Contribution of Irrigation to Sustaining Rural Livelihoods

KAR Project R 7879

Literature Review

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MDS 0537

Report OD/TN 109
September 2001

HR Wallingford

DFID Department For International Development

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Summary

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Background
Project R7879, "Contribution of Irrigation to Sustaining Rural Livelihoods", has the purpose of seeking to help governments reduce poverty in rural areas in developing countries by providing information and policy guidelines to ensure that irrigated agriculture secures productive livelihoods for the poor. Primary research for the project is to be conducted on case-study irrigation systems in Bangladesh and Nepal.

This literature review examines agricultural intensification through the practice of irrigation as a strategy for sustainable rural livelihoods. Core concepts to be applied in the research are those of the Sustainable Livelihoods Approach (SLA), as described by DFID (1999). These emphasise that the approach will be people-centred, holistic and dynamic in seeking to understand, learn from and build upon the changes introduced by irrigation development. It will start from an analysis of people's assets, opportunities and constraints, seeking to build on existing poverty-reducing potential and emphasising the issue of sustainability. Asset endowments to be considered are the five forms of 'capital': human, physical, social, natural and financial. Further emphases are the linkages between activities at the macro and micro levels and the importance of the policy and institutional environment in influencing chosen livelihood strategies and outcomes. There is also a need to understand the 'vulnerability context': the trends (e.g. economic and technological), shocks (e.g. climatic or market related) and cultural practices, which affect livelihoods.

Poverty can be characterised in numerous ways, ranging from traditional approaches that emphasise low consumption or income, to broader conceptions of well-being or livelihood. No single measure will be adopted for this research, which will draw on a range of primary and secondary information sources in assessing poverty in the case-study areas. Applying the concepts of the SLA, broad and multiple measures of poverty will be used, including assessment of vulnerability/resilience, asset endowments, participation and empowerment.

Summary *continued*

Processes of Irrigation Impact on Livelihoods
The literature identifies four inter-related mechanisms through which irrigated agriculture can enhance and sustain rural livelihoods. These are:

i) improvements in the levels and security of productivity, employment and incomes for irrigating farm households and farm labour;
ii) the linkage and multiplier effects of irrigation development (as part of wider agricultural growth) for the wider economy;
iii) increased opportunities for rural livelihood diversification;
iv) multiple uses of water supplied by irrigation infrastructure.

For i)-iii), it is often not possible to separate assessment of the impact of irrigation from assessment of the effects and impact of the "green revolution" (GR) package of technology. This is because of the strong synergy or complementarity, between use of irrigation and use of improved seed and fertiliser technology. (These are described in Section 4.)

(i) Improved levels of productivity, employment and income
Evidence on the improved levels of productivity, employment and income resulting from irrigation is widespread, well documented and relatively uncontroversial. Both empirical studies of the GR and of irrigation development alone, confirm that higher value crops, higher yields and the more intensive cultivation techniques lead to higher, less risky and more continuous levels of rural employment and income, for both farm families and landless labour. Landowners may also benefit from increased land values, often enhancing their access to credit, social standing and empowerment within the community. Landless labourers and rural households with small landholdings, but also dependant on on-farm employment as a source of income, benefit from: increased and more evenly spread farm labour opportunities, improved wage rates, reduced out-migration and increased return migration and improved security against impoverishment. Raising incomes from wage employment is critical to poverty alleviation, as so many of the poor are primarily landless agricultural workers. All rural households, and particularly those who are net purchasers of staple foods, may also benefit from lower food prices and potentially better nutrition throughout the year. If so, they also gain from a positive correlation between nutritional status and labour productivity, which is enhanced when improvements are not just in terms of physical productivity but a greater ability to learn and invest labour and knowledge (Dasgupta 1998). (See Section 4.11.)

Research priorities will be to assess the extent of these effects in the case-study schemes, and the processes by which improvements in productivity, employment and incomes can lead to enhancement of the 'capital' endowment and livelihood opportunities and sustainability of both land-owning and landless households.

(ii) Linkage and multiplier effects
Income, employment and wage rate effects are vitally important. Recent research and accumulated empirical evidence (particularly from Southeast Asia and Latin America) supports the renewed understanding that the central driver of poverty reduction is economic growth. Therefore, it is critical to support the productive activities of the rural poor, given the structure of developing economies (high proportion of GDP and employment in agriculture) (Dollar and Kraay 2000).

Summary continued

Agricultural intensification and productivity improvements can be both poverty reducing and growth promoting, and have been found to be causally prior to growth in manufacturing and services. The reverse is not true, and hence the sectoral composition of economic growth matters. Similarly, rural growth reduces poverty in both rural and urban areas, but urban growth does not alleviate poverty in rural areas. A growing farm sector may also generate increased tax revenues to help finance provision of infrastructure and social services to all rural households, and/or facilitate sustainable provision via higher user charges and cost recovery. It should also be noted that the poverty-reducing employment benefits of irrigation/agricultural growth may stagnate over time as the labour force grows and wage levels are held down, unless non-farm sources of employment develop.

It is widely argued that agricultural growth is the key to poverty reduction because it is ubiquitous in rural areas, geographically dispersed, massive in aggregate and labour intensive. Demand growth for this sector can initially come only from rising farm incomes that then stimulate the rural economy via production and consumption linkages, and the transfers associated with decline in the real price of food. Research shows that production linkages stimulate the input supply and output processing and distribution industries associated with agriculture, while even larger multiplier effects arise from consumption linkages, as rural households purchase more locally produced goods and services (Delgado and Hopkins 1998). It is the combination of rapid productivity growth in farm and non-farm rural sectors, the latter made up of commodity and service producers, linked to agricultural households as suppliers of production inputs and consumer goods, that produces an outcome that is pro-poor. This is reinforced when the purchases made by farm households are non or semi-tradables that benefit from a degree of ‘natural’ trade protection, and tend to be labour intensive.

The relevance and importance of production and consumption linkages is supported by a number of empirical studies. These tend to show that at the income levels relevant for most of the countries of Africa and Asia, multiplier effects are of the order of 1.3 to 1.9, that is a 1% increase in agricultural output gives a 0.3 to 0.9% increase in non-agricultural output. Also, most of these studies show that at least 75% of these effects arise through consumption linkages (Thirtle et al. 2001).

Criticisms of the importance of linkages and the models used to quantify them do exist. While insufficient to dismiss the ‘model’ of agriculture as ‘the engine of growth’ for the rural economy, they emphasise that stimulating agriculture (and hence irrigation development) may be necessary, but not sufficient, to achieve economic growth and poverty reduction in rural areas. Complementary interventions such as investment in physical and human capital may also be needed to achieve growth and poverty reduction in the agricultural and non-farm rural economies. (See Section 4.1.2.)

It is unlikely that the research will seek to quantify multiplier effects in Bangladesh and Nepal given methodological and data constraints for the relatively small-scale irrigation development cases selected, and also because of the chosen emphasis on the micro-level processes of irrigation impact. However, the research will investigate the existence and nature of the processes that would lead to such multipliers. For example, the extent of development of backward and forward linkages for farm input and service supply, and output marketing. These are expected to be greater in cases with a higher density of population and rural infrastructure development, or where there is a need for immediate and local processing of farm produce. Alternatively, some authors have argued for the existence of strong consumption linkages in situations where isolation means that incremental farm income is disproportionately spent on locally produced goods and services.

(iii) Rural livelihood diversification

Expansion of the non-farm labour market also provides opportunities for diversification of livelihoods for rural households. This is pro-poor when the opportunities are in low barrier-to-entry employment or micro-enterprise (Reardon et al. 2000), and may provide higher and less variable incomes in aggregate. This may feed back into agricultural growth and/or poverty reduction by reducing risk aversion, helping finance use of inputs, facilitating commercialisation and specialisation, or financing investment in any of the five forms of ‘capital’, thereby further enhancing livelihood opportunities.

Alternatively, prior to irrigation, rural households may have had complex livelihood strategies that crossed the simple boundaries of hunting and gathering, farming, labouring, and being an entrepreneur and a consumer. For such households, the changes in farm output, prices, employment, wages and natural resources that may have arisen from irrigation development may have complex effects. (See Section 4.1.3.)

The research will seek to determine whether livelihood diversification in the case-study areas exists as a means of survival, but doing little for poverty reduction, or as a means to sustainable improvements in living standards through exploitation of new opportunities created by irrigation development. Whether the rural non-farm economy is a residual sector offering only distress or coping activities, mopping up labour displaced from a failing or land scarce smallholder farm sector; or whether it is a dynamic diversifying economy, stimulated by irrigation, creating new jobs and averting downward pressure on wages, such that livelihood diversification is a progressive and positive strategy of adaptation leading to accumulation by rural producers (Start 2001). Also whether there are differences between relatively rich and poor with regard to non-farm activity as a survival or accumulation strategy.

(iv) Multiple uses of water

Irrigation often provides water for drinking, washing, homestead gardens and trees, livestock, replenishment of aquifers (affecting quality and quantity), urban water supply, rural industries, artisanal fishing and aquaculture. The quantities used may be small but vital in maintaining the viability of the livelihoods of certain groups, their income, nutrition and health. Such uses of water may be critical to the livelihoods of women and other disadvantaged groups. However, it needs to be recognised that the range of stakeholders with an interest in the water resources of an irrigation system go far beyond the owners and cultivators of irrigated fields. Multiple uses of irrigation water are also related to linkage effects and livelihood diversification described above. (See Section 4.1.4.)

The research will identify such multiple uses, and assess their importance to livelihood strategies in the case-study schemes

Effects on social equity

Despite the literature providing clear evidence that irrigation development can be poverty reducing, bringing absolute benefits to the poor, a further issue is whether it tends to be equity reducing. In other words, does irrigation tend to deliver proportionally greater benefits to the rich, even when it improves the absolute position of the poor; or are there instances when irrigation development may actually be harmful to the livelihood opportunities of the poor and lead to an increase in poverty. The processes by which either of these two outcomes can arise are identified in section 4.2. Studies of the impact of both irrigation development and the GR (excluding impacts of large dam construction) suggest that the first of these two outcomes is most common, but that the second is possible.

The research will seek to identify how factors such as biases in technology development and transfer, infrastructure provision, market failures in input and output markets or farm credit provision, or constrained participation by poor households may influence the distribution of gains from irrigation.

All four mechanisms by which irrigation development may improve livelihoods are likely to be less effective in poverty reduction when prior distributions of income, land and/or water rights are highly skewed, or when irrigation reinforces land consolidation processes in which some groups lose access or rights to cultivate land or rights to water. The extent to which the rural poor can benefit from expanded opportunities in non-farm employment and micro-enterprise can also be limited by barriers to entry arising from: ethnicity or caste, gender, skill and education levels, access to information, mobility, transaction costs and risks (Reardon et al. 2000).

Gender, irrigation and sustainable livelihoods

With regard to gender, the literature clearly shows that the link between rural poverty and women's unequal access to productive resources has often not been acknowledged, and that irrigation policies have been consistently addressed to men with little or no attention to women's needs and multiple uses of water (IWMI). Studies have shown that where gender-based needs and uses of water are not accommodated, risks are high that the goals of irrigation management are not achieved (Jones 1983), (Blumberg 1989), and that an untapped source of productivity could therefore lie in addressing gender disparities in agriculture (Brown et al. 1995). Understanding the full livelihood impacts of irrigation development in the research will require investigation of the gender differences in relation to water use, control of household assets and productive resources and differentiation in labour allocation. (See Section 4.3.)

Summary continued

Environmental impacts of irrigation development
Most literature concerning the environmental impact of irrigation falls into two categories. First, sets of guidelines for identification and appraisal of impacts at the design stage. These tend to emphasise direct negative impacts and while useful in identifying categories of potential impact and mechanisms for their measurement, do not relate these impacts to indicators of productivity loss or to impacts on rural livelihoods. Second, a set of publications investigating the effects of waterlogging and salinisation on agricultural productivity levels, which cite the resulting depletion of the natural capital stock, or assess impacts on public health, i.e. human capital. Although providing more tangible relationships between the use of irrigation and productivity levels, these studies tend to be context specific, and rarely assess consequences for the livelihood strategies of the rural poor.

As increases in agricultural production are central to improvements in the livelihoods of the rural poor, irrigation development is only one of a range of strategies for agricultural intensification (or extensification) that will be implemented. Each of these may also have impacts upon natural capital, and hence a negative environmental impact should be viewed as a mismanagement of the agricultural modernisation process (Pinstrup-Andersen and Pandya-Lorch 1994), rather than being attributed to a specific strategy. A more balanced view of the *net* contribution of irrigation related activities to changes in environmental status, both in the irrigated command area and at a wider basin/regional level, is therefore required.

This implies assessment of environmental impacts at two levels. The *direct* impacts of the construction and subsequent operation and maintenance of irrigation on the natural capital stock, can be assessed in terms of change in the status of natural capital for productivity and sustainability of resource use, both within the command area and downstream. The *indirect* impacts of irrigation development are through its *net* effects on farming practice and hence livelihood strategies. This requires assessment of the "without irrigation scenario" that would be adopted to increase agricultural output (e.g. extensification onto more marginal lands, or intensification of rainfed production through increased agro-chemical use), or alternatives such as out-migration. (See Section 4.4.)

Empirical Evidence
Sections 5, 6 and 7 review available studies providing empirical evidence relating to all the processes described above; globally in section 5, and for Bangladesh and Nepal in sections 6 and 7 respectively.

Irrigation, and particularly groundwater development, was a critical element in the success of the GR, which has generally been deemed to have been poverty-reducing, primarily through its productivity, employment and income effects. However, in relation to changes in equity, a range of distributional outcomes arose, dependent on prior and evolving conditions, notably distribution of landholding. Most commonly for both evaluation of the GR and irrigation development, the majority of marginal landowners and landless households were found to have become absolutely better off. However, the changes in technology introduced were equity reducing because the increase in returns to land has disproportionately favoured those with the most land.

Summary *continued*

Analysis for India has shown that the level of physical capital i.e. the stock of irrigation infrastructure, is a determinant of marginal returns to further investment, in terms of agricultural productivity and poverty reduction. Thus expansion of irrigation was vital in the early stages of the GR, but laid the foundation for the current situation in which marginal returns to investment in roads and agricultural research and extension are now greater than those for further expansion of irrigation (Fan et al. 1999).

It is also notable that groundwater use is generally judged superior to surface irrigation for productivity gains and poverty reduction. With regard to equity, access to the groundwater resource is the key. While water markets can play a positive role, equitable access is also positively influenced by availability of diverse equipment, well matched to conditions, and including manual technology such as treadle pumps.

These observations about groundwater apply in particular to Bangladesh, where the main impetus to foodgrain output growth came from the rapid development of minor irrigation technologies and especially tubewell irrigation. This followed liberalisation of the market for irrigation equipment in the 1980s. The resulting productivity, employment and income effects for irrigators and landless labourers have been significant and widespread. There is less evidence from Bangladesh regarding the linkage and diversification effects of irrigation development, which reflects a lack of a livelihoods focus in most evaluations of irrigation impact to date. The gender concerns summarised above generally apply in Bangladesh, and the increased labour burden of increased cropping intensity with irrigation often falls primarily on women. Surprisingly, despite the abundance of aquifers as a resource, environmental concerns are also arising from depletion of groundwater levels in some areas, intensification of agro-chemical use, and conflict over water resources given alternative uses such as fishing.

The main focus of irrigation investment in Nepal has been on expanding supplementary monsoon irrigation (mainly through run of the river diversion schemes). It is argued that year-round, well controlled water, is an essential element for more widespread and successful adoption of GR technology and to raise returns to other key investments such as roads (APROSC and JMA Inc. 1995). Despite these limitations, and as in Bangladesh, there is clear evidence that irrigation has delivered widespread benefits through increases in productivity, employment and incomes. Gender issues are also again highly significant, and one detailed study concluded that irrigation had positive effects on total food production and farm income distribution, but long-term negative effects on child nutrition via the effects on women's time allocation. Environmental issues are potentially complex, even though direct negative environmental impacts of irrigation to date appear limited, as there is a particular need to consider the "without irrigation" scenario in terms of alternative livelihood strategies for remote rural areas. There is some controversy about the extent to which population pressure and expansion of cultivation in hill areas causes deforestation and erosion, and this merits further investigation.

