has opportunity costs and may limit or influence what can be done elsewhere. Tackling elements in isolation is also likely to fail.

Building resilience thus depends on consideration of each of the three main components: systems, institutions (rules) and actors (agents), with some examples tabulated below, and further details in the next subsections:

Systems (infrastructure):	Institutions (rules)	Agents (individuals, organisations)
Modified design criteria, particularly flood and dry season flood estimates.	Arrangements for cooperative management of natural resources, including river bed materials as well as water.	Farmer ability to absorb, adapt, anticipate change, in response to climate uncertainty and other non-climatic changes.
Design of structures and systems to be adaptable as the need changes	Water rights, across the river basin - to avoid causing adverse impacts, and taking account of traditional rights as well as new policy provisions.	Access to knowledge, willingness and resources to adapt or diversify agriculture, and livelihoods more widely.
Flood capacity – exclusion of peak floods, safe escape structures and fuse plugs, protection of vulnerable canal reaches.	Mechanisms for preventing /resolving conflicts.	
Control of water at low flows; impact on improved control other users.	Enhanced ability to raise finance.	
Development of new sources, with conjunctive management.	Markets and subsidies for crops, and support systems for agricultural development.	

7.3.1 Systems (Infrastructure)

One of the most obvious impacts of climate change is likely to be more intense rainfall, leading to bigger floods. This has immediate and direct impacts on irrigation systems, causing potential damage particularly to structures in the river and wherever the system crosses drainage channels. Other possible changes are longer periods between rainfall events which may change the irrigation requirements and hence canal capacity. However, the challenge is to set appropriate design parameters. Some, such as flood flows may be largely (but not entirely) be controlled by climatic considerations, others (such as low flow flows) are more influenced by upstream uses. For small and medium irrigation, which is largely designed by empirical methods and with an almost total absence of data, simple methods have to be followed.

Small and medium irrigation, however, has the advantage over large-scale irrigation in requiring relatively little commitment to rigid infrastructure and thus changes can be made relatively easily as requirements change.

There is a need to distinguish between rapid-onset changes, such as flood levels, where there may already be a risk of climate change causing immediate catastrophic damage, and slow-onset impacts such as drought, which leave some time for more gradual responses and adaptation.

Flood capacity

The most critical weakness may be flood capacity. Modern irrigation systems are resilient against design floods but vulnerable to more extreme events which might cause catastrophic damage. This can be contrasted with traditional systems which require lots of labour to maintain systems and to repair flood damage even under normal situations, but may not be damaged much more fundamentally by extreme floods. In some situations, it may be appropriate to keep traditional intakes and make improved arrangements for maintenance, and in others it would be preferable to build permanent intakes.

Design criteria for new structures are currently derived from the 1980 PDSP Manuals, and are believed to be too low. Increasing design flood flows should, however, not be undertaken lightly: it is potentially very expensive; it might be unnecessary and it might render projects uneconomic. It should also be noted that despite anecdotal evidence of change, a recent study by Lahmeyer (2016) did not find any evidence to support that. Equally if a big flood does destroy a new weir the impact would be devastating. Assessing the risk and consequence of failure is important. Options include:

- Design according to current parameters – a safe option if the consequences of failure are small;
- Design according to current parameters, but build in additional safety features (eg extra freeboard, fuse plugs, spillways with flashboards, etc);
- Design according to current parameters and undertake sensitivity analysis to assess the damage that would occur if floods exceed the design by say 10% or 20%;
- Design for higher flood discharge.

The Singeghat weir has an estimated design capacity of 560m³/sec, but safely passed 675m³/sec in July 2016 (20% above design) suggesting considerable resilience despite inadequate freeboard.

Damage to smaller structures such as cross-drainage is much less significant and it may be sufficient just to ensure that flood damage does not result in excess water entering the canals. This can cause much greater damage further downstream.

The PDSP manuals date back to 1990, when much less data was available. It is likely that the procedures could be improved and it is recommended that there is a comprehensive review of the methods.

Where intakes are supplied from temporary brushwood weirs, it is not the flood capacity of the 'weir' which is important so much as the impact that diverting flows has on the canal system and adjacent river bank which can be assessed qualitatively. 'Canal capture' is a serious and common problem when uncontrolled floods enter traditional canals. Structures to exclude floods and protect the adjacent river bank may be needed even if no weir is built in the river.

Floods and high rainfall intensity can have indirect impacts through increasing sediment loads or causing landslides, which are hard to quantify, but would also increase construction and maintenance costs. Long supply canals in the hills are particularly vulnerable, and in future it may become preferable to use lift irrigation from closer major rivers to reduce the need for such canals. Increased availability of power, and affordability of solar photovoltaic systems will accelerate this trend.

Low flows

Low flows may be decreasing due to changing rainfall patterns, but there are also increasing upstream demands which reduce the availability for downstream users: 50-90% of the natural runoff from the Banganga and Girwari catchments is used in the upper catchment before it reaches the irrigation offtakes, and this percentage has increased markedly in recent decades – presumably due to population growth and changes in land use. More efficient irrigation should be advocated enabling more precise delivery of water when and where it is required, and reducing flows to unproductive land. However, unless abstractions from the river are reduced at the same time this may have a negative impact further downstream since losses would previously have flowed back to the river and been available for reuse. There is a need to make best use of scarce resources but equally there needs to be caution in calculating the impact of more efficient irrigation – particularly piped distribution systems – which may help upstream users to the detriment of downstream users. It is no longer sufficient just to consider systems in isolation, but the use of water resources at a sub-basin level is critical. Furthermore, activities in the river bed, for quarrying construction materials can have a profound influence on water levels and on the ability to abstract water.

As climate changes, it will affect the balance between area which can be protected, risk of failure and cost. More costly solutions (both infrastructure, such as inter-basin transfers or water storage, and better management through enhanced participation by users) may become more viable but they may have other social and environmental impacts. The common implicit assumption is that climate resilient irrigation should protect the same area, with the same reliability but at greater cost. However, this is an oversimplification and climate may interact with other changes affecting the optimal cropping pattern and intensity and thus requirements for irrigation. There is a need for much more than just climate proofing existing or proposed infrastructure, and there may be opportunities for transformational change by facilitating more productive uses of scarce water. Making conservative assumptions on water availability might reduce the area which could benefit from a new system, and might even result in it not being deemed viable.

Again, a sensitivity analysis to changes in water supply would be appropriate although it must be noted that assessing the impact of small changes in water availability is more complex than a hydrological / engineering calculation. This will also depend on institutional capacity to manage water in dry years, as well as on the sensitivity of the crops. Rice requires a large volume of water but is relatively tolerant to variations in supply, whereas many higher value crops such as

vegetables are less resilient but require less water per unit area. But the ability to change from rice to vegetables depends on socio-economic conditions, market availability and management arrangements. There are, however, some high value crops, particularly fruit tree crops, which have a wider tolerance to water availability.

Planning improvements to efficiency of water use must be undertaken in the context of use across the river basin. Improving local efficiency may reduce return flows and availability for others – a recent review by FAO has demonstrated that high tech irrigation almost invariably results in increased consumption of water (Perry and Steduto, 2016). It is only by formalising and enforcing reduced water rights that consumption of water can be controlled, but this is rarely possible on small/medium scale irrigation in Nepal. Fortunately, natural recharge of aquifers in Nepal (unlike in many parts of India) is still much greater than abstraction and thus canals can be improved without having a negative impact on groundwater irrigation. It is the impact of improvements on surface return flows which is important in Nepal and which needs to be considered carefully.

The changes in dry season water supply expected specifically because of climate change are unlikely to be significant in the decisions on cropping in the short term, and other changes are more critical. Climate is unlikely to require a change in this respect, but it may provide an impetus to improve management and water use. The additional resources available for irrigation because of the existence of new climate funds should be used to facilitate this change to more productive agriculture.