Summary continued

General conclusions
Irrigation can play a central and dynamic role in the improvement of rural livelihoods, but is often subject to criticisms of inefficiency in water use, high capital and recurrent costs, lack of sustainability, and association with inequity in the distribution of both land and water.

Irrigation is an effective, but blunt, instrument for reducing rural poverty, and research is needed on the best means to reduce disparities among landowners and between landowners and other groups, without compromising productivity and wider poverty alleviation gains.

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This report is an output from the Knowledge and Research (KAR) contract R7879, "Contribution of irrigation to sustaining rural livelihoods" funded by the British Government's Department for International Development, (DFID) for the benefit of developing countries. The research team comprises the International Development Group, HR Wallingford, the Agricultural Economics and Business Management Research Group, Imperial College at Wye, the Local Development Training Academy (LDTA), Nepal, Bangladesh Agricultural University, Mymensingh, Bangladesh, Dr P. Pradhan from Nepal and Professor S. Mandal from Bangladesh.

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Acronyms

APP	Agricultural Perspective Plan (Nepal)
APROSC	Agricultural Projects Services (Nepal)
BADC	Bangladesh Agricultural Development Corporation
BSERT	Bureau of Socio-economic Research and Training (Bangladesh)
CBS	Central Bureau of Statistics (Nepal)
CIRDAP	Centre on Integrated Rural Development for Asia and Pacific
CPR	Common Property Resource
DFID	British Department for International Development, UK
DTW	Deep Tubewell
FAO	Food and Agriculture Organisation
FMTW	Farmer Managed Tubewells
GDP	Gross Domestic Product
GIS	Geographical Information System
GR	Green Revolution
HDI	Human Development Index
HYV	High Yielding Varieties
ICID	International Commission on Irrigation and Drainage
IFAD	International Fund for Agricultural Development
IIMI	International Irrigation Management Institute
IPTRID	International Programme for Technology and Research in Irrigation and Drainage
IWMI	International Water Management Institute
JMA	John Mellor and Associates (Nepal)
MV	Modern Variety
NLSS	Nepal Living Standards Survey
NMIDP	National Minor Irrigation Development Project (Bangladesh)
NPC	National Planning Commission
NR	Natural Resources
NSSO	National Sample Survey Organisation (India)
OECD	Organisation for Economic Co-operation and Development
PRA	Participatory Rural Appraisal
SLA	Sustainable Livelihoods Approach
SOM	Soil Organic Matter
STW	Shallow Tubewell
TFP	Total Factor Productivity
UP	Uttar Pradesh
UN	United Nations
UNDP	United Nations Development Programme
WUA	Water User Association

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1. INTRODUCTION

Rural people partake in a number of strategies, including agricultural intensification, migration and livelihood diversification, which enable them to attain a sustainable livelihood. This literature review examines agricultural intensification, through the practice of irrigation, as a strategy for sustainable livelihoods. It has been prepared as part of project R7879 -"Contribution of Irrigation to Sustaining Rural Livelihoods", the purpose of which is to help governments reduce poverty in rural areas by providing information and policy guidelines to ensure that irrigated agriculture secures productive livelihoods for the poor. Primary research for the project is being conducted in Bangladesh and Nepal.

Sections 2-3 briefly review the concepts of the livelihoods approach and the definition and measurement of poverty, as they underlie and frame the research. Section 4 considers the processes by which irrigation development may have impacts on rural livelihoods, including distributional, gender-related and environmental effects. Impacts that arise through linkages to the wider economy parallel those of agricultural growth more generally, and hence debates concerning the role of agricultural growth in economic development and poverty reduction are also briefly summarised.

Sections 5-7 review the evidence in the literature of the livelihood impacts of irrigation development for farm families and other rural households, with particular emphasis on impacts for poor and vulnerable groups. Global examples from the literature are cited where relevant, but priority has been given to review material from South Asia and particularly that relating to the case-study countries of Bangladesh and Nepal. Given irrigation's role as one element of the green revolution package of technical change, the established consensus concerning the impact of the green revolution is also reviewed.

2. SUSTAINABLE LIVELIHOODS

The conceptual framework that underlies both the design of this research project and the interpretation of literature in this review is that of the Sustainable Rural Livelihoods (SRL) approach developed by the Department for International Development (DFID). The following definition is used: 'A livelihood comprises the capabilities, assets (including both material and social resources) and activities required for a means of living. A livelihood is sustainable when it can cope with and recover from stresses and shocks and maintain or enhance its capabilities and assets both now and in the future, while not undermining the natural resource base' (DFID 1999). In the achievement of a sustainable livelihood the tradeoffs between productivity, equity and sustainability are critical.

Core concepts are that the approach is people-centred, holistic and dynamic in seeking to understand, learn from and build upon change. It starts from an analysis of people's strengths, opportunities and constraints rather than needs, seeking to build on existing poverty reducing potential and emphasising the issue of sustainability. Further emphases are the linkages between activities at the macro and micro levels and the importance of the policy and institutional environment in influencing chosen livelihood strategies and outcomes. There is also a need to understand the 'vulnerability context': the trends (e.g. economic and technological), shocks (e.g. climatic or market related) and cultural practices which affect livelihoods.

At the heart of the approach lies analysis of the five different types of assets upon which people draw to build their livelihoods. These are: natural capital (e.g. land, water, biodiversity), social capital (social resources including networks, group membership, trust and access to wider institutions in society), human capital (skills, knowledge, health and ability to work), physical capital (infrastructure and goods that support livelihoods such as transport, energy, tools and buildings), and financial capital (financial resources including savings, remittances, pensions and credit) (Carney 1998), (DFID 1999).

These assets constitute livelihood building blocks. To a limited extent they can be substituted for each other. Thus, the poor may draw on social capital such as family or neighbourhood security mechanisms at times when financial capital is in short supply. Within this context, people are likely to pursue multiple activities and outcomes. They may, for instance, depend on their own farming, on selling their labour locally, or on migration, all within the same year (diversification of livelihoods is discussed further in section 4). Outcomes will not be simply monetary, nor even tangible in all cases. They may include, for instance, the sense of being empowered to make wider, or clearer, choices. Indicators of sustainable livelihoods include consumption levels, access to and levels of the five forms of assets, and processes such as resilience and adaptation. As "livelihoods thinking" is relatively recent, few of the empirical studies of irrigation impacts reviewed in sections 5-7 refer explicitly to such indicators, although their findings are in general highly relevant though more narrowly focused on productivity, income and distributional effects.

2.1 Social capital

Compared to the other four forms of capital the nature of social capital is less well known but has recently received much attention. It refers to the institutions, relationships and norms that shape the quality and quantity of a society's social interactions. Increasing evidence shows that social cohesion is critical for societies to prosper economically and for development to be sustainable (World Bank 1999). A narrow view of social capital comprises a set of horizontal associations between people, consisting of social networks and associated norms that facilitate co-ordination and co-operation, and have an effect on community productivity and well-being (World Bank, 1999). Social networks can increase productivity by lowering the cost of information and the transaction costs of implementing and enforcing contracts (trade). Important in this, is the role of trust, i.e. the expectation of regular, honest and co-operative behaviour, based on commonly shared norms. Schmid (2000) argues that the source of social capital lies in attitudes and these shared norms. Thus commonly used indicators, such as number of associations, number of members, social events attended, donations given, degree of civic involvement, may be useful measures of social capital, but are difficult to benchmark and only measure behaviours and not attitudes. Alternatives are to use ranking questions or scales to assess whether people can be trusted, or whether certain actions are acceptable or justified in the society, and what the consequences for unacceptable actions may be. For example, in relation to the impact of interventions such as irrigation development, can people perceive changes in themselves or their community with regard to their motives or attitudes and in relation to participation in social networks, both over time and in comparison to other communities?

A broader understanding of social capital includes vertical as well as horizontal associations between people, and includes behaviour within and among organisations, such as firms. This view recognises that horizontal ties are needed to give communities a sense of identity and common purpose. However, it also stresses that without "bridging" ties that transcend various social divides e.g. religion, ethnicity, and socio-economic status, these horizontal ties may preclude access to information and material resources which could be of use to the community (e.g. information about job opportunities, access to credit). The most encompassing view of social capital includes the social and political environment that shapes social structure and enables norms to develop. This extends the importance of social capital to formalised institutional structures such as government, the political regime, the rule of law, the court system, and civil and political liberties (World Bank 1999).

3. DIMENSIONS OF POVERTY

Poverty can be characterised in numerous ways, ranging from traditional approaches that emphasise low consumption or income, to broader conceptions of well-being or livelihood. In recent years, researchers have made progress in broadening the understanding of poverty and demonstrating some shortcomings of measures based on consumption or income (UNDP 1998).

What is necessary to satisfy basic needs varies across time and societies. Poverty lines, therefore, vary in time and place, and each country uses lines, which are appropriate to its level of development, societal norms and values (World Bank 2000). Poverty reduction can be achieved not only by increasing the means and possessions of the poor, but also by increasing the output and value of the limited means they have, and reducing negative shocks and stresses on production. Therefore, the standards used in different countries vary. For example, the National Planning Commission in Nepal (NPC) defines the poverty line on the basis of income needed to supply minimum caloric requirements, while the World Bank defines poverty as less than 1$/day for all basic needs. In central Asia standards are close to US$4, whereas in China the standard is only US$0.6 per person per day. Consumption standards are usually preferred over income standards for measuring poverty because, among other reasons, consumption is more stable from year to year.

A poverty measure often used in South Asia is the head-count ratio, which measures poverty as a percentage of the rural population falling below the poverty line. For example, this ratio is the most important indicator used by the Indian government in setting its goals to alleviate rural poverty. The poverty line is based on a nutritional norm of 2400 calories per day and defined as the level of average per capita total expenditure at which this norm is typically attained (Fan et al. 2000).

Increasing well-being is also a component of sustainable development and poverty-reduction. Chambers (1997) argues that the objective of development is well-being for all, where well-being refers to a good quality of life. It is much broader than wealth and includes the whole range of human experience: social, mental and spiritual as well as material. Two basic components of well-being are having a secure livelihood to meet one's basic needs and realising and expanding one's capabilities in order to achieve fulfilment (Chambers 1997), (Sen 1993).

The World Development Report defines poverty as being not just about income but as multi-dimensional, including access to social services, self-respect and autonomy (World Bank 2000). Participation is viewed as central to poverty alleviation and will include elements of opportunity (i.e. growth), empowerment and security (Maxwell et al. 2001).

Most of the world's poor are rural based and, even when they are not engaged in their own agricultural activities, they rely on non-farm employment and income that usually depend on agriculture, either directly or indirectly. Rural poverty has several specific features, including relatively low population densities, heavy reliance on natural resource-based production and more limited access to public infrastructure and services. Rural people are usually more exposed to risk than urban people, and less able to rely on state intervention to mitigate risk or relieve its effects. Livelihood vulnerability may be increasing as a result of rising inequality, civil conflict, climate change and increasingly severe weather events, as well as adverse consequences of globalisation (Maxwell et al. 2001).

However, as the rural economy is broader than agriculture, any assessment of sustainable livelihoods and poverty reduction should also investigate the effects on non-farm employment as well as agricultural income. In addition, the heavy reliance on natural resource-based production in rural areas leads to seasonal and annual variations in income and has an impact on the environment. Social capital is also an important aspect in rural areas, as it may strongly influence decisions that affect livelihoods. Good health and adequate nutrition are not only important goals in themselves, but they also raise workers' productivity and earnings. The loss of adults of prime working age to disease and illness often leads to shifts in cropping patterns, and may reduce investments in soil enhancement, irrigation and other capital improvements. This may in turn lead to long term effects on output. Investment in primary and secondary schooling may also promote agricultural productivity growth.

4. IMPACT OF IRRIGATION ON SUSTAINABLE RURAL LIVELIHOODS: PROCESSES AND CROSS-CUTTING ISSUES

4.1 Processes

The importance of irrigation to rural livelihoods is highlighted by the fact that irrigated farmland provides 43% of global cereals production and 60% of the grain production in developing countries (IWMI 2000). Of the near doubling of world grain production that took place between 1966 and 1990, irrigated land (working synergistically with high-yielding seed varieties and fertiliser) was responsible for 92% of the total production. Irrigation is also the key to developing high-value cash crops, and, by helping guarantee consistent production, it stimulates agro-industry and creates significant rural employment (World Bank 1997).

Robert Chambers, a pioneer of livelihoods approaches, argued that the generation and support of livelihoods has a higher priority than production *per se* (Chambers 1988). He emphasised that the impact of irrigation on the rural poor depends on who produces the food and who has the ability to obtain it, on who gains and who loses more generally. Overall, he argued that the poor gain from irrigation through increased employment and income, in improved security against impoverishment, from less out-migration and in improved quality of life.

In irrigated agriculture there are four inter-related mechanisms which have the potential to enhance and sustain rural livelihoods. These include:

i) improvements in the levels and security of productivity, employment and incomes for irrigating farm households and farm labour;
ii) the linkage and multiplier effects of irrigation development (as part of wider agricultural growth) for the wider economy;
iii) increased opportunities for rural livelihood diversification;
iv) multiple uses of water supplied by irrigation infrastructure.

Opinion and evidence regarding the scale and effectiveness of each of these mechanisms is summarised below. As cross-cutting issues, key insights into the distributional, gender and environmental dimensions of irrigation's impact on livelihoods are also reviewed.

It is also essential to recognise the synergy, or complementarity, between use of irrigation, and seed and fertiliser technology. Thus, in reviewing empirical evidence of irrigation's impact, it is often not possible to distinguish between the assessment of the impact of irrigation from the assessment of the effects and impact of the "green revolution" (GR). This is illustrated by the work of Evenson et al. (1999). They found that irrigation investment in India generated growth in agricultural total factor productivity (TFP). This was over and above the contribution to output growth that irrigation makes as a conventional input by providing an improved environment for crop technology. Literature assessing the impact of the green revolution on rural livelihoods is thus also reviewed below.

4.1.1 Productivity, employment and income effects for farm households and farm labour

First and most directly, where conditions are favourable irrigation can raise the incomes of those farmers with access to irrigated land. Water control in agriculture may boost productivity and incomes by:

- providing adequate water throughout the growing season, thus contributing to higher yields by eliminating water deficits and providing at least a measure of drought protection;
- securing at least one crop, by making water available in areas where rainfall is inadequate, highly variable or during drought;
- providing a cheaper or more secure supply of fodder for livestock;

- supplementing rainfall in humid regions to ensure high yields and quality, which generally leads to higher farmgate prices;
- allowing experimentation with new crops and varieties for which market opportunities exist;
- improving timeliness or crop duration allowing area expansion;
- enabling farmers to adapt timing of production to take into account market demand, higher prices, weather conditions and to avoid adverse weather extremes;
- reducing production risk and the need for farm output diversification, thereby encouraging farmers to gain the benefits of greater specialisation and commercialisation;
- reducing risk and raising returns in the use of complementary inputs such as improved seed and fertiliser;
- reducing problems of flooding, waterlogging and soil salinisation;
- improving the quality of soils through leaching and drainage, especially in the case of tubewell irrigation;
- enabling management of the micro-climate to reduce incidence of frost or low temperatures that damage crops;
- facilitating development of multiple farm enterprises around livestock, crops and agro-processing;
- raising farm household and hired labour productivity.

A further benefit for landowners may be appreciation of the value of land with irrigation, which often enhances access to credit, and social standing and influence within the community.

Landless labourers, and those with small landholdings but who also depend on on-farm work as a source of income, will benefit from:

- increased and more evenly spread farm labour opportunities and improved wage rates;
- reduced out-migration and increased return migration;
- improved security against impoverishment.

Raising incomes from wage employment is critical to poverty alleviation because so many of the poor are landless agricultural workers. As with other forms of agricultural intensification, impacts of irrigation on wage employment are both indirect and partial due to the confounding effects of other factors that drive agricultural wages. These include population growth, labour migration, economic policies and changes in the non-agricultural sector (IPTRID 1999).

All rural households, and particularly those who are net purchasers of staple foods, will also benefit from lower food prices and potentially better nutrition throughout the year.