Water Storage

Surface water storage is usually only possible on a very small scale, but can be useful for horticulture. Larger reservoirs have significant social and environmental impacts and can be subject to rapid sedimentation (such as has affected Jagadishpur Reservoir on the Banganga system), but there are options for small-scale storage in other areas which should be explored.

A much easier option for storage, however, is in the groundwater aquifers. Many parts of Nepal are fortunate in having under-exploited shallow aquifers which are replenished annually by monsoon rainfall groundwater. Shallow groundwater is relatively low cost but is not always available; there may be deep groundwater in other areas but this is much more expensive (due to pumping costs). This is usually only economic if it is managed conjunctively with surface supplies or if there is diversification to higher value crops.

Combination of systems

Traditional systems were small and often entailed as series of parallel adjacent systems drawing water from independent intakes on the same river. These have become increasingly difficult to manage and maintain, and there is often strong pressure to build a single good intake and link the previously independent systems to a new main, link canal. This has many advantages, but it also comes with risks as set out in Table 13 below.

Table 13: Combination of traditional systems

Advantages	Disadvantages
Single permanent, reliable intake can be constructed at an economic price	Link canal may be vulnerable if it is very close to the river
Land acquisition for new link canal	Inadequate land to construct reliable link canal
May be able to build on existing informal water sharing arrangements from the river	Management systems differ, and a new central management organisation may need to be set up

Advantages	Disadvantages
More reliable abstraction of water and ability to control actual volumes	Water rights between canals are usually different, meaning that canals need to be designed for different irrigation duties or rights need to be change
Better control enables more precise deliveries and increased water productivity for rights holders	Impact on return flows and losses to downstream users
Maintenance costs reduced	Maintenance is a traditional basis for cooperation, which may be lost
Reduced/shared maintenance rights may give an entry point for reforming water rights	Traditional rights generally give preference to upstream users, who are unwilling to give up rights All users dependent on a single intake – if that fails everyone suffers
Flood and sediment entry to canals can be avoided, but only if there are good operational rules and they are enforced	Risk of damage unless standards of operation are good

7.3.2 Institutions (Rules)

Water rights

Water rights are complicated but important. Modern water rights are proportional to area, but traditionally they could be defined in many different ways (area, prior access, contributions to construction etc.) and they be might different between or across systems, and between seasons. This has important implications if systems are to be combined or changed in area (as described above).

The nature of traditional infrastructure means that water is only approximately delivered in accordance with the allocation, but it was usually a transparent and well understood system. These traditional rights have been largely maintained in nominal terms even when modern structures have been built. New structures, however, may still influence the actual amount of water abstracted from the river, the distribution within the canal system, and the loss of water to drains and back to the river of use of water. Although the modernised systems are built to comply with traditional rights, there is a risk that they will improve management within the system but at the expense of downstream users.

There thus may be a need to reform water rights on the basis of a better understanding of water resources and uses at river sub-basin level if there is to be a successful intervention. In the short term a more pragmatic acceptance of the current inequitable water rights may be unavoidable. The need for this is well-recognised, with the gradual introduction of IWRM and river basin organisations, but formalisation of rights is a slow and contentious process. This is emerging at two levels – relatively top-down way for the major basins (with the Bagmati being furthest advanced), and bottom up through less formal collaboration between WUAs of individual systems such as that observed in the upper Girwari khola

Upstream land use affects river flows, and thus population growth and intensification of agriculture in the catchment area will affect runoff to the river. There appear to have been substantial changes in recent years, with flows dropping to 30-50% of the flow in the 1980s. Minimum flows are now 10-20% of the natural runoff in the two study catchments It is unlikely that there will be substantial further changes in the short to medium term since most land which can be farmed has been developed and cultivated intensively in recent decades, but there is still a need to understand the impact of land use changes which would affect runoff and downstream water rights.

Equally, irrigation has an impact downstream, as there are large return flows from traditional irrigation which are used downstream via drains or the river itself. Improving the efficiency of

upstream uses, through better infrastructure and irrigation methods can decrease these return flows and thus reduce availability downstream even if the formal rights holders do not change their abstractions from the river. Changing water rights to be based on water consumption rather than abstraction is needed, but this is extremely challenging, particularly since they are not formally quantified or measured, or even based on irrigated areas.

Conflicts

These factors also point to the need for stronger mechanisms for preventing and resolving conflicts - which might otherwise become more frequent and more contentious, particularly at critical times, and may be spread over a larger area. Historically conflicts would have arisen within individual irrigation systems or between adjacent systems, but are increasingly likely (for multiple reasons) to have an impact across the sub-basin.

This will also have an impact on ability to raise finance and other resources needed for management in the sub-basin. This is true both in areas where agriculture is still largely for subsistence (food security), and in areas where cash crop agriculture operates in markets where there is international competition from subsidised crops (i.e. mainly in the tarai). It is still relatively rare for farmers to develop new markets (for example off-season vegetables, ginger, areca nut) and this impinges on their wider livelihoods, but is important for irrigation sustainability.

Changes that have occurred in recent decades have put immense pressure on traditional irrigation management systems, but some have been able to withstand this and have adapted to changing needs.

7.3.3 Agents/Actors (individuals and organisations)

Farmers

Farmers have always had to cope with climate uncertainty: they have had to absorb the impact of adverse years and thrive during more favourable seasons. Increasing off-farm opportunities as well as new crops, varieties and techniques help farmers to cope with this existing uncertainty, and to adapt to changes both climatic and other (population growth, urbanisation, living standard aspirations, etc.). Many are able to diversify their livelihoods (and thus adapt to changing circumstances), but it is those who are most vulnerable who are least able to adapt. Changing to more resilient or profitable crops or varieties requires knowledge, resources and markets. Some can access these and diversify their irrigated agriculture, or alternatively switch more fundamentally to new employment opportunities combined with low intensity agriculture for food security. Others cannot neither adapt nor find good alternatives, and thus are forced into less profitable activities and wage labour.

Population growth means that the number of people involved is increasing, but migration means that the farmers who most need to adapt may not be the original farm households and thus not connected with traditional management. This requires cooperation between water users, and shared arrangements for resource mobilisation to maintain and operate canals, and increasingly to cooperate between systems. Changing patterns of land use make it more difficult to sustain traditional cooperative arrangements, which in some cases were already under threat even before consideration of climate change.

There are increasingly opportunities for improved information which should help farmers to anticipate climate – seasonal projections of monsoon timing and intensity, short term weather forecasts, information on incipient floods. There is scope to improve the availability, reliability and access to such information.

Government Organisations

Whilst irrigation was traditionally managed by local organisations with little government intervention at any level, this is no longer the case. Local or central government has intervened in or is involved to some extent in the management of many (perhaps most) systems. The roles, responsibilities, capacities and relationships of the various organisations now have a significant impact on performance of irrigation. Their roles may need to be increased to address the need for management at a larger scale than in the past. This will include both technical agencies (DOI, DOLIDAR, DOA, etc) as well as local government (LDO, DDC, VDC etc). Implementation of the new constitution will influence this in ways which cannot yet be predicted, although work is in hand to develop future arrangements.