Evidence for these effects is widespread, well documented and relatively uncontroversial. The FAO state that in developing countries irrigation can increase yields for most crops by 100 to 400%, whilst also allowing farmers to reap the economic benefits of growing higher-value cash crops. Higher, less risky and more continuous levels of rural employment and income, for both farm families and landless labourers, can result from the higher cropping intensities, higher yields and more intensive and higher value cultivation techniques of irrigated compared to rainfed agriculture (FAO 1996).

Scoones (1996) argued that in semi-arid areas there is potentially no better way to reduce rural vulnerability and ensure the viability of people’s livelihoods than to enhance natural capital and the productive base. Protecting the system against drought requires investment in water management, and it is irrigation and the water storage provided by small dams or enhanced recharge of aquifers that can reduce the vulnerability of rural communities to periods of drought.

For landless labourers, increased cropping intensity has the greatest impact on employment. Chambers (1988) cites several empirical studies in different countries that show that irrigation systems directly raise employment, by increasing both days worked per hectare and days worked during a cropping season, as well as creating additional employment in a second or third irrigation season. Irrigation also affects the labour use of different groups in different ways. The landless gain on-farm work for more days of the year, especially when there is more than one irrigated crop in a year. For small and marginal farmers, an irrigated crop typically means more use of family labour on their own land, earning an implicit wage rate higher than the next best source of employment. Some farmers who used to work for others, may find themselves hiring labour as a result of the intensification (Chambers 1988). The employment impact is also felt in rain-fed areas, as landless workers in rain-fed villages can migrate long distances to take advantage of employment opportunities in irrigated areas (IPTRID 1999).

The potential benefits of irrigation to labourers are thus a rise in daily wages, longer and more reliable employment, higher and less variable income, and potentially lower food prices, if higher production brings prices down. Counter-migration effects can be of great social and economic value, for example, when two or three crops a year replace one, the need for labourers and marginal farmers to migrate diminishes and may disappear. Families can stay together, it is less difficult to send children to school and home improvements, such as sanitation, are easier to undertake. There are also indirect gains to other poor people in the areas to which the out-migrants formerly went, since competition for work is reduced and wages may even rise. Through increased employment, irrigation also protects against the impoverishment of having to dispose of assets or enter into debt (IPTRID 1999).

The benefits of irrigation development are passed on from farmers to consumers in the form of lower prices. For example, the fall in rice and wheat prices in real terms in India and elsewhere has benefited the urban and rural poor more than the upper income groups, because the former spend a much larger proportion of their income on cereals than the latter (Kumar et al. 1995). In fact, 60% of the money spent on food by people living below the poverty line in Asia is apportioned for cereals (which provide as much as 70% of their total nutrients) (IPTRID 1999).

Irrigation schemes may also function as a development ‘pole’ in rural areas, where increased output and population concentrations attract additional services and infrastructure. Also, the increased incomes from production and employment mean that more families can afford schooling and health care, meaning that services are more likely to be present (IPTRID 1999).

In the past, irrigation has also been used for many political aspects of nation-building, being seen to contribute to improvement of national wealth and well-being. It has been used as a means to open remote or under-populated areas through new settlement schemes. It has also been used as a means to reduce migration, or discourage landuse practices that governments considered unsustainable, such as pastoralism and shifting cultivation, though it has sometimes been used unsuccessfully. Irrigation schemes have often been a powerful means for governments to develop closer political links with the rural population (IPTRID 1999).

Tubewell development may also reduce flood-proneness and waterlogging, thus reducing crop damage and expanding monsoon season cropping. As with drought, flood-proneness also induces risk aversion and as a result farmers may cling to traditional mixed-crop farming systems that offer some insurance against risks and minimise cash costs of cultivation (Shah 2001). Livestock production may also be constrained by flooding if grazing lands are submerged for long periods, so there is a greater tendency for small stock production. Waterlogging may also be the cause of degradation of saline-alkaline lands.

4.1.2 Linkage and multiplier effects of irrigation development

4.1.2.1 The role of agriculture in economic growth

The International Fund for Agricultural Development’s (IFAD) Rural Poverty Report 2001 claims that 75% of the 1.2 billion people living below $US 1 per day are rural and estimates that by 2020, 60% of the world’s poor will still be rural. Thus most poverty in the world is rural, and reaching the UN International Development Targets means giving high priority to rural development (Maxwell et al. 2001). South Asia and Sub-Saharan Africa continue to be the regions with the greatest concentrations of absolute poverty, and only East Asia has managed to substantially reduce the proportion of its population that is absolutely poor (Brown and Haddad 1994).

Recent research and accumulated empirical evidence (particularly from Southeast Asia and Latin America) supports the renewed understanding that the central driver of poverty reduction is economic growth. Therefore it is critical to support the productive activities of the rural poor, given the structure of developing economies (high proportion of GDP and employment in agriculture) (Dollar and Kraay 2000). Fan et al. (1999) argue that economic growth is the only way of providing a permanent solution to the poverty problem and increasing the overall welfare of rural people.

Farm-led growth in employment and real purchasing power has received renewed recognition in recent years as the most effective “engine” of economic development and pro-poor growth. Agricultural growth supplies basic foods and raw materials for industry and exports. It frees foreign exchange for import of industrial and capital goods, releases labour and capital (rural savings and taxes) to the non-farm sector, generates rural purchasing power for non-food consumer goods and services, supports growth in services and trade and provides a nascent market for an emerging manufacturing sector (Thirtle et al. 2001). For the majority of the rural poor there may also be few alternatives, for example, Kydd et al. (2001) have argued that the majority of the rural poor are located in areas with no viable alternative income generating activities to agriculture.

This recognition that it is economic, and particularly agricultural growth that reduces poverty, is not new, but it has been relatively neglected over the past 20 years during which the focus has been on macro policy. Foreign aid has turned away from agriculture in favour of social service provision and urban oriented developing country governments have given inadequate attention to agriculture. Brown and Haddad (1994) contend that economic growth, while by no means a sufficient condition for sustained poverty alleviation, is undoubtedly a necessary one, and that for many developing countries, agriculture is the most effective and frequently the only viable sector to generate economic growth. Indeed, very few countries have experienced rapid economic growth without agricultural growth preceding or accompanying it, while in the last 20 years countries that experienced real declines in agriculture had the lowest economic growth rates (Brown and Haddad 1994).

For the poorer developing countries, economic growth is dependent on increases in agricultural productivity, which provides sufficient food for a growing non-agricultural population. The expectation is that as this structural transformation proceeds, agriculture accounts for a falling proportion of employment and income. However, the growth process is driven by the development of the agricultural sector. Increases in food supply keeps food prices down, which is critically important to the poorest people who spend up to three-quarters of their income on food. This will not only benefit the urban poor, but also large numbers of people who are net purchasers of food in rural areas. In an economy where food is only partially tradable, productivity increases in agriculture should result in a decrease in food prices that primarily benefit the poor. Recent studies of poverty reduction in India support this view (Datt and Ravallion 1996). Population growth may offset this by keeping food prices up and rural wages down, however, overall agricultural intensification and productivity improvements have the potential to be both pro-poor and pro-growth (Thirtle et al. 2001).

The literature on growth theory backed up by empirical studies also shows that agricultural productivity growth is required for industrialisation to take place. The need for agricultural growth became part of the conventional wisdom with the Berg Report (World Bank 1981) and the 1992 World Development Report (World Bank 1982), which stressed that growth in manufacturing and services is dependent on agricultural growth, but not vice-versa. This suggests there is a case for agricultural growth-led industrialisation. This is supported by Rangarajan (1982), who estimated that a 1% addition to the agricultural growth rate in India stimulated a 0.5% addition to the growth rate of industrial output and a 0.7% addition to the growth rate of national income.

Thus, the sectoral composition of economic growth matters. Rural growth reduces poverty in both rural and urban areas, whereas urban growth does not alleviate poverty in rural areas. Similarly, growth in the primary sector reduces poverty in rural and urban areas, while growth in manufacturing has no impact on poverty in either (Datt and Ravallion 1996). Thirtle et al. (2001) cite a range of other empirical studies that show similar results.

4.1.2.2 The role of agricultural growth in poverty alleviation

Agriculture is often seen as a source of broad-based growth that reduces poverty rapidly. The majority of the poor live in rural areas and derive most of their income from their labour, hence labour-intensive agricultural technologies are particularly suited to alleviate poverty (Lipton 1977).

Agricultural productivity growth can:

- benefit poor farmers directly by increasing their production;
- benefit small farmers and landless labourers through greater employment;
- lead to lower food prices for all consumers;
- increase migration opportunities for the poor;
- benefit the rural and urban poor through growth in the rural and urban non-farm economy;
- provide access to crops that are high in nutrients;
- empower the poor by increasing their access to decision-making processes, increasing their capacity for collective action, and reducing their vulnerability to shocks via asset accumulation (Thirtle et al. 2001).

There is a also a positive correlation between nutritional status and the labour productivity of the poor (Dasgupta 1998). This is by a greater ability to learn and invest labour and knowledge in improvements.

Few studies have directly investigated the empirical relationship between agricultural productivity and measures of poverty. However, Thirtle et al. (2001) found that for a sample of 40 countries, the headcount index of poverty (the percentage living on less than one dollar a day) fell by close to 1% for every percentage increase in agricultural productivity. For a different and larger sample, the figure was close to two thirds of a percentage point. This was a higher figure than in other sectors.

It is widely argued that agricultural growth is the key to poverty reduction because it is ubiquitous in rural areas, geographically dispersed, massive in aggregate and labour intensive. Demand growth for this sector can initially come only from raising farm incomes. These then stimulate the rural economy via production and consumption linkages and the transfers associated with decline in the real price of food. Research shows that production linkages stimulate the input supply and output processing and distribution industries associated with agriculture, while even larger multiplier effects arise from consumption linkages as rural households purchase more locally produced goods and services (Delgado and Hopkins 1998). In order to produce an outcome that is pro-poor, it involves the combination of rapid productivity growth in farm and non-farm rural sectors. The non-farm rural sectors are made up of commodity and service producers linked to agricultural households as suppliers of production inputs and consumer goods.

Expansion of the non-farm labour market also provides opportunities for diversification of livelihoods for rural households. This is pro-poor when the opportunities are in low barrier-to-entry employment or micro-enterprise (Reardon et al. 2000), and may provide higher and less variable incomes in aggregate. This may feed back into agricultural growth by reducing risk aversion, helping finance use of inputs and facilitating commercialisation and specialisation. A growing farm sector may also generate increased tax revenues to help finance provision of infrastructure and social services to all rural households, and/or facilitate sustainable provision via higher user charges and cost recovery.

As noted above, the spread of benefits of agricultural growth beyond farming households depends on linkages with the rest of the economy. Higher real incomes in the agricultural sector stimulate demand for the products of other sectors and labour within the sector. Higher agricultural outputs stimulate the creation of non-farm rural and urban employment opportunities, through backward and forward linkages to service and manufacturing sector activities. These linkages are categorised by Thirtle et al. (2001) as:

- Production linkages: from the farm 'upstream' through demand for inputs and services for agriculture, and 'downstream' through demand for processing, storage and transport of produce;
- Consumption linkages: through demand from farmers spending increased income on goods and services;
- Enhanced human capital: through increased food (or cash crop) production allowing better nutrition of rural workers and investment in education.

The relevance and importance of these linkages is supported by a number of empirical studies. These tend to show that at the income levels relevant for most of the countries of Africa and Asia, the agricultural linkages can be well established. A range of models has been used to estimate such production and consumption linkages, or multipliers for specific regions. Thirtle et al. (2001) cite a number of studies and resulting estimates, which tend to be quite high. They are of the order of 1.3-1.9, that is a 1% increase in agricultural output gives a 0.3 to 0.9% increase in non-agricultural output. Also most of these studies show that at least 75% of these effects arise through consumption linkages. Similarly, Hazell and Haggblade (1990) report several estimates of agriculture's growth multipliers based on a variety of models. Excluding models with less realistic assumptions, they estimated multipliers ranging from 1.3 to 1.8, again meaning that one dollar of agricultural growth would lead to increased non-farm income ranging from $0.30 to $0.80. For India, Hazell and Haggblade (1990) report that an increase of Rs 100 in irrigated agricultural output stimulates Rs 105 worth of additional manufacturing output and Rs 114 additional tertiary output, a total non-farm multiplier of 2.19. Often cited is the 1972 study of the Muda Valley in Malaysia where extensive irrigation development took place, and for which Haggblade et al. (1991) cite a multiplier of 1.71. Overall, the studies suggest that improved farm productivity has widespread benefits to society, especially in cases where growth reduces the real prices of staples that are non or only semi-tradable.

The precise form and degree of linkages will be affected by:

- rural infrastructure development,
- rural population density,
- the need for immediate and local processing of farm produce,
- the nature of technical change in farming,
- the tradability of goods and services demanded by farm households, and
- the tradability of farm output (Thirtle et al. 2001).

Areas with more infrastructure and well-developed rural-urban links tend to show higher multipliers. However, Delgado and Hopkins (1998) have produced some comparable or higher estimates for cases in Africa where this does not apply. They argue that isolation can mean that any exogenous increase in farm earning will be spent disproportionately on locally produced goods and services.

A number of authors question both the assumptions built into the models used to quantify these growth multipliers and their actual importance. Hart (1989) suggests that the Muda Valley study underplayed the extent to which increased spending went on goods that were imported into the region, and also argues that capital has been exported from the Muda Valley. In a detailed study of a market town and its hinterland in North Arcot in India, Harriss-White (1997) also suggests that capital is exported from rural to urban areas. She also questions the extent to which the farm economy stimulates the non-farm economy. She suggests that the growth of rural industries owes more to the links with urban hierarchies than to farming activity in rural areas.

Clearly, backward and forward linkages do not encompass all rural non-farm activity. Some activities have no linkage to farming other than employing rural labour, using capital and materials from towns or elsewhere and selling output back to towns. In a similar context are remittances and transfers from household members with jobs in urban areas or overseas. This questions whether farming is always the core of the rural economy, or whether it sometimes receives net transfers of capital from non-farm sectors. This is in contrast to the conventional models of development where agriculture is the source of surpluses (Ellis 1998).

Although little empirical evidence is available to resolve this, Thirtle et al. (2001) have observed that thriving farm economies are closely associated with prosperous non-farm economies, for example in many parts of SE Asia. Their study also suggests that there may be wider linkages or complementarities in terms of investments in physical and human capital between farming and other sectors. Thus the rural non-farm economy may be most dynamic and productive in areas where farming thrives.

In terms of complementarities, access to infrastructure and urban markets may again be crucial. Urban areas demand both farm produce and services in their peri-urban hinterlands, so that urban economic growth may drive both agriculture and the rural non-farm economy. Increased productivity in farming may not stimulate rural industry directly, but it may create conditions conducive to investment by facilitating the creation of road, power and communications networks, and a more healthy and educated workforce(Thirtle et al. 2001).

It can also be examined as to whether more social capital is generated as a thriving farm economy promotes the links that establish trust and lower transactions costs between transacting agents. This may reduce risk and transactions costs for investment in non-farm businesses in rural areas (Thirtle et al. 2001).

Agriculture clearly remains of great importance as a source of 40% or more of the livelihood of the majority of the rural population, and in particular the rural poor. Also, a substantial proportion of non-farm income must be linked to agriculture. No other activity consistently offers the same degree of importance. Thus the notion of agriculture as the ‘engine of growth’ for the rural economy cannot be dismissed. However, to achieve economic growth and poverty reduction in rural areas, stimulating agriculture may not be sufficient. Complimentary interventions, such as investment in physical and human capital, will benefit both agriculture and the rural non-farm economy. Also, less favoured (low potential) areas will have different needs to high potential areas where modernisation is already underway. Low potential areas will generally need a strong focus on agriculture-based development, being less likely to benefit from other sources of growth. However, they will generate lower returns to investment in agriculture because of their inherent disadvantages.

The arguments concerning the role that agriculture can play in both economic growth and poverty reduction clearly apply to both rainfed and irrigated agriculture. Although empirical evidence to support this is sparse, it seems reasonable to argue that the potential of the irrigation sector is greater because of the greater intensity of the direct effects on productivity and incomes (as stated above). In addition, there will be fewer technological, institutional and infrastructural constraints to achieving growth compared to rainfed areas, particularly remote and low potential areas. The irrigation sub-sector will tend to be ‘richer’ in terms of the crucial multiplier and linkage effects. As Reardon et al. (2000) emphasise, the potential for livelihood diversification by the poor will be greatest in areas with good infrastructure and dynamic agriculture. This facilitates and creates spin-off employment and micro-enterprise.

4.1.3 Rural Livelihood Diversification

As noted above, the linkages from irrigation development may expand the non-farm labour market as well as providing rural households with opportunities for livelihood diversification. Diversification is a key feature of livelihood strategies. It is defined as the process by which rural families construct a diverse portfolio of activities and social support capabilities in order to survive and to improve their standards of living (Ellis 1998). Smallholders and landless workers may earn around half their total household income from non-agricultural sources. Thirtle et al. (2001) cite several reviews of farm household surveys for Latin America, the Caribbean, Africa and Asia. They established that in most cases, 25 to 60% of household income was from non-farm sources. Most estimates were in the 40-50% range. It is generally assumed that the share of income from non-farm sources has been increasing over time, however, there is a lack of comparable farm surveys to establish this.

Many rural households may therefore have complex livelihood strategies that cross the simple boundaries of hunting and gathering, farming, labouring, being an entrepreneur and a consumer. They may engage in all of these activities, farming a small plot and selling some of the product, earning wages as labourers, purchasing agricultural products and other commodities on the market, and collecting wild resources. For such households, the in-farm output, prices, employment, wages and natural resources that may arise from irrigation development may have complex effects.

Livelihood diversity results in complex interactions with poverty, income distribution, farm productivity, environmental conservation and gender relations. Poor people seek to diversify livelihoods, and may do this locally or over long distances. Seasonal or more permanent migration of some or all household members means that the phenomenon of 'multi-locational' households is increasingly familiar. The personal and social costs of migration can be high, for example, families being separated, physical and psychological stress, vulnerability, and prevention of children's education. In addition women left behind by male migrants suffer increased work burdens and more difficulty in basic survival (Jetley 1987).

Ellis (2000) identifies six determinants of diversification: seasonality, risk, labour markets, credit markets, asset strategies and coping strategies. One dimension of a sustainable livelihood is adequate and stable flows of income and consumption the whole year round. Seasonality is known to cause troughs and peaks in labour utilisation, and can lead to food insecurity, due to the mismatch between uneven farm income streams and continuous consumption requirements. These are often called the 'labour smoothing' and 'consumption smoothing' problem, respectively. Diversification can contribute to reducing the adverse effects by utilising labour and generating alternative sources of income during off-peak periods.

Livelihood diversification reduces the risk of losing all income sources simultaneously, for example in an emergency (Ellis 2000), (Start 2001). It also implies trading a higher but more risky income for a lower diversified and less variable income. However, this may not apply if households can exploit complementarities between their asset endowment and varying demand and returns in product and labour markets. Labour markets may offer opportunities to achieve higher returns to labour (Ellis 2000) or prompt diversification because of the discontinuity of casual employment (Start 2001).

Cash resources obtained from diversification may be used to invest in, or improve the quality of, any or all of the five forms of livelihood assets. They may be critical when access to credit is limited, for example, sending children to secondary school or buying equipment, such as an irrigation pumpset, that can be used to enhance future income-generating opportunities. It is also possible for diversification to improve the independent income-generating capabilities of women. By achieving this it also improves the care and nutritional status of children, since a high proportion of cash income in the hands of women tends to be spent on family welfare.

Coping strategies are *ex-post* responses to shocks or unanticipated livelihood failure, demonstrating that diversification may arise from necessity or choice (Ellis 2000). Thus diversification can be either a means of survival but doing little for poverty reduction, or a means to sustainable improvements in living standards through exploitation of new opportunities. In the context of economic and population growth trends, the question is whether diversification is a reflection of worsening impoverishment and desperation as land becomes increasingly scarce, or increasing prosperity as labour is attracted into higher paying non-farm jobs. Additional concerns are whether the rural non-farm economy is a residual sector offering only distress or coping activities, and mopping up labour displaced from a failing smallholder agricultural sector; or a dynamic diversifying economy that is growing, creating new jobs and averting downward pressure on wages. The latter implies that livelihood diversification is a progressive and positive strategy of adaptation which can lead to accumulation by rural producers (Start 2001), for example in SE Asia (Rosegrant and Hazell 1999) where smallholder farms are becoming part-time enterprises.

Diversification is more likely to be associated with impoverishment when increasing land scarcity occurs in conjunction with slow agricultural growth, and stagnant national and regional economies, and falling wages. This scenario is more common in South Asia and in Africa (Thirtle et al. 2001). Where the positive scenario exists, diverse and multiple livelihoods should be part of a structural transformation leading to specialisation, but this may be a slow process (Start 2001).

Maxwell et al. (2001) observe that in many places there is a U-curve of diversification, which sees non-farm activity concentrated among the poor, as a survival or coping strategy, and among the rich, as an accumulation strategy. With less access to land and greater dependence on waged work and micro-enterprises, non-farm income may be disproportionately important for the rural poor. However, wealthier households may still earn more from this sector in absolute terms, and in terms of return to labour invested (Adams 1994). For the poor, diversification may thus be far from a solution if they find themselves in a casualised labour market, frequently searching for work, with low returns, high transaction costs (both economic and social), high vulnerability, and little scope for accumulation (Maxwell et al. 2001).

Local diversification rather than diversification through out-migration is only likely where rural areas have a strong growth sector with good potential for linkages. This can be seen in Nepal when comparing the Terai to the hill regions. Requirements are infrastructure, adequate human capital, working credit, input and land markets, as well as access to output markets (Reardon et al. 2000), (Maxwell et al. 2001). Barriers to entry are critical in affecting access to non-farm employment for different groups, and in explaining why the distribution of non-farm income is skewed in favour of the relatively rich. Formal salaried jobs or business beyond the most micro-scale require formal qualifications or adequate working capital, and also often participation in social and political networks. Returns to labour are high compared to farming, but only relatively resource-rich households can access this. Poor households tend to be engaged in non-farm employment that is low skilled or not requiring of investment or working capital, for example, manual labouring, petty trading and some crafts. Returns per hour worked may be lower than in farming, reflecting the low productivity of the activity plus the surplus labour available (Reardon et al. 2000). Pro-poor labour markets have few or lower barriers to entry and contribute to diversification. However, due to diversification many farmers may need labour-saving, not labour-using technologies (Maxwell et al. 2001).

4.1.4 Multiple uses of irrigation water supply

A neglected and under-researched area is that rural households may derive multiple uses from water delivered by irrigation infrastructure. Irrigation often provides water for drinking, washing, homestead gardens and trees, livestock, replenishment of aquifers (affecting quality and quantity), urban water supply, rural industries, artisanal fishing and aquaculture. The quantities used may be small but vital in maintaining the viability of the livelihoods of certain groups, their income, nutrition and health. Such uses of water may be critical to the livelihoods of women and other disadvantaged groups. It needs to be recognised that the range of stakeholders with an interest in the water resources of an irrigation system go far beyond the owners and cultivators of irrigated fields.

Multiple uses of irrigation water are also related to linkage effects and livelihood diversification. For example, horticultural, livestock, and aquacultural products enjoy greater elasticity of demand than staple foodgrains, particularly in urban areas. As a consequence these can make greater contribution to raising farm incomes and the associated multipliers.

It is plausible that over 95% of all irrigation systems are also used for non-cropping purposes (Yoder 1983). Categories of use include the following.

i) Domestic use
It is common for surface systems to provide supply for drinking, washing and preparation of food and washing dishes. Problems include:

- high wastage from transportation losses,
- inequitable distribution (head v tail),
- the need for continuous flow which makes it difficult to schedule channel maintenance,
- damage to channels by people and animals, greater health risks than groundwater (particularly in spreading major diseases); and
- households may come to expect and/or feel a moral entitlement to water supply, or have no alternative source of supply.

In Nepal, small mountain irrigation systems are purposely channelled through villages for domestic supply. Rubbish from the house and street is often disposed of in the canal. Integrated provision of supply for cropping and domestic use may bring benefits. Yoder (1983) cites the case of a small piped irrigation system in Guatemala where a tap was routinely installed in each yard. The extra cost was low and it stimulated additional co-operation in building, maintaining and operating the system.

Use of groundwater irrigation supplies for domestic use has fewer health risks compared to surface supplies and has often been encouraged. Arsenic contamination in Bangladesh is an exception. Also, in some areas of Bangladesh, irrigation tubewells have lowered the water table below the level of existing wells used for domestic water supplies (Yoder 1983). Farmers in Sindh in Pakistan complain of the same problem in relation to handpumps following installation of drainage tubewells. Alternatively, groundwater can be recharged by irrigation systems making shallow wells possible for domestic use or supplementary irrigation. Irrigation tubewells can only be used intermittently for domestic purposes and therefore storage facilities are required.

ii) Washing clothes and bathing
Canals are frequently used for washing and bathing. Flow control or measurement structures may be popular places because of higher velocities and reduced silt. Lining canals and provision of steps is common at village access points. This may be convenient but is primarily done to protect the canal bank. Bathing may also play a role in religious activities or as an aspect of social capital. It provided one of the main opportunities for males to have social contact in Egypt (Yoder 1983). Washing clothes and utensils is also frequently one of the main opportunities for social interaction for women and children.

iii) Home gardens
Home gardens, common on small-scale systems and groundwater irrigation, are used to grow produce either for home consumption or to sell.

iv) Sewage disposal
Building latrines over canals occurs in Indonesia, Egypt and Nepal. Water sources are often used for separate purposes e.g. in Central Java, the irrigation system was used for defecation, the wells for drinking water, and the rivers and wells for washing clothes and bathing (Yoder 1983). Clearly this is a health risk as sometimes irrigation canals will be the only available water source for drinking and bathing.

v) Animal use
Irrigation systems can be an important source of drinking water for animals. Aquatic resources can also make an important contribution to household welfare, particularly in poor areas or for vulnerable groups with few alternative assets or sources of employment.

vi) Power
Irrigation canal drops can be used for power generation.

vii) Milling
Water-powered grain milling is a long established practice, and particularly common in mountainous countries such as Nepal. Used for grinding flour, hulling rice and pressing oil from seeds, such mills may make an important contribution to reducing women's labour burdens in food processing (Yoder 1983).

viii) Transportation
Most surface systems have roads and paths along canal embankments. Paths along canals are usually adequately drained during the rainy season and have an easy gradient for bicycles and walking. Water from irrigation systems may also be used to soften road surfaces prior to grading. Irrigation canals, particularly in SE Asia and China, may also be used for boat transport.

ix) Religious
Irrigation systems may be used for ritual bathing and other ceremonies. Temple gardens, ponds and lakes may also be supplied with water.

x) Trees
Planted along canals they provide benefits of shade, beauty and timber or other products. This can cause damage to canal linings. Consumptive use of water by trees can be high but probably insignificant in aggregate, given supply volumes in the scheme.

xi) Rural industry and micro-enterprises
Water from irrigation systems can also be used in rural industries and micro-enterprises, for example brickmaking (Barker and van Koppen 1999).

Several other authors have highlighted these multiple uses of irrigation water (Bhatia 1997), (Meinzen-Dick 1997), (Bakker et al. 1999), and (Barker and van Koppen 1999). They argue that when irrigation is seen as a 'low-value' use of water compared to municipal, industrial and even environmental uses, there has often been a failure to realise that irrigation systems may supply water not only for crops, but also for this range of other uses. "Unlike other uses of water, the direct financial benefits to the farmers often form a small proportion of the total benefits to society of using water in irrigated agriculture" (Bhatia 1997). Recognising the importance of this water source to the health and social well-being of the community is essential (Bakker et al, 1999). The World Water Vision, Gender Mainstreaming Project 2000, recognised that water is vital for multiple and universally recognised aspects of well-being, health, incomes, safety and freedom from drudgery (World Water Vision 2000).

4.2 Distributional impacts of irrigation development

Although irrigation development has the potential to be poverty-reducing, it is clear from experience that the gains from irrigation development are often inequitably distributed. Even if the poorest groups gain in absolute terms, wealthier groups may gain relatively more. It is important to understand the processes involved as well as the means by which this effect can be reduced. These issues are considered in the review of empirical evidence below.

An unresolved question in the literature is whether growth associated with progressive (i.e. equity increasing) distributional changes can have a greater impact in reducing poverty than growth that leaves distribution unchanged. In other words, even if both richer and poorer groups are gaining absolute improvements in livelihoods and welfare, is an inequitable distribution of welfare an undesirable thing for society in itself, and in this context can it act as a constraint to achievement of sustainable rural livelihoods?

Equity issues may arise with regard to the distribution of gains from irrigation between geographical areas, between households within an area, and between the members of households (the latter is considered in more detail below).

Thirtle et al. (2001) argue that technological change for productivity growth will inevitably be better suited to some regions than others. Technology alone is also not enough without infrastructure and education. It will be ineffective in poverty alleviation in situations where inequalities in land ownership are too great. This raises the issue of land reform and the need for investment and institutional change. Deficiencies in locally adapted technology development and transfer, infrastructure provision, in input and output markets or farm credit provision may thus limit the improvements in productivity, employment and incomes arising from irrigation development. This may occur even though irrigation tends to be located in higher potential and more economically favoured regions than rainfed agriculture.

It is generally argued that yield-enhancing technologies are likely to have equitable on-farm benefits when:

- technology can be profitably adopted on farms of all size;
- land is equitably distributed with secure ownership or tenancy rights;
- efficient input, credit and product markets exist so that farms of all sizes have access to the required modern farm inputs and information, and are able to receive similar prices for the products;
- polices do not discriminate against small farms and landless labourers (e.g. no subsidies on credit, mechanisation, or large-scale biases in research and extension) (Thirtle et al. 2001).

These conditions could be met by improved varieties of cereal crops, but are rarely met by irrigation development. Irrigation may therefore be equity reducing, even if it still improves the absolute position of the poor.

In irrigation, and particularly groundwater use, adoption of a new technology requires familiarisation/re-education and is also cash-intensive. Both factors make it difficult for the poorest farmers to adopt. In the first stage, innovations tend to raise inequality, since few people get a share in the relatively high income generated by the new technology. If higher aggregate output results and output prices fall, non-adopting farmers may even become absolutely worse off. However, as more people take advantage of the superior technique, inequality tends to fall. Thus again, technology is more likely to have widespread benefits if assets are equitably distributed and infrastructure and social services are well developed. Secondly, the full impact of a new technology in agriculture can only be assessed after a significant time lag. Thirdly, in order to limit the negative effect of innovation on income distribution, policies should be introduced to help the poorest adopt the new technology (Thirtle et al. 2001), (Kerr and Kolavalli 1999).

Irrigation may have a negative impact on the rural livelihoods of some groups if it:

a) helps to reinforce processes of land consolidation in which some groups lose access or rights to cultivate land; or
b) furthers inequity in the distribution of, or rights to, water (including head v tail end problems).

The intensification of irrigated agriculture can also be associated with the displacement of labour by mechanisation, inputs such as herbicides, or an increase in unpaid work for women. People may simply have been displaced by the construction of irrigation and particularly reservoirs. While there are both gainers and losers from new irrigation developments, it is usually the poorest that make up the majority of the losers. Badly designed or managed irrigation can also have negative impacts on public health and human capital through the spread of water-borne diseases. Again, this usually has greater effects on the poor.

For agricultural productivity growth to be equity reducing or increasing may depend on a variety of factors. These include the nature of agricultural intensification that takes place, prior distribution of assets, and on the policy and institutional environment within which growth takes place. For example, the consumption linkages that are potentially primary drivers of poverty reduction are less likely to be effective when income and land distribution are highly skewed. The consumption patterns of large and wealthy landowners may tend to be oriented towards imports and capital intensive goods and services rather than the goods and services of rural non-farm suppliers and local townspeople. This may not only explain why agricultural growth has been less favourable to poverty reduction in parts of Latin America and South Asia compared to SE Asia, but also the intractability of the poverty problem in those countries.