7.3.4 Example application of the Framework

As noted earlier, the Akase kulo in Girwari system has been badly damaged by floods. There is scope to merge this system with Julphe, which would be a structurally sound approach but it will have institutional impacts which need to be addressed as indicated below. This highlights the importance of understanding and addressing water rights, which differ according to season and location in the Girwari systems and are not proportional to area. It has been possible to reconcile this at Singheghat by allocating water to branch canals according to traditional rights; the difference at Girwari is that combining systems would affect the ability to deliver water within the branch canal. It has presumably been made more complex by the existing long-standing conflicts in other parts of the system (particularly with Tribhuwantar). The table below analyses the impact of the proposal to link Akase and Julphe kulos from the consideration of the three components of the framework

Table 14: Application of Framework to the Proposal to link Akase kulo (Girwari)

Component		Impact
System	Safety / Reliability	Safety and reliability of the water supply would be greatly increased by linking Akase to the much more stable and accessible Julphe intake. This is still a temporary structure so requires considerable labour for maintenance, but it is manageable and affordable.
	Redundancy	The reduced of the combined system would be less – in the event of a failure of Julphe intake, a larger area would be affected. However, this would be more than offset by the greater reliability. It would not be practicable to retain the old intake as a back-up. However, groundwater development (including better management of existing tubewells) could supplement the supply.
	Flexibility	For the same reason, operational flexibility would be reduced but the risk is again offset by the greater reliability.
	River basin	Combining two of the systems would bring irrigation in most of the sub-basin into a single entity which should enable coordinated management
Institutions	Decision-making	The individual sub-systems are governed by different organisations, and they have slightly different approaches to management, and there is a risk that this would undermine the organisations and affect their performance or sustainability – ensuring agreement between them and shared approaches is essential
	Dispute resolution	This shared approach should included agreement on issues such as mobilisation of resources and resolving or avoiding disputes. This a risk that combination of systems may introduce new conflicts, or highlight different approaches to resolving conflict
	Rights to land	The canals are physically adjacent and can be combining without encroaching on adjacent private land - no land acquisition is required
	Rights to water	The two systems have different bases for water rights, which are partly based on development history and contributions to construction. These are difficult to reconcile and are probably the main constraint to combining the systems. Some upstream farmers would have reduced rights, which would be difficult for them to accept (particularly given the overall shortage of water) even if it is more equitable

Component	Impact
Agents (actors)	
Ability to absorb shocks	From the perspective of individual farmers, the combination would be beneficial for most and will increase their ability to absorb shocks increased due to more reliable or predictable water supply. However, those who have their water rights reduced will need assistance to adapt to the new situation
Ability to adapt	Upstream farmers will need to adapt agricultural practices, given the reduction in water rights, and this will have to be mirrored by downstream farmers to reduce conflict.
Ability to anticipate	better climate information, flood forecasts and projections of water availability will help farmers plan and reduce the risk of crop loss. Better agricultural support services will encourage diversification.
Ability to mobilise resources	The need for maintenance resources should be no greater than for the existing upstream system (Julphe), but the Akase farmers will be available to contribute which should increase reliability of water supply and reduce the workload for the upstream farmers. This could be one factor which will encourage them to accept changed water rights.

Figure 23: Water Control Structures



Figure 24: Intake Arrangements



8 Conclusions

8.1 Key Findings

Climate is changing, with higher temperatures unequivocally demonstrated. Changes in rainfall are less clear, but there appear to be some changes in magnitude, timing and intensity which will have an effect on water resources and on irrigated agriculture. Climate change has probably not yet had a measurable impact on irrigation, although it may have had some influence and changes are expected to increase and become more significant.

Despite much publicity, there is still an imperfect public understanding of climate change and its impacts, and hence there is insufficient appreciation of the measures needed to cope with it.

There are also many other concurrent changes, which are having a greater impact at the moment. There can be a tendency to attribute all changes to the climate, with insufficient recognition of other political, socio-economic, developmental and even globalisation trends, which creates a risk of maladaptation. However, an understanding of climate in conjunction with all the other changes can also reveal other opportunities – diversification of livelihoods and improved access will create new markets for diversified climate resilient crops.

Irrigated agriculture is very dependent on rainfall and only provides partial protection against drought: any changes to rainfall patterns will affect both supply and demand for irrigation water. There are few irrigation systems which have access to a reliable and adequate supply of water even under the present climate, so any change in climate can be expected to have an immediate impact.