With regard to livelihood diversification, Reardon et al. (2000) explain that the extent to which the rural poor can benefit from expanded opportunities in non-farm employment and micro-enterprise can also be dependent on location and a complex range of factors. These factors include: ethnicity or caste, gender, skill and education levels, access to information, mobility, transaction costs and risks. Diversifying income away from the farm may require investing in assets specific to non-farm activities. The ability to invest is a function of incentives, the possession of capital and willingness to accept risk. In the absence of credit and insurance markets, wealthy households have greater capacity to invest in diversification. This is important where there are barriers to employment such as required education levels, or where the new employment is initially risky. Rich farm households that can employ more labour (or substitute machinery for labour) can also achieve better diversification without sacrificing farm output or efficiency. Poor farm households who diversify their income sources because of risk aversion, may in fact be paying a price for this "insurance" compared to concentrating their labour on farm.

Equity, with regard to multiple uses of water, will depend on the pattern and nature of water rights, and how these are related to asset endowments and the ability of individuals and households to protect their rights. Water can have multiple uses within a household, different villages or clans, farmers at head and tail. Water rights for any of these uses or users may be dependent on a combination of state law, religious law, customary law and local norms. The strength of rights, i.e. the degree to which they can be defended, may fluctuate with water supply and demand. Stronger rights will apply even during scarcity, whereas weaker rights tend to lapse, particularly if based on open access use of a water source or locally tolerated rights that have no legal basis.

4.3 Gender, irrigation and sustainable livelihoods

The impacts of irrigation development therefore may be felt differently at different levels, often mirroring the differential allocation of resources at national, regional, community, and household levels. Access to resources such as land, water and agricultural inputs are vital to a rural household's economic status, and often, these stand between them and poverty. While at community level all poor families may be disadvantaged with regard to entitlement over such resources, at the household level, poor rural women face additional difficulties accessing resources. Although these women work at least as hard as men, women typically have less access to productive resources such as land, water, credit, training, fertiliser and marketing channels (Agarwal 1994). Often this link between rural poverty and women's unequal access to productive resources is not acknowledged. Irrigation policies have been consistently addressed to men, with little or no attention to women's needs and multiple uses of water (IWMI). Studies have shown that where gender-based needs and uses of water are not accommodated, risks are high that the goals of irrigation management are not achieved (Jones 1983), (Blumberg 1989). An untapped source of productivity could therefore lie in addressing gender disparities in agriculture (Brown et al. 1995).

Women can be seen as the pivotal agents in relation to poverty alleviation, as they devote a larger share of their earnings than men to basic family maintenance, namely household food consumption, schooling and health care of children, withholding less for personal use (Mencher 1988), (World Bank 1990). In many developing countries women are responsible for generating food security for their families. Therefore in order to improve household incomes and nutrition, women need to have their own income-earning activities and should participate more in the identification of their needs and priorities and should have equal access to co-operative and credit facilities (Carr 1991). Studies have shown that failure to support women in agriculture can adversely affect productivity.

The intensification of agriculture that accompanies irrigation development usually requires more labour input per unit of land and it is women who tend to provide the additional labour. In addition to their multiple domestic tasks, women's traditional tasks in agriculture, i.e. weeding and transplanting, increase with the introduction of irrigation. Ploughing and land preparation, traditionally male tasks, may not increase significantly. Also, where irrigated cash crops have been introduced, women have often been regarded only as assistants to male farmers, while their own growing activities, mostly subsistence crops, have tended to be regarded as unimportant. As a result of this assumption, women have received little assistance in the form of training, loans and other inputs.

Also, within farming households, men and women tend to have separate but interdependent responsibilities. This has implications for water delivery, improved agricultural productivity and poverty alleviation. Where women grow different crops, they need water at different times and in differing quantities. Women's crops, for example, vegetables for household consumption, may have higher return per unit yield than the crops typically grown by men. In such cases water delivery schedules that take into account gender-based differentiation of crop production can add to household income and well-being. For example, Zwarteveen and Neupane (1996) found that in a scheme in Nepal, men wanted water in the early stages of rice production because they were responsible for land preparation. Women, however, wanted water during the growing season because they were responsible for weeding and greater water depth reduces weed growth.

There also often tends to be a predominant division between water for domestic use (drinking, bathing, cooking, washing) and water for productive use (irrigation, rural industry) (Ahmed and Krishna 1998), (Cleaver and Elson 1995). The former is normally seen as the women's domain and the latter as men's. However, women could use the 'domestic water' to generate income, for example, in food processing, thereby helping to alleviate their household poverty.

Women are often excluded from becoming members of Water User Associations (WUAs) because they usually do not own land. However, lack of membership should not imply that women do not use irrigation water. WUA decisions concerning water allocation should take account of the rights of women to water and give appropriate priority to their needs and uses. Without this, it is likely that unscheduled uses of water by women may conflict with local goals of water prioritisation and conservation. Alternatively, women's lack of timely access to water for their crops or other uses may undermine the overall goal of achieving sustainable livelihoods.

To make irrigation policies effective, women's contributions to the household economy need to be recognised, and their concerns heard. There is therefore a need to incorporate gender into irrigation planning and management.

4.4 Environmental impacts of irrigation development and their assessment

4.4.1 Introduction

Leaving aside the impacts of large dam construction, the most cited environmental impacts of irrigation development are waterlogging and salinisation and the resulting depletion and/or degradation of water and land resources.

However, as argued above, increases in agricultural productivity are central to improvements in the livelihoods of the rural poor in many developing countries. Whilst investment in irrigation is one potential component of an agricultural modernisation strategy, increases in agricultural output levels can also be achieved by the extensification and/or intensification of rainfed agriculture. These strategies can also have impacts upon the natural capital stock. A negative environmental impact should therefore be viewed as a mismanagement of the agricultural intensification process (Pinstrup-Andersen and Pandya-Lorch 1994), rather than being attributed to a specific strategy. A more balanced view of the net contribution of irrigation related activities to changes in environmental status both in the irrigated command area and at a wider basin/regional level is therefore required.

The impact of irrigation on the environment should therefore be analysed at two levels. This is to determine whether this system of agricultural modernisation is unsustainable due to poor design and/or management of irrigation infrastructure, or irrigation *per se*. The *direct* impacts of the construction and subsequent operation and maintenance of irrigation on the natural capital stock, can be assessed in terms of change in the status of natural capital for productivity and sustainability of resource use, both within the command area and downstream. Positive impacts include an improvement in agricultural productivity as a result of improved control of soil moisture, and increased farmer ability to invest in land improvements that enhance sustainability. Negative impacts such as waterlogging and salinisation may constrain productivity and threaten sustainability.

The *indirect* impacts of irrigation development are through its ***net*** effects on farming practice and hence livelihood strategies. Given the essential role of agriculture as an engine of growth and hence poverty reduction in rural areas, it is necessary to consider what would be a "without irrigation scenario" that increases agricultural output. Production increases in the absence of irrigation may be feasible by the extensification of agriculture onto more marginal lands, or by further intensification on existing rainfed land (e.g. increased fertiliser use, change in cropping patterns or other technological change such as varietal improvement). These alternatives will also have an impact upon the environment. Hence, the focus needs to be on whether irrigation is a less environmentally damaging approach to increasing productivity, which requires consideration of both on-site and off-site impacts. Given increasing population pressure on the land resource and a lack of viable means to increase productivity of rainfed agriculture, it is likely that out-migration will become a significant livelihood strategy. This in turn will have environmental consequences in urban or rural areas that become temporary or permanent destinations for the migrants.

Carruthers (1996) suggests that the population absorption capacity of an irrigation-led strategy is greater than the alternatives and that pressure on the resource base will be less severe in situations characterised by population growth. Thus migration patterns for alternative agricultural development strategies may be quite different, and irrigation development may even result in in-migration from more fragile ecosystems. Migration from the hills to the Terai in Nepal may provide an example of this, although it is the availability of land itself, as well as better infrastructure and other services, that are attracting migrants, and not just the potential of irrigation.

4.4.2 Direct impacts of irrigation development

To assess the direct environmental impacts of irrigation development on rural livelihoods indicators are needed of changes in the stock of natural capital available to rural households, and determination of the causes and implications of this.

A key issue in attributing the causes of environmental impacts is the extent to which the impact (whether positive or negative) is a function of irrigation *per se,* or of the institutions that govern its use. For example, poor system design or poor management and maintenance can both result in waterlogging and salinisation, and thus reduced productivity (Movaridi 1997). Potential impacts can be compounded by limited access to inputs, resources, markets and information if these factors act as constraints to the adoption of appropriate farming strategies following adoption of irrigation technology.

Most literature related to irrigation and the environment falls into two categories. First, the provision of sets of guidelines formulated to ensure that the potential environmental impacts of irrigation development are identified and considered at the project design stage (e.g. (Petermann 1996), (Dougherty and Hall 1995), (World Bank 1991), (Asian Development Bank 1987), (African Development Bank 1997), (The Overseas Economic Cooperation Fund 1997), (ICID 1994)). These tend to emphasise the direct negative impacts associated with irrigation development, and while useful in identifying categories of potential impact and mechanisms for their measurement, they do not relate these impacts to indicators of productivity loss or to impacts on rural livelihoods.

A second set of publications investigates the effects of specific negative impacts of irrigation on agricultural productivity levels, or via waterborne diseases on human health. For example, a recent review of approaches to quantify the impact of waterlogging and salinisation is given in Wichelns (1999), and a comprehensive set of more technical papers is provided in Dinar and Zilberman (1991). Although providing more tangible relationships between the use of irrigation and productivity levels, these studies tend to be context specific, and again do not assess consequences for the livelihood strategies of the rural poor.

The detail within these two sets of publications is too great to summarise here. Therefore guidelines which are relevant to research on livelihood impacts are presented below.

The natural capital stock directly affected by the use of irrigation comprises a number of components:

(1) Water resources - quantity;
(2) Water resources - quality;
(3) Soil/water relationships;
(4) Land/Soil - quantity;
(5) Land/Soil - quality;
(6) Other natural capital.

Once changes in the status of the components of the natural capital stock have been ascertained it is necessary to determine the causes of change that might be attributable to irrigation development. These are potentially numerous, but might include: deteriorating infrastructure; poor system design; state of drainage; water allocation policy and the implications of such changes in the institutional and policy context and agro-climatic conditions.

Table 1 provides a list for each component of:

(i) Changes in the status of the stock and associated indicators
(ii) Causes/factors affecting that change and associated indicators
(iii) Implications of that change and associated indicators

The table highlights a range of indicators, contributory factors and implications that may be directly attributable to the introduction of irrigation technology. However, as noted above, it is also important to assess the impact of irrigation on livelihoods (via its impact on natural capital) in the context of alternative strategies to agricultural modernisation.

Table 1 Impact of irrigation investment on components of natural capital

	Change in status - indicators	Contributory factors	Implications of change
Water resources - quantity ***How has water use, and practices affecting use, changed over time***	*Indicator* How much water is available for different uses at identified points/times	Change in condition of catchment: ➢ Typology and land coverage ➢ Past/Present/Future land uses ➢ Impact on water availability, via use, increased flooding and erosion. ➢ Build up of silt in dams ➢ Upstream users of water – past/present/ future Change in condition of command area ➢ Past/Present/future land uses Irrigation technology introduced ➢ System type o spacing of tubewells o number of pumps ➢ Maintenance regime ➢ Reuse of drainage water etc Change in water use efficiency ➢ Abstraction and return flow as % of abstraction Change in cropping pattern ➢ Type and extent of main crops – changes in incidence of double/triple cropping ➢ Factors influencing choice- economic growth, market access, price expectations ➢ % devoted to cash crops ➢ Crop water requirements/ha Changes in water rights ➢ Water market development ➢ Flexibility of allocation system ➢ Certainty of supply Change in other water uses ➢ Other agriculture e.g. livestock ➢ Drinking water – population increases; improved facilities ➢ Aquaculture (may or may not directly link to irrigation)	Displacement of upstream actors by headworks/canals /inundated land Change in availability of water for other water uses in command area ➢ Extent to which baseflow is a function of irrigation efficiency. ➢ Recharge of groundwater system ➢ Impact on productivity of agricultural: irrigation, livestock; fishing, aquaculture; hydropower etc Deprival of downstream users ➢ Current/future requirements of downstream users ➢ % stream flow abstraction in low flow periods. Is a minimum ecological flow required? (e.g. Saline intrusion at river mouth – impact on abstracted water/ estuary degradation)

Table 1 Impact of irrigation investment on components of natural capital (continued)

	Change in status - indicators	**Contributory factors**	**Implications of change**
Water resources - quality ***How has farming practice (and livelihood strategies) associated with irrigation investment had an impact on water quality?***	*Indicators:* Change in levels of pollutants into drainage water: ➢ Particulates; ➢ Prganic matter; ➢ Eutrophication associated with N and P; ➢ Toxic substances ➢ Salts	Upstream activity ➢ Change in area of agrochemical use ➢ Change in intensity of application ➢ Policy on inorganic fertilisers ➢ Pollution from other sources ➢ Sanitation and sewage as result of in migration/population growth ➢ Industry - discharge	Changes in Health ➢ Implication for labour productivity Changes in Natural Resources (NR) Productivity ➢ Can be positive or negative (e.g. Indonesian example of increased productivity resulting from application of water with high heavy metal content) REF
Soil/water relationships ***What is the extent of salinisation and waterlogging?***	*Indicators:* Change in: ➢ Water table depth and annual fluctuation ➢ Area of waterlogging (and tolerant plants) ➢ Area of salt crusts (and tolerant plants) Some indication as to cause of salinity is needed. Salinity can result because soils themselves have a high level of soluble salts. Even good quality irrigation water (200 ppm soluble salts) can add 0.2t/ha of salts with normal application of 10000 cubic metres/ha/yr.	Relates to water resources utilisation/ water regime impacts. Exacerbated by conditions such as impeded drainage, stagnant water, leakage, excessive applications ➢ Leakage (visual indicator) ➢ Overwatering (+ head/tail implications) ➢ Overleaching (+ reduced soil condition)	Effect on crop productivity Mitigation requirements/activities: ➢ Crop choice ○ how has cropping pattern changed ○ does this reflect on-site impacts ➢ Restriction on crop type ➢ Drainage requirement; ➢ Pre-planting irrigation requirement
Land/ Soil - quantity ***Have there been changes in the quantity of land available for different uses?***	*Indicators:* *Land use change (% on timelines)* ➢ Infrastructure ➢ Irrigated farming ➢ Dryland/rainfed farming ➢ Permanent grazing ➢ Seasonal grazing ➢ Ungrazed scrubland ➢ Forest ➢ Permanent wetlands	Change in: ➢ Land tenure system ➢ Land rights ➢ Consolidation Extent of: ➢ Flooding ➢ Migration	Conflict with other land users Conflict with other NR users ➢ Reduced access to Forest and other Common Property Resources (CPRs) Encroachment onto CPRs

Table 1 Impact of irrigation investment on components of natural capital (continued)

	Change in status - indicators	Contributory factors	Implications of change
Land/Soil - quality ***Have there been changes in the quality of land?***	*Indicators:* Change in proportion of land suitable for different uses Incidence of: ➢ Pesticide use ➢ Soil conservation measures ➢ Terrace/conservation work ➢ Extent of abandonment	Increased cropping intensity/changes cropping pattern resulting in increased rate of nutrient removal Over watering Land clearance Population pressure	Productivity declines ➢ Loss in fertility ➢ Loss in Soil Organic Matter (SOM) ➢ Soil compaction ➢ Soil loss/accumulation ➢ Soil erosion on slopes greater than 5% ➢ Increased incidence of pests Migration to more suitable land
Other Natural Capital ***Status of other components of natural capital***	*Indicators:* Change in amount and quality of: ➢ Forest ➢ Existing wetlands or new wetlands created by project (paddy, drainage, waterlogging) ➢ Biodiversity levels	Changes in the roles that other forms of natural capital/environmental resources play in supporting livelihoods Examples: ➢ Vulnerability linked to over-abstraction/pollution of groundwater ➢ Increases in use of/ decreases in availability of fuel-wood	Impact on CPRs and the contribution of CPR to livelihoods ➢ Diversification away from NR use ➢ Impact on labour allocation
Other Capital ***Have there been changes in the status of other forms of capital***	*Indicators:* Relationship between social capital and maintenance of physical capital and use of natural capital e.g. functioning WUA	Social capital is enhanced as a result of the required organisation of farmer operated and maintained systems Social capital degraded as result of a range of factors including increased conflict, increased disease and pest prevalence etc	Impact on human capital ➢ Change in productivity Impact of increased disease on health Impact on vulnerability

4.4.3 Indirect impacts of irrigation development

This assessment requires determination of the net change in environmental status associated with irrigated agriculture in comparison with alternatives to increasing agricultural output. Farming practices are varied, and this impinges not only upon the likely response to a new technology and/or policy in terms of changes in farming practice, but also upon the magnitude and significance of any resulting increase or decrease in the status of an environmental indicator. These impacts are likely to be ambiguous due to the initial starting point of the agriculture sector in the particular agro-climatic area, of the current level of intensification and/or extensification of the production system, and the likely direction of change. The alternative farming practices need to be predicted to allow the determination of those indicators likely to be affected.