Climate change potentially has four major and important effects for irrigated agriculture:

- Reduced runoff in rivers, due to changing rainfall patterns in the catchment
- Increased flood flows due to more intense rainfall
- Increased demand for water due to more erratic rainfall
- Changes in crop suitability due to crop changes

There are many other changes which are affecting both supply and demand for irrigation water, and also influencing the importance of agriculture and its place in livelihoods and the economy. These include:

- increasing water uses upstream due to increasing population and the changing socio-economic situation,
- degradation of watershed,
- mining of riverbed materials,
- declining interests in agriculture,
- improvements in rural access,
- globalisation of agricultural markets,
- urbanisation and migration.

Measures to make irrigation perform better under the present climate are likely to be equally appropriate under future climate, although they will not be able to offset fully the impact of

climate change. Some changes to design parameters may be appropriate, but irrigation should be designed to be adaptable rather than to suit a particular future climate. Small and medium irrigation can generally be adapted at relatively low cost, and it is more sensible to do this than to plan now for a future situation.

Performance of Irrigation.

Field studies indicate that irrigation performs well at present if the institutions are strong and the infrastructure is appropriate. The greater uncertainty that will come as climate change becomes more severe will require greater sensitivity in management and, in particular, more coordinated operation of systems within a single catchment. Most small river basins are stressed with significant water shortage, with strong interdependencies between users. There is some evidence that physical infrastructure to improve water control or reduce losses has a detrimental impact on downstream farmers, so all interventions need to be evaluated and implemented in a river basin context.

- Water is inadequate: demand is almost always greater than supply even allowing for rainfall and even in many parts of well-supplied systems. The situation deteriorates towards the tail of most systems, although return flows can result in excess water at a late stage.
- There have been substantial reductions (measured) in river and canal flows in dry season over the past 20 years, and reported increases in flood flows (anecdotal but supported by water level observations). These are believed to be mainly a consequence of changes in land and water use in the upper catchments which affect runoff.
- Canal flows follow rainfall: flows increase in response to rainfall, ie. they match supply in the river rather than crop water requirements; abstractions are not reduced at time of high rainfall, except in the case of extreme events and then sometimes because of flood damage rather than deliberate operation.
- Permanent weirs and intake structures prevent many problems with abstraction of water from the river and, combined with better control structures, can significantly improve water management within individual systems. However, this can influence downstream farmers/systems – particularly those reliant on direct return flows via drains, but also downstream systems taking water from the same river.
- Equitable management is very challenging, usually with pronounced head-tail variations in access to water, sometimes enshrined in water rights. Surface storage is only possible on a very small scale, and few people have access to tubewells. Large-scale conjunctive management of surface and groundwater would be needed to improve this situation.
- In many cases command areas are declining, partly due to shortage of water. Loss of agricultural land as a result of urban development and decreasing interest in subsistence agriculture in marginal areas appear to be more immediate reasons for the changes.

8.2 Recommendations

8.2.1 Policy

Although climate is not mentioned in detail in the irrigation policy, there are few specific additional requirements which are required to cover the needs of small and medium scale irrigation and climate change. Climate resilience should be mainstreamed rather than an additional separate factor.

Policy and program support is needed for to strengthen governmental coordination mechanisms between technical departments/ministries and local government, to improve coordination in critical areas related to irrigation performance and resilience. It is also needed to strengthen

technical units in DOI and DOLIDAR to ensure human resources available to design, implement and manage climate resilient irrigation.

Water is scarce and needs to be managed to take account of all uses – this requires promotion of IWRM, including establishment of river basin organisations and ensuring a coherent approach to rehabilitation of water systems in a cluster within a basin / sub-basin. This includes small-scale individual actions for soil and water conservation in the upper catchment. There need to be rational procedures for quantifying impacts, analysing trade-offs between users and other stakeholders, and developing appropriate cost and benefit sharing arrangements.

There needs to be strengthened research capacity and linkages between DOI, DHM, DOA, DOLIDAR, DSWC and related agencies to ensure that research is planned appropriately and put into use.

8.2.2 Planning

There is inadequate data for reliable assessment of the climate and water resources. This lack of data is a significant constraint to design of infrastructure even under current conditions. There is a need to increase the density of rain gauges and introduce streamflow gauging on representative small catchments. This is an urgent need.

Irrigable areas may need to be reviewed to suit the new estimates of rainfall and runoff, particularly in the case of new systems, although the changes are likely to be small in comparison to other uncertainties in the data.

Provision of storage would have substantial benefits, but this is difficult to achieve. There is sometimes scope for small ponds along canal alignments, but a greater opportunity is by development of tube wells to be managed conjunctively within the surface irrigation command. Inter-basin transfer of water is another option for augmenting supply, but again is generally very expensive.

8.2.3 Design and Construction

Resilient design will depend on revisiting the hydrological and related parameters, including:

- Low flow calculations in heavily modified ungauged catchments, with changing land use patterns and increasing non-agricultural uses (domestic, industrial, etc).
- Flood estimates under existing conditions as well as potential increased rainfall/intensity conditions.
- Calculation of crop water requirements, taking account of increased temperature.
- Estimation of effective rainfall, and any changes anticipated as a result of increased intensity of storms.
- Estimation of return flows, and the impact of changes in infrastructure (eg control structures and canal lining) and institutions (eg management arrangements or water rights). This will include analysing both the impact on downstream users, and on the impact of upstream changes on the system being designed or managed.

The design parameters under climate change scenarios is one of the main local concerns. The general finding of this study is that there are larger concurrent changes which affect design, and there some weaknesses in application of the existing design procedures. It is important to ensure that hydraulic structures are designed rigorously and scrupulously checked. Even small structures are technically demanding, and poor design can lead to damaging failures. There may need to be additional components like design of safety embankment as fuse plugs, canal escapes, spillways with flashboards, review of freeboard requirements and so on. Sediment

exclusion structures are unlikely to be feasible on most small or medium systems, but preparation and use of appropriate operating rules would reduce the problem

A risk-based approach is needed, as described in Section 7.3.1, to consider the consequences of design parameters being exceeded – what will fail, what is the impact of failure (timing duration, etc); what measures can be brought into to protect against large-scale damage; design to enable to modification if necessary. This will include both flood flows (to avoid catastrophic damage) and droughts (to enable fair water sharing when the 80% reliable flow is not available).

However, simple procedures are inevitably necessary for these small schemes and the important requirement is that designs should either be robust or adaptable.

Modern delivery systems, particularly drip irrigation, will result in a much higher proportion of the abstracted flows being consumed. At present this is a very small-scale activity but if it is adopted widely in the longer term, it will affect the water resources available to others. In the shorter term, farmers may need assistance with integrating drip irrigation into a traditional surface system. This will usually need intermediate small-scale storage and pumping.

Dry season irrigation is difficult with traditional designs as canals are large and have high seepage losses. Innovations to deal with this include piped systems, lift irrigation from alternative sources, and so on.

8.2.4 Management, Operation and Maintenance

National Level

There is a need for improved climate monitoring and forecasting, by DHM, for flood and drought risk management as well as for developing appropriate design parameters as described above. There needs to effective communication mechanisms to reach WUAs and farmers would enable farmers to adjust cropping to suit the expected climate, and possibly to adjust irrigation plans. WUAs can be involved in some aspects of data collection and management to supplement the official activities. This can be a useful additional source of data as well as building local awareness and understanding of climate and water.

River Basin Level

A combination of good infrastructure and good management is needed. At a higher level this may include establishment of River Basin Organization (RBO) for water accounting, water regulation, monitoring, and providing techno-economic clearance of potential interventions. Initially river basin based management of water resources could be through a federated WUA. Working with the DDC (or successor local bodies) this will include management of river bed quarrying (and associated environmental protection measures), river training flood alleviation works, and dispute resolution at river basin level.