Taking investment in irrigation as an example of a productivity enhancing intervention, under some physical and institutional conditions farming practice will result in increased use of non-land inputs, such as irrigation water and fertiliser. Such a trend may be associated with increased salinisation, water pollution and soil compaction. In other circumstances, for example, where access to land is less constrained but fertilisers are less accessible, more land may be brought into cropping, resulting in increased erosion. The change in farming practice is therefore determined, by the initial starting point and the trajectory, which will differ depending on the site specific constraints such as resource availability, land tenure, access to inputs, local adaptation of High Yield Varieties, etc.

Literature addressing these issues is limited, but Morrison and Pearce (2000) provide a conceptual framework that classifies responses to incentives to increase agricultural production in terms of an extensification or intensification of farming practices. Developing the distinction between extensification and intensification, two broad forms of environmental degradation can be considered. First, any form of cropping exposes the land to the risk of soil erosion through a combination of wind and water. Within certain limits, the more extensive these cropping practices become, the greater the risk of erosion, with consequent on-site and off-site costs. Second, as the land use activities become more intensive, there is a greater risk of environmental degradation from a number of other causes, including salinisation, chemical pollution and soil compaction.

Separating the two functions therefore facilitates the separate consideration of the two underlying features of agricultural change:

- extending the **extensive** margin of cultivation (ploughing of pasture, shortening of fallows, increasing cropping intensity, cultivating marginal land such as hillsides, etc.); and
- extending the **intensive** margin of cultivation (typically through the use of improved varieties, agricultural chemicals and notably, investment in irrigation).

Substantial work has been undertaken by the OECD in developing a range of agri-environmental indicators that could be considered under this categorisation (OECD 1999), (OECD 2000), (OECD 2001).

Any investigation of the environmental impacts of alternative farming practices also needs to consider their capacity to support livelihoods in a way that reduces pressure on other forms of natural capital. For example, a labour-intensive agricultural modernisation strategy, such as irrigation in smallholder farming, may also reduce pressure on the use of natural resources in other agricultural and/or non-agricultural activities (for example, the case-study described by Shively (1999)). On-site impacts can also reduce the potential for off-site activities reliant on natural capital, e.g. more efficient use of surface and/or groundwater within a scheme can reduce water availability downstream.

From a planning viewpoint, a criterion for irrigation investment would be to compare the returns to marginal investment (net environmental impacts) from irrigated agriculture with those of rainfed agriculture. Where the productivity of irrigated agriculture was constrained by, for example, market or credit access, and/or where the environmental costs of irrigation were high compared to those of rainfed intensification/extensification, then irrigation might not be a component of an optimal agricultural modernisation strategy.

5. IMPACTS OF IRRIGATION ON SUSTAINABLE RURAL LIVELIHOODS: EMPIRICAL EVIDENCE

The following sections present empirical findings from the literature that illustrate the processes of irrigation impacts described above. A summary of evaluations of the green revolution is presented first, followed by leading global examples of evaluations of irrigation development. Following this are summaries of the available empirical evidence with regard to the impacts of irrigation in Bangladesh and Nepal.

5.1 Impacts of Irrigation as Part of the Green Revolution

Early evaluations of the GR were critical as only wealthier farmers gained benefits because they had access to the credit necessary for the investment and the purchase of modern inputs accompanying new agricultural technologies (Pearce 1980). The potential displacement of labour by accompanying mechanisation was also feared. However, later studies have clearly shown that although small farmers did lag behind in adopting GR technologies, most of them did eventually adopt and benefit from increased production, as well as from greater employment opportunities and higher wages in the agricultural and non-farm sectors (Hazell and Ramasamy 1991), (Lipton and Longhurst 1989),(Rosegrant and Hazell 1999). Most smallholders were able to keep their land, and in some cases small farmers and landless labourers actually gained proportionally more income than larger farmers, with a net improvement in the distribution of village income (Hazell and Ramasamy 1991).

The finding that poorer groups gained proportionally more than rich is however probably only representative of cases where the distribution of land ownership and social and political power were relatively equal prior to the adoption of GR technology. While it is safe to say that the GR reduced the incidence of absolute poverty in the regions where it was successful, disparities have widened between favoured and less favoured regions, and within areas of success several researchers have still found the relative gains of the rich to be greater than those of the poor.

For example, Beck (1995) analyses the green revolution from the perspective of the development and use of irrigation facilities in one village in West Bengal, India, between 1986 and 1989. Evidence from a plot-to-plot survey of land farmed by the study villagers over three consecutive winter seasons shows that the benefits of new irrigation facilities have been affected by already existing village power structures and have flowed in a disproportionate fashion to the richer villagers. The poor gained some absolute benefits, mainly through extra employment, but these were marginal when compared to the increased revenue flows to their richer neighbours. In particular, the poorest villagers, mainly living in female-headed households, gained least from the green revolution. It was concluded that, in addition to the development of irrigation infrastructure, state intervention is necessary to support the livelihoods of the very poor, if levels of poverty are to be reduced. Harriss-White (1997) also argues that intensification did result in increasing inequalities with landholdings and access to credit did become increasingly concentrated in the hands of the few.

It can be concluded that a range of distributional outcomes is possible, which are dependent on prior and evolving conditions. In India's semi-arid tropics, Singh (1994) found that investment in a technology package of irrigation, improved seeds and fertiliser contributed substantially to agricultural productivity. In addition, differential use of these inputs led to increased regional, as well as within village, disparities in income. Although all households in a village could gain from adoption of the technology, the top and bottom income groups gained proportionately more than the middle. Higher income groups gained from access to land and investment in irrigation, whilst low-income groups gained from increased farm and off-farm employment opportunities.

Adopting a modelling approach, Fan et al. (2000) show that improvements in agricultural productivity, higher agricultural wages, and increased non-agricultural employment opportunities have all contributed significantly to reducing poverty in India. Improvements in the terms of trade for agriculture (agricultural prices relative to non-agricultural prices) significantly increase rural poverty. The majority of the poorest are net purchasers of food, therefore increases in total factor productivity in agriculture exert a significant downward pressure on agricultural prices. Overall they show that improvements in agricultural productivity in India not only reduced rural poverty directly by increasing income, but also indirectly by improving wages and lowering agricultural prices. On the other hand, improvements in agricultural productivity also contributed to worsening poverty by increasing landlessness, though this effect was relatively small and insignificant (Fan et al. 2000).

Thus the steady decline in poverty from the mid-1960s to the early 1980s in India was strongly associated with agricultural growth, and particularly the impact of the GR. Since then, the causes for the decline seem to have become more complex. Non-farm wages and employment now play a much larger role in reducing poverty, and these are less driven by agricultural growth than before. Further, government spending on rural poverty and employment programmes has increased substantially in recent years, and this has directly benefited the rural poor (Fan et al. 1999).

Some authors also place particular emphasis on the contribution of groundwater development to the success of the green revolution, and also as an explanation of regional differences in its impact across South Asia. Evenson et al. (1999) report that the impact of the expansion of irrigated area on productivity increased over time through the periods of pre, early and mature GR (1956-87). They argued that this could be attributed to rapid growth in the proportion of private tubewell irrigation.

According to Dhawan (1982) (cited in (Shah 2001), the GR in Punjab, Haryana and W. Uttar Pradesh (UP) in India was fuelled by the tubewell revolution that preceded it in these states. Thus its refusal to progress east-ward from Lucknow is explained by the inadequacy of groundwater development in the East. This argument is based on empirical evidence that fertiliser use is directly related to tubewell irrigation and that pump-irrigated farms perform better that those irrigated from other sources. This is indicated by cropping intensity, input use and yields. There are also observations that tubewell irrigation is superior to surface irrigation in terms of reliability, timeliness, and adequacy (Shah 2001). Shah (2001) also argues that Eastern UP is catching up with the north-western states in productivity, land use intensity and other parameters of agricultural growth because of effective tubewell development. Generally, in Eastern India, stimulating groundwater development is not only central to launching the region's GR and creating livelihoods for its poor, but also to addressing its syndrome of extensive waterlogging and flood-proneness.

At the micro-level, Sharma and Poleman (1993) contend that the green revolution in a studied village in Uttar Pradesh, India, was driven by the interaction of the new seed varieties, fertiliser and tubewell irrigation. From 1963 to the mid-1980s the area served by tubewells rose from 20% to 85%. Cropping intensity rose from 155% to 230%. Paddy replaced coarse cereals in the rainy season, and the proportion of dry season area planted to wheat increased by nearly 250%. Marginal farmers, with less than 1 hectare of land, nearly doubled their area of fodder crops in support of growing dairy enterprises. Marginal farmers also increased off-farm employment by 50% at higher real wages than before, and reduced their agricultural labour on other farms to one-third of their total labour.

Considering future food and livelihood security, Kumar et al. (1995) considered the most disquieting feature in Indian agriculture to be the decline in real investment in irrigation, which could be traced to a paucity of financial resources caused largely by the rise in subsidies.

5.2 Evidence of irrigation impacts on agricultural growth, poverty and livelihoods

5.2.1 Global examples

As livelihoods approaches are relatively recent, the majority of assessments of the impact of irrigation focus on one or more of the following: agricultural production methods, productivity, farm incomes, poverty alleviation, farm employment and income distribution. Most are also micro-level evaluations of individual irrigation schemes, but a few are broader sectoral or national level evaluations based on more aggregated data.

5.2.1.1 National or Sectoral Assessments

Fan et al. (2000) found that agricultural research and extension, improved roads, irrigation and education have all contributed significantly to growth in total factor productivity in agriculture in India. Rural electrification, government spending on health, rural development and soil and water conservation were not statistically significant. With regard to distribution, they found that growth in total factor productivity in agriculture in India has not led to any significant increase in the incidence of landlessness among rural households ("immiserising growth") (Fan et al. 2000).

Fan et al's model (2000) confirmed that government investments in irrigation significantly increased the percentage of the cropped area under irrigation, and that public irrigation (canal irrigation area) contributes significantly to additional private irrigation (area under well and tubewell irrigation). Additional irrigation investment was found to have the third largest impact on growth in agricultural productivity, after agricultural research and extension, and roads. Therefore an additional Rs100 billion would add 0.6% to the growth rate of total factor productivity. However, the same investment was found to have a smaller impact on rural poverty reduction, even after trickle-down benefits had been allowed for. It was ranked fifth after roads, agricultural research, education and rural development. It was estimated that the marginal impact of government spending was such that another Rs1 million of expenditure on irrigation would raise 7 poor people above the poverty line. They concluded that public irrigation affects poverty primarily through its impact on productivity. This impact is enhanced by its catalytic role in stimulating additional private investment in irrigation (Fan et al. 1999), (Fan et al. 2000).

However, it can also be argued that increased investment in irrigation played a large role in production growth during the GR. Without this input, the returns to investments in roads and agricultural research over the period studied would have been much smaller (Fan et al. 1999). Indeed, these higher returns were conditional on the past investments in irrigation. Decision-makers are now concerned with the marginal returns of each additional unit of future investment. Fan et al (1999) conclude that increasing spending on irrigation may yield lower returns to productivity growth and poverty reduction than investing in roads and agricultural research. Similarly, government spending on power was found to have little impact on either productivity growth or poverty. It is speculated that while irrigation and power have been essential investments in the past for sustaining agricultural growth in India, the levels of investment stocks achieved may now be such that it may be more important to maintain those current stocks rather than to increase them further.

Evenson et al. (1999) observed that further investment in irrigation in India may have only a limited impact on agricultural production and productivity growth. They estimated that the marginal economic rate of return is only about 4-6% for irrigation, but 45% for extension, and 55% to 59% for research.

More positively, the World Bank (1991) cites that studies in India in 1988 demonstrated an inverse relationship between the incidence of poverty and the extent of irrigation development. For districts in India where less than 10% of gross cropped area was irrigated, 69% of the population had incomes below the poverty line, while in districts where irrigation covered more than 50% of crop area, the poverty incidence was only 26%. Similarly, along with other variables, availability of irrigation facilities was found to be statistically significant in explaining variation in the level of household incomes across provinces in the Philippines (de la Cruz-Dona 2000).

Fan and Hazell (1997) used Indian district level data from 1956 to 1990 to examine the relationships among technologies and infrastructure, productivity growth and poverty reduction in both rainfed and irrigated areas. There was no noticeable difference in the literacy rate of the rural population between irrigated and rainfed areas in the 1950s and 1960s, but over the past 20 years literacy improved more slowly in rainfed than irrigated areas. Production growth in irrigated areas generally outperformed growth in rainfed areas, where land productivity was only 57% of that in irrigated areas in 1990. Labour productivity was higher in rainfed areas than irrigated areas in 1956, but in 1990, labour productivity in rainfed areas was 17% lower than in irrigated areas.

Rural poverty was estimated on the basis of consumer expenditure surveys carried out by the National Sample Survey Organisation (NSSO). The poverty line was defined as Rs15 per capita per month at 1960-1961 prices. The poverty gap between rainfed and irrigated areas grew larger between 1972 and 1987. In 1972, the incidence of poverty was 43% in irrigated areas, and 53% in rainfed areas. In 1987, the poverty incidence had declined to 31% in irrigated areas, but to only 41% in rainfed areas. It was found that irrigation had a positive impact, which was greater in the low-potential areas than in the high-potential areas. Indirect effects arose mainly from improved agricultural productivity, and direct effects from improved off-farm income earning opportunities. For example, improved education could help farmers find a better job in the non-farm sector, thereby increasing their incomes and reducing poverty. Increased wages reduced poverty in both rainfed and irrigated areas, but the effect in irrigated areas seemed greater.

In their analysis of determinants of rural poverty in the semi-arid tropics of India, Singh and Hazell (1993) found that by increasing education levels, providing a pair of bullocks, increasing irrigation by 40% and increasing wage rates were equally effective in reducing poverty in this region. They recommended that the most important policy intervention for poverty alleviation was a complete package of irrigated land with a pair of bullocks and a minimum of eight years schooling.

In contrast, Lieten (1996) proposed that the debate on the agrarian problem in developing countries has alternated between a stress on the necessity for land reforms and an emphasis on the introduction of productivity-enhancing technology, leading to a trickle-down effect. In the Indian state of West Bengal, the former strategy has been pursued since the mid-1970s. It is claimed that this approach has stimulated a 'virtuous circle', leading to higher production, a decrease in poverty and polarisation, and a perceptible improvement of the human development index. Addressing causality, namely, whether land reform or irrigation has acted as the kick-start mechanism to these improvements, Lieten (1996) argues that irrigation has not been impressive, either in comparison with the outlay in other Indian states, or in terms of crop coverage.

Irrigation not only contributes to increased crop production but may also reduce variability in production through improved control of the crop environment. However, the dependence of modern seed-fertiliser technology on irrigation and fertiliser, which are subject to unreliable supply, may contribute to increased variability in production. Rosegrant (1992) examined this issue in diversion irrigation systems in the Philippines. He used an irrigation system simulation model to analyse the impact of irrigation on the variability in area, yield, production, and farm income. Irrigation more than doubled crop-year rice production and income. However, because the diversion irrigation systems studied were dependent on highly variable dry-season streamflows, irrigated dry-season production and income were highly variable compared to wet-season rainfed farming. Thus on a crop-year basis, production and income variability under irrigated conditions were slightly higher than under rainfed conditions. Although improved management of irrigation systems could reduce income and production disparities among farmers within the system, it had little impact on system-wide variability. It was concluded that investments in irrigation infrastructure and management are not substitutes for other policies that will offset the adverse effects of production instability, such as buffer stocks or import management.

5.2.1.2 Micro or Scheme Level Evaluations

Assessment of the impact of small-scale irrigation on the rural poor, was undertaken by the Centre on Integrated Rural Development for Asia and the Pacific (CIRDAP). It involved an interdisciplinary study in five of its member countries in South Asia (Bangladesh, India, Nepal, Pakistan and Sri Lanka) (Ahmed and van Vuren 1990)[1]. It was found that irrigation water, if properly utilised, could bring about significant changes in the production and socio-economic situation of the community concerned. In all of the ten case-study schemes cropping intensity increased. In Bangladesh, with irrigation from a deep tubewell (DTW), farmers shifted from traditional *aus* to irrigated *boro* cultivation with HYVs. They also produced HYV *aman* rice. The change in cropping pattern was associated with a move from broadcasting to transplanting, increased fertiliser use and modern agricultural tools. In India, irrigating farmers diversified from paddy to higher value crops such as tomato, chilli and potato. Cropping patterns did not change but cropping intensity increased in Nepal and Sri Lanka. In northern Pakistan, increased irrigation encouraged extra production of fodder and vegetables, alongside the staple crop of wheat.

With regard to employment effects, in two schemes in Bangladesh, an irrigated *boro* paddy crop required about 73% and 44% more workdays per acre than a partly irrigated *aman* crop. Comparison with unirrigated land would have revealed a greater difference. In Bangladesh, the increase in labour required may come from migration from other areas. This is due to a lack of institutional mechanisms mediating between labour-surplus and deficit households that can adjust total farm family labour availability in a village (Ahmed and van Vuren 1990).

For two cases in India, the increase of labour per acre, when compared with rainfed cultivation, was about 188% for crops like tomato and chilli and 108% for food crops. Hired labour provided 52% of labour requirements in one scheme. In Gilgit-Hunza in Pakistan, irrigation generated demand for unskilled local labour for construction and maintenance. Increased cultivation also absorbed more family labour. In Nepal, the topography often limits labour mobility, which leads to more intensive use of family labour and exchange labour (often paid in food) (Ahmed and van Vuren 1990).

Overall, the CIRDAP study showed that if small and marginal farmers have command over inputs, including irrigation water, then the impact of increased agricultural production becomes significantly positive. When trying to establish the impact of irrigation on employment and income, there does, however, tend to be a time lag between production of outputs and generation of impacts. Also, without base-line data, it is difficult to assess the changes that have occurred due to an irrigation scheme, or to attribute causality.

Despite these methodological limitations, it was concluded that by reducing risk in crop production and by increasing yields, irrigation can lead to a secured survival status for poor farmers and improve their "livelihood condition". The case-studies showed how small-scale irrigation helped farmers to fight impoverishment by reducing their indebtedness and "eliminating any contingency that the poor might fear". In Bangladesh for example, subsistence farmers now generate some marketable surplus of rice. The standard of living of farmers in Bangladesh also improved when there was some increase in non-farm activities, and where incomes from petty businesses and services contributed to improving the condition of the poor. However, none of the ten case-study schemes showed a significant positive relationship between adoption of irrigation and generation of saving and investment in the agricultural sector. Accumulation of capital by farmers was thus not sufficient to lead to investment in agriculture and other sectors, but this was attributed to supply constraints faced by farmers with regard to inputs (Ahmed and van Vuren 1990).

The CIRDAP study also considered whether small-scale irrigation had contributed to marginalisation or increased disparity in wealth and power. In Bangladesh, groundwater irrigation had a positive impact on all farmers, but the benefits were distributed proportionately to landholding size. Farmers stated that the introduction of irrigation had reinforced the traditional social system. In India, small-scale irrigation was thought to be an effective instrument for achieving distributive justice and alleviating rural poverty, such that priority should be given to the development of small-scale irrigation in backward and tribal areas. Irrigation was found to bring little distributional change in Nepal, where population pressure on the limited land was the main source of marginalisation. In Pakistan, researchers concluded that small-scale irrigation

[1] In Bangladesh small-scale irrigation was taken to include low-lift pumps, deep tube wells, shallow tubewells and a few indigenous gravity-irrigation and lift-irrigation schemes. In Nepal, small-scale irrigation covered systems up to 50ha in the hills and 2000ha in the plains.

could provide increased production and income to poor farmers in backward areas, but only when supplemented with a package of agricultural support services including training, credit and system monitoring and evaluation. In Sri Lanka, state intervention had eroded traditional social mechanisms for conflict resolution and water management, resulting in less equitable outcomes for irrigation now, than had been the case in the past. None of the case-studies provided conclusive evidence that large landowners had benefited from small-scale irrigation at the cost of small and marginal farmers (Ahmed and van Vuren 1990).

For the Ghataprabha command area in India, Reddy (1990) reports the results from a baseline survey of over 400 households in 1975/76 and a re-survey in 1986/87. The sample was drawn from 31 villages (15 irrigated, 13 to be irrigated and 3 unirrigated). Data was collected in two rounds, after *kharif* and *rabi* seasons, for a wide range of variables. Effects of irrigation included a change in cropping pattern over the period, with maize replacing sorghum as the dominant crop. There was also a shift in favour of increased *kharif* season cropping, and increased areas of commercialised crops such as sugar cane and introduction of bananas. While unirrigated crop yields remained about the same, there were significant yield increases for all the major crops under irrigation, such that in the command area the gross output per acre was almost three times that of the rainfed area.

This increase in productivity led to higher agricultural output, marketable surpluses and incomes for individual farmers. Including crop and non-crop income, incomes for landowners increased 328% on average, whereas for landless labourers the increase was only 183%. The number of landless labourers, and hence the population of irrigated villages increased over the study period, whereas for rainfed villages, change was only marginal or there was a decrease. Increased employment opportunities were created by the higher cropping intensity and cultivation of labour intensive HYVs.

The study also examined the change in status of assets between the benchmark survey and the re-survey. There was a positive relationship between landholding size and assets. Since irrigation there has been a great increase in the number of non-farm assets, reflecting the increased prosperity. An increase in non-farm assets was also perceptible for landless households, showing that they had also benefited from increased employment and incomes.

Although irrigating landowners gained the most incremental income, non-irrigators also gained considerably. The irrigators spent more on superior items of food such as milk, fruits, vegetables, meat and eggs, indicating that irrigation had helped to improve the quality of life. Also, the per capita expenditure on education showed that farmers in irrigated zones were able to send their children to school, and the number of literates had increased in the command area villages, compared to dry villages.

House construction increased substantially in villages after irrigation. In aggregate terms the gross savings in the region increased from negative savings at the time of the baseline survey, to a very positive amount at the re-survey. Irrigation helped the beneficiaries increase their incomes and save substantially (although small and medium-sized farmers less so than large farmers). Landless households generally had negative savings, but the negative ratio was less in irrigated villages. Interaction with urban centres became necessary because of higher levels of inputs required for irrigated farming, and to dispose of surplus agricultural produce in markets. These interactions induced many farmers to invest in transport equipment like bicycles, scooters, and motorbikes. Farm investment was also higher in irrigated villages and was concentrated on purchasing land, agricultural implements and construction of wells.

The distribution of this range of benefits was not even and large farmers were found to benefit more from irrigation than small and marginal farmers. There were also differences in value of output per acre, with the value in head and middle reaches being almost double that in tail-end plots. Equity in water distribution in proportion to land ownership would have reduced inequalities.

Irrigation and the need for interaction with urban centres were also believed to have influenced the social outlook and life style of the beneficiary groups. There was also an increase in conflicts over water allocation, leading to social tensions and even murder. Although many believed it had heightened income inequalities and some blamed it for increased alcohol consumption, interviewed households were almost unanimous about the positive impacts of irrigation in improving their living standards. There were changed perceptions, for example, on whether some castes were allowed to eat non-vegetarian foods, and dress styles had also changed, especially among women. The farmers attributed these changes in lifestyles and outlook partly to affluence and greatly to urban linkages necessitated by the introduction of irrigation. Extravagant spending on marriages also seemed to have increased because of the assured income under irrigated conditions. The prosperity brought about by irrigation had broken traditional kinship barriers and had extended matrimonial relations from known nearby kinship circles to far off urban centres. Expenditure on children's education had increased as had access to health care. Many farmers went to urban centres for treatment, which was not the case before irrigation.

The re-survey found that about 3% of the area brought under irrigation had been adversely affected by salinity, alkalinity or waterlogging. Violation of recommended cropping patterns, and lack of adequate drainage facilities and appropriate water distribution strategies were the main causes for these adverse effects.

In the Mwea Irrigation Project in Kenya, target families were found to be less vulnerable than off-scheme families during the famine period (Korte 1973). In the Muda irrigation project in Malaysia, irrigation and the use of new rice varieties resulted in an increase in cropping intensity and the net income of target families. There was also a reduction in income disparities between farm households (Goldman 1982).

In the Gambia, the introduction of pump irrigation raised rice productivity and labour demand, and the real income of participant households by 13%. A 10% rise in annual income led to a rise of approximately 4% in caloric consumption, with a positive effect on weight for height and height for age. However, benefits for women were less than intended. Although aimed at women, women acquired only 10% of the pump-irrigation plots. Production of traditional swamp rice fell because women's labour was transferred to pump irrigated lands (von Braun et al. 1989).

In Northern India, it was found that irrigation increased cropping intensity, farm income, and also job opportunities for the landless. As a result of increased cropping intensity, women's participation in agricultural work increased. Cropping became more diversified and of higher value. Increased fodder from weeds and crop residues led to an increase in the number of buffaloes kept. Crop residues (cotton sticks) replaced dung cakes for fuel, saving time for women (Stanbury 1984).

In Mexico, a comparison of the situation before and after irrigation, showed improvements in income, diet and nutritional status, but only for the middle and higher socio-economic classes. Increased agricultural production did not necessarily lead to an improvement of the diet or nutritional status of the poorest segment of the population (Hernandez et al. 1974).

Silliman and Lenton (1985) reviewed evidence from 45 micro-studies, 25 of them from India, and with few exceptions they confirmed a positive relationship between irrigation and employment. A sharp contrast for male labourers between irrigated and unirrigated conditions was illustrated by two West Bengal village studies cited by Ghosh (1984, 1985). In the irrigated village, work was all year round, with additional immigration of seasonal labourers at peak periods. In the un-irrigated village there were two severe gaps with almost no work, implying that labourers had to seek other low paid work, migrate or suffer serious deprivation.

Studies from India in the mid 1980s showed that the increase in days worked on irrigation schemes, compared to rainfed conditions, was over 100% in the Damodar valley canals in West Bengal, over 150% in Ferozepur (Punjab), 61% on the Dantiwada canal in Gujarat, and over 100% under the Kakitiya canal in Andhra Pradesh (Chambers 1985).

Incremental employment generated by tubewell irrigation has been estimated as 840 and 697 workdays per shallow tubewell (STW) per year in Bangladesh and West Bengal, respectively. STWs were found to normally serve between 6 and 30 farmers, whereas deep tubewells (DTWs) serve around 40 farmers (Pitman 1989).

According to Widanapathirana (1991), the labour absorption capacity of paddy cultivation in Sri Lanka has been stagnant in the years following the advent of new high-yielding paddy varieties. Labour absorption per hectare remained around 120-130 labour days during the 1980s. Introduction of technologies such as mechanisation or herbicides, in place of hand weeding, displaced labour that would otherwise have been absorbed. Where population and labour force were growing, a lack of alternative employment opportunities both within and outside the irrigated sector was leading to low level returns per labour unit, growing employment and ultimately poverty. Thus the poverty-reducing employment benefits of irrigation may stagnate over time as wage levels are held down and the labour force grows, unless alternative sources of employment develop.

Chambers et al. (1989) argued that a growing body of evidence showed that support to small-scale, privately managed groundwater irrigation targets poor rural households better than other poverty-reduction interventions and improves more livelihoods than large agency-managed irrigation schemes. The potential advantages of groundwater, compared to surface irrigation, were also discussed with relation to the success of the green revolution above.

The treadle pump provides an example of how access to groundwater irrigation can significantly improve the livelihoods of the ultra-poor (Shah 2001). It has been found that the technology does self-select the poor, although the first-generation of adopters tend to be the less poor. Use of treadle pumps can transform smallholder farming in different ways, e.g. cultivation of HYV rice in the *boro* season in North Bengal and Bangladesh, and vegetable cultivation and marketing elsewhere. Such changes result in increased land-use intensity as well as priority cultivation i.e. adopters provide crop-saving irrigation in a large part of their holding but practise intensive farming in the priority plot. Average crop yields on priority plots tend to be much higher than obtained by farmers using diesel pumps or other irrigation devices. The impact on income varies across households and regions, but $100 per year has been cited as a conservative estimate of annual net income. In addition, fuller employment can be achieved at an implicit wage rate that is 1.5-2.5 times the market rate. The more enterprising farmers who take up commercial farming can earn substantially more. The low investment cost and rapid returns ideally meet the needs of marginal farmers, but challenges still lie in marketing and distribution of the equipment. Despite these, in Bangladesh, treadle pumps have reached a significant proportion of the rural poor (Shah et al. 2000).

It is anticipated that, through adopting treadle pumps, increased income and cash flows will result in greater investment in fixed and working capital in smallholder agriculture. Better food and nutrition security will produce health benefits that in turn will enhance the household capacity to earn. Also, backward and forward linkages are expected, as in the models described above. As the treadle pump economy expands, it is expected that a growing number of people will be engaged in supporting it in a variety of ways, including manufacturing, marketing, maintenance and repair. As the number of pumps grows, such upstream jobs and livelihoods will increase from backward linkages. Similarly, forward linkages through processing and marketing of treadle pump induced output will also create indirect employment effects, especially as a tonne of additional vegetable output involves more processing and marketing effort than a tonne of grain or fibre crops (Shah et al. 2000).

The success of the treadle pump is in overcoming at least some of the constraints to access to groundwater for resource poor farmers. Inevitably, the costs of tubewell irrigation favour the relatively richer farmers. As far back as the 1960s, it was acknowledged that purchased pump irrigation from private tubewell owners was an important way for resource poor farms to gain access to groundwater irrigation. However, the power and reach of the new institution of water markets was only recognised during the late 1980s (Shah 1991). In India, canal irrigation has replaced private TWs and deep public TWs as being superior in terms of access for the poor. Although water markets have a wide reach, water buyers invariably use less water than TW owners themselves. A further critical factor influencing access to groundwater is the availability of a range of pumps and power units that can be matched to on-farm conditions and farm size. For example, farmers in Bangladesh have adopted Chinese micro-diesel pumps (<5hp). These are suited to STWs and dug wells in the Ganges-Megna-Brahmaputra (GMB) basin where the suction head is so low that the power of a larger engine is not used at full rpm.

For Sri Lankan irrigated settlement schemes, Widanapathirana (1991) comments that an important factor contributing to poverty was the relative wealth of people at their time of settlement in an irrigation scheme. In traditional village life, prior to settlement, income may be derived from several non-irrigation sources such as highlands and rainfed crops, tree crops and other non-farm activities. Adaptation by wealthier groups in the new irrigation environment is likely to be faster and more stable compared to those relatively poorer. Thus relative poverty status may widen in new settlements. With limited potential to redistribute land or improve productivity in many irrigation schemes, alleviation of poverty may require attention to other aspects such as highland production, livestock enterprises and non-farm enterprises. This study also emphasised that livestock provide draught power, milk, eggs, meat and other products, and that development of the livestock industry within the overall irrigation sector may be an important component in generating income.

6. BANGLADESH: IRRIGATION DEVELOPMENT AND IMPACTS

6.1 Review of irrigation development in Bangladesh

6.1.1 Development of agriculture

Bangladesh is a country of 135 million people living in a land area of 0.15 million sq. km. It has a high population density of about 880 persons per sq. km. About 84% of the total population live in rural areas and are directly or indirectly engaged in a wide range of agricultural and non-agricultural activities for employment, income and livelihoods. The Gross Domestic Product (GDP) was estimated to grow by over 6% in 2000/2001, while the average rate of growth of GDP during the 1990s stood at nearly 5% per annum. Per capita GDP grew at about 7% annually during the 1990s. The structural composition of the economy has also changed significantly in the last decade. While the relative contribution of agriculture as the primary sector decreased to some extent, the share of modern sectors, such as manufacturing, construction and service sectors, increased (Planning Commission 2001).