Community level

There needs to be greater understanding of the nature of climate change and the practical implications of this. This will help develop mechanisms for responding to seasonal and short term forecasts, as well as improve system management.

Operating rules may need to be adjusted to ensure that floods do not cause damage or allow unnecessary amounts of sediment to enter the system.

Ground and surface water are generally used independently, but conjunctive management would enable more effective and economic use of water.

Farmer level:

Farmers will need some capacity building to enhance their ability to absorb, adapt, anticipate change, in response to both climate uncertainty and other non-climatic changes.

Providing better access to knowledge, and building willingness and resources to adapt or diversify agriculture, and livelihoods more widely will farmers help cope with change.

Training and support for better on-farm water management and uses of modern irrigation techniques, including optimal use of agricultural mechanization and land levelling.

Role of the private sector

The private sector including input providers and markets has an increasing role in agriculture, which is being promoted by DOA. The value chain approach will help identify commercial elements which are vulnerable to climate change, and appropriate climate smart agriculture measures

Crop insurance is a new development which could help cope with climatic risks, but this is a difficult subject and will need to be introduced on a pilot scale as the insurance market is weak in Nepal.

8.3 Concluding observations

Climate is changing and this will get worse. Water is already scarce: river basins are stressed and need to be better managed to ensure that water is, overall, used in the best way possible. The smaller the basin the more sensitive it is to change, and most irrigation is dependent on small catchments. Adaptive management is essential – irrigation can be developed gradually as the situation changes. Climate finance also provides new opportunities for facilitating transformational change of agriculture and enabling a more resilient and prosperous society.

Irrigation is highly sensitive to climate, and actions to reduce this sensitivity are likely to be complex in terms of both infrastructure and institutions. Actions in one area may have negative impacts in other areas, so it is recommended that any changes are carefully monitored and introduced incrementally as they are needed. Sensitivity tests can be done to analyse and mitigate the risk of catastrophic damage in the short term.

A coherent approach requires consideration of the three components of a resilience framework:

- Systems (infrastructure and river basins)
- Institutions (rules)
- Agents (actors/individuals/organisations)

This leads to the following recommendations for each component, for improving the performance and resilience of small and medium scale irrigation in Nepal.

Systems:

- Climate stations are improved, at least for key parameters (min and max temperature, and daily rainfall), with river flow monitoring introduced in representative small basins.
- More reliable methods are derived for flood and low flow forecasting in ungauged catchments, and estimation of effective rainfall.
- Research is undertaken on the impact of soil and water conservation in upper catchments, including small-scale water harvesting as this can reduce availability further downstream.
- Risk-based approach to design is introduced, with improved procedures for

- Design of diversions and intakes, particularly in flashy Siwalik rivers
- Flood and sediment control at permanent intakes
- Consideration of lift irrigation to reduce the need for long vulnerable canals in the hills
- Management of low flows, diversified cropping, crop water requirements and delivery mechanisms for winter and spring cropping
- Evaluation of new approaches to infrastructure, including
 - Lift irrigation in hills and on river terraces (*tar*)
 - Provision and use of small-scale and on-farm storage.
 - Tubewells integrated into surface systems

Institutions:

- Water management is improved (at system level and on-farm), with development and use of appropriate operating rules.
- There is a value chain approach to agricultural development, linking producers to markets and addressing constraints at all levels.
- Support is provided for deep and shallow development to supplement surface irrigation, and for conjunctive management of surface and groundwater (covering arrangements for both development and management of tubewells)
- Institutional arrangements for river basin management are developed and strengthened (considering all water users, and actions in the river), with better understanding of the trade-offs between different users and optimal sharing of benefits.

Agents

- Actions are taken to promote understanding of climatic and other changes, their impacts, and coping mechanisms in the context of irrigated agriculture.
- Make better use of short term and seasonal forecasts on water availability and floods, and adapt crop and water management decisions accordingly.

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