Agriculture contributes about a quarter of the country's GDP, one-third of export earnings and provides employment to two-thirds of the civilian labour force (MOA 1999), (Planning Commission 2000). The crop sector alone contributes 20% of total GDP and 56% of agricultural GDP. Although very sluggish, growth of 0.43% was observed in the crop sub-sector during the early 1990s. It picked up sharply and registered as high as 4.27% during the latter half of the 1990s.

In Bangladesh, there is hardly any scope for bringing new land under cultivation. The country lost about 1 million ha of arable land during the twelve year period between the two censuses of agriculture (1983/84 and 1996). This was due to excessive pressure on land for housing and settlement, building physical infrastructures, river erosion and various other non-agricultural uses. As this trend continues, the country has only about 7 million ha of land cultivated by about 12 million farm holdings. This has meant a rapid decline of average farm size from about 0.81 ha in 1983/84 to 0.7 ha in 1996, with a simultaneous increase in land sub-division and fragmentation (Bangladesh Bureau of Statistics 1999). While there has not been any apparent adverse impact of declining farm size on productivity or equity, such change in the land resource base warrants appropriate technological innovations, as well as new forms of production organisation. Development of irrigation water markets, power tiller hire services, contract growing of vegetables and poultry are some of the recent examples of changing production organisation in Bangladesh.

About 80% of farm holdings are small farms, cultivating on average only 0.30 ha. Marginal farmers comprise 34% with an average farm size of only 0.08 ha. While about 18% of farm holdings are medium farmers cultivating 1-3 ha, the remaining 2% are large farmers cultivating above 3 ha (Bangladesh Bureau of Statistics 1999). The majority of the expanding non-farm population (34% of rural households) earn livelihoods in diverse, rural, non-farm activities such as petty business, grain and input trading, shop keeping, rural transport, construction work and carpentry. There has been a slow growth in the farm labour force, whereas nominal and real wage rates of farm labourers have risen. This has not, however, affected crop sector output growth because significant parts of farming operations are now performed by an increasing farm mechanisation, e.g. use of power tillers/tractors, irrigation pumps, hand weeders and paddle threshers.

During the 1990s, agriculture and horticulture (excluding fisheries) grew, on average, at about 2% per annum, which has been above the population growth rate. The average growth rate of the sector in the second half of the 1990s has risen sharply to over 4%. The major source of agricultural growth was the accelerated production of foodgrains, i.e. rice and wheat, which has grown at over 4.5% annually since 1995/96. Total foodgrain production in the country rose to 26.49 million tons in 2000/01. The surge in food production in recent years has been above the long-term trend line. This has resulted in a cereal food surplus of about 1.5 million tons above the country's total food intake requirements (World Food Programme 2001).

The growth of the economy has been predominantly led by agriculture. Agriculture has been characterised by smallholder farming and has diversified considerably into crop and non-crop enterprises. This, coupled with the growth of rural non-farm activities, as well as expansion of government income transfer programmes, has had profound implication for poverty reduction. The head count ratio of rural poverty dropped from 47.9% in 1995/96 to 44.9% in 1998/99 (Planning Commission 2001). The rapid growth in foodgrains, fishery and livestock sub-sectors linked with service sectors has generated additional employment opportunities. The real wage of agricultural labourers, in terms of rice, has improved significantly and has led to an increase in average per capita calorie intake from 2206 kcal in 1995/96 to 2268 kcal in 1999/2000 (Mandal and Palmer-Jones 2000).

6.1.2 Irrigation as the leading input

Since the early 1980s, the main impetus to foodgrain output growth in Bangladesh came from the rapid development of minor irrigation technologies, especially groundwater irrigation by tubewells. The earlier development of minor irrigation depended heavily on the actions and support of the government through the Bangladesh Agricultural Development Corporation (BADC). Irrigation engines and pumps were heavily subsidised to supplement the high capital costs of equipment and also to popularise green revolution technologies for augmenting production of rice. However, growth of irrigation in the public sector domain turned out to be very slow and rice production suffered (Palmer-Jones 1988).

Since the late 1970's, a series of policy reforms have been pursued by the government to liberalise the market for irrigation equipment and to create opportunities for the private sector to play more roles in the development of minor irrigation. The major policy reforms in irrigation included:

(i) liberalisation of imports and distribution of irrigation engines and spare parts;
(ii) rationalisation of duties and taxes on irrigation equipment import;
(iii) removal of engine standardisation restrictions;
(iv) withdrawal of tubewell spacing and siting regulations; and
(v) withdrawal of subsidies on irrigation equipment prices (Mandal and Parker 1995).

Recently, financial and technical support has also been extended to promote supplemental irrigation for *aman* rice in the drought prone areas. Adherence to these policies has been committed in the Ministry of Agriculture's National Agriculture Policy (MOA 1999).

The most significant impact of the market liberalisation and privatisation policy has been a marked reduction in prices of engines and other irrigation equipment. This means that irrigation equipment is now more widely available at the local level and is affordable to the farmers. Farmers have a wide range of choices about the brand and size of engines. Local workshops have grown rapidly to manufacture spare parts and provide repair services immediately (IIMI and BSERT 1995), (Mandal 2000). Minor irrigation is currently the most dynamic private sector. It involves about 1.7 million full or part owners/managers of mechanised irrigation pumps with another 0.76 million owners and operators of unmechanised and traditional irrigation devices. In addition to this are about 0.16 million rural mechanics who are engaged in installation, repair and servicing of irrigation pumps and engines (Mandal 2000).

This has led to a rapid growth in irrigated area of about 8% per annum since 1991/92. STWs, whose number increased from 235,900 in 1988/89 to 757,044 in 1999/00, have propelled the growth of irrigation. The STW area grew from 0.94 million hectares in 1988/89 to 2.64 million hectares in 1999/00. This meant an average annual growth of around 14 % in STW irrigation, which covered 81% of groundwater irrigation, 64% of minor irrigation and 59% of total irrigation in 1999/00. Growth of Low-lift Pump and major canal irrigation was moderate, while there has been virtually no growth in DTW irrigation. In 1999/00, total irrigated area stood at 4.48 million hectares, which accounted for around 64% of approximately 7 million hectares of cultivated land. Groundwater irrigation technologies as a whole (i.e. STWs, DTWs, Farmer Managed Tubewells (FMTWs)) covered about 73% of total irrigated area (NMIDP 2000).

There are inter and intra-regional variations in the extent of irrigation development. For example, the National Minor Irrigation Development Project (NMIDP) census of minor irrigation shows that the Districts of Bogra, Jaipurhat, Naogaon, Dinajpur, Rangpur, Gaibandha, Chuadanga and Tangail have experienced relatively higher growth of minor irrigation, compared to slower growth in other areas with high groundwater potentials. The variations are attributed to socio-economic conditions such as farm size and land tenure systems as well as physical conditions, including agro-ecological characteristics, groundwater aquifers, development of an equipment market at the local level, growth of physical infrastructure, availability of institutional credit and provision of electricity (Murshid 1985), (NMIDP 1999).

In areas where bank loans are either insufficient or difficult to obtain, the growth of irrigation markets has been generally slow. In areas with intense competition for command area plots, a new form of partnership arrangement has emerged for taking up irrigation as a business enterprise. This should not be seen only as a credit market failure. There is a whole range of valid socio-economic rationales behind choosing partners in irrigation business in a highly competitive rural environment. The major reasons for choosing partners include:

- mobilisation of enough capital for purchase and operation of irrigation machines,
- meeting kinship or social obligations,
- enlarging and protecting a viable command area with partners' land and social support, and
- acquiring adequate financial and moral strength to carry out water selling business without threat of encroachment from the competing pumps (Mandal 2000).

6.2 Evidence of irrigation impacts in Bangladesh

Irrigation development in Bangladesh has had a profound impact on rural livelihood strategies through significant improvement in cropping intensity, grain production, household income from rice production, wage labour employment and irrigation service provision. Literature is replete with evidence on the contribution of irrigation. The notable impact of the spread of minor irrigation includes: increase in cropping intensity, shift from low yielding wet season rice to high yielding dry season rice cultivation and increased labour employment (Alamgir 1983), (Chowdhury et al. 1988), (Hamid et al. 1982), (David 1994), (Ahmed et al. 1982), (Miah and Hardaker 1988). In low-lying, deeply flooded areas, cropping intensity has not necessarily increased. However, replacement of low yield rain-fed *aus/aman* rice in summer by irrigated HYV *boro* rice has contributed to an increase in rice output as well as financial and economic returns to producers (Miah and Hardaker 1988), (Mandal 1989).

Irrigation in Bangladesh is also particularly attractive in the dry winter months of November to March, including the *boro* season for rice, because there is no risk of crop damage from flooding. Incidence of floods and droughts are key determinants of food availability in Bangladesh. Historically, droughts have proved more devastating than floods, as insufficient rainfall compromises the largest rice crop, rainfed *aman*. However, since the severe drought of 1992, expanded HYV technology has provided drought insurance. For example, when late-season irrigation of the *aman* crop converted a potentially devastating drought into an all-time record *aman* harvest (Haggblade and Ahmed 2000).

Employment impacts of irrigation have been more pronounced through change in cropping patterns, increased cropping intensity, intensification of cultivation practices and harvest and processing activities related to increased production (Alam 1989), (Hamid et al. 1982). In particular, irrigation has created opportunities for inter-district migration of harvest labour. This means that labour from less intensively irrigated areas migrate to more intensively developed areas, taking advantage of differences in planting and harvesting time. In many areas, increased rice production, due to irrigation expansion, also led to increased net employment for women in rice processing facilities, e.g. rice parboiling, drying and milling (Ahmed et al. 1982), (Mandal 2000).

The profitability of irrigated agriculture is the most important factor contributing to rapid expansion of irrigation. Earlier studies, based on inter-district data by Boyce (1986) and Hossain (1986), showed existence of very strong complementarities between irrigation on the one hand, and fertiliser use and spread of HYVs of rice on the other. Hossain (1986) also found a very strong relationship between irrigation development and agricultural growth. Generally, earlier research has shown the high profitability of irrigated rice production, mainly due to the subsidised cost of irrigation, fertilisers, pesticides and credit (Hamid et al. 1982), (Jaim and Rahman 1978), (Biswas and Mandal 1982). However, gradual reduction of direct and indirect subsidies has led to a rise in production costs relative to rice prices and returns from irrigated rice production have decreased (Quasem 1985), (Mandal 1989). Mandal and Parker (1995) showed that very low paddy prices in the 1993 *boro* season in Faridpur District, discouraged many farmers from growing irrigated *boro* rice in 1994.

A recent NMIDP census of minor irrigation revealed that a high price for *aman* rice in the previous season encouraged potential investors to respond quickly to foodgrain shortages. They achieved this by increasing the number of irrigation units and by increasing command area per unit of equipment (NMIDP 2000). More importantly, diversification of irrigation from dry season rice irrigation, to year round irrigation of rice, vegetables and fruit, has increased returns to both irrigators and pump owners (Biswas and Mandal 1993), (Mandal and Dutta 1995). Therefore, it is important to maintain a favourable price regime for foodgrains as well as other irrigated crops.

Irrigation institutions, especially farmers' co-operatives (KSS) or the previous rental system for DTW and Low Lift Pumps under the BADC, turned out to be an inadequate innovation. Such inappropriate institutions not only resulted in irrigation inefficiency, but also inequality in terms of farmers' access to irrigation and income distribution (BAU 1985), (Mandal 1987), and (Palmer-Jones and Mandal 1988). The growth in minor irrigation, as a result of large scale privatisation in agriculture, has led to the emergence of a rapidly expanding irrigation water market, which has largely been competitive and more efficient than before (BAU 1986), (Mandal 2000). Irrigation privatisation has also demonstrated a significant positive impact in terms of equity, as increasing numbers of small and medium farmers gained greater access to irrigation benefits through ownership of cheaper tubewells and pumps (Mandal et al. 1995). One innovative system of payment for water is by sharing a quarter of the crop at harvest once all the irrigation pumping costs have been met by the water sellers. This may seem high compared to payment of cash per unit of land or cash per hour. However, if one translates this as credit advancement to water users for the whole season and also as premium to risk of crop loss, this crop share payment may not look so exorbitant. The other tangible benefits from irrigation development include:

- increased income of rural mechanics fixing irrigation equipment,
- local blacksmiths and workshop owners manufacturing equipment spare parts,
- van drivers transporting diesel/ fuel, fertilisers and crops and vegetables.

The increased access of the small farmers to irrigation was facilitated by significant reduction in the costs of engines and pumps. It broke up monopolistic control by the landed rich or 'water lords' (Boyce 1987), (Quasem 1985). The spatial inequity of DTWs was the result of a misdirected policy which encouraged installation of subsidised DTWs in areas suitable for STWs. The latter are more appropriate and affordable to small and medium farmers (Gisselquist 1991). It was recognised that where land is unequally distributed, irrigation development would initially favour the larger farmers. Benefits from increased production due to irrigation could then be distributed more widely through appropriate policies.

Irrigation benefits reflect the inequalities in the distribution of land. Glaser (1989) observed that small farmers who sharecropped land to wealthier farmers or to pump owners, were deprived of potential benefits from irrigation. However, there are instances of owners of small parcels of land engaging in related activities, e.g. trading in irrigated crops, working as linemen/drainmen in irrigation command areas or equipment mechanics. White (1986) showed that the increased cost of irrigated crop production in sharecropping families falls on women members. Other studies show that tubewell irrigation has a tendency to redistribute income from landowners to small farmers and landless households via higher rural employment and wages (Alam 1989), (Hossain 1989).

In their study of crop diversification and supply response in Bangladesh, Mahmud et al. (2000) found that expansion of modern irrigation had a positive impact on adoption of HYV rice in all seasons. This displaced local *aus* and broadcast *aman* during the monsoon season (*kharif*) and reduced the area under pulses, oilseeds and spices in the winter (*rabi*) season. Several crops showed a potential for returns higher than those of HYV rice, but crop diversification may have been constrained by the high price risks associated with the marketing of crops such as potatoes, vegetables and spices. Also, existing on-farm water management systems did not allow rice and non-rice crops to be planted in the same service units. Irrigation also had a favourable impact on cropping intensity on high and medium to high land but a negative impact on lower lands. Among all land in the floodplain, the proportion of land allocated to non-cereal crops was markedly lower under irrigated conditions than under rainfed ones.

Alam (1991) examined the impact of irrigation on income distribution in Gazipur District, Bangladesh, focusing on farmers in Sador and Kapasia upazilas. Data from 80 respondents, of whom half had access to irrigation, showed that irrigation reduced income inequalities slightly. Smaller farmers benefited more, because they did not need to incur costs in hiring labour. Generally, access to irrigation facilities was considered satisfactory.

Ahmed (2000) explains that step-by-step liberalisation of markets for modern inputs in agriculture was carried out in Bangladesh under pressure from foreign donors. It was realised that various direct interventions were fiscally unsustainable and unproductive. Prior to liberalisation, the Bangladesh Agricultural Development Corporation (BADC) had a virtual monopoly over fertiliser and agricultural equipment markets, while conforming to government pricing and related policies. Most of BADC's equipment was imported using foreign aid because domestic capacity for producing diesel engines and pumps and other irrigation equipment was small. Thus liberali7sing the import trade became the key element for agricultural equipment markets. Prior to the mid 1970s, there was hardly any private initiative in the development of modern irrigation. Publicly initiated programmes implemented by BADC had evolved from expensive large-scale projects to low-cost, small-scale ones using low lift pumps and then deep and shallow tubewells. Initially, BADC owned, maintained and operated these pump sets, supplying water to farmers for a flat charge per hectare. By the end of the 1960s there were increasing efforts to transfer operational responsibilities to farmer groups and co-operative societies.

In the first major reforms, from 1980 to 1982, BADC sold all its low-lift pumps to private parties. From 1983 to 1985, all irrigation tubewells were transferred to farmers and co-operatives. In both cases, sales were supported by special credit arrangements for purchasers and elicited a good response from farmers. In 1988, restrictions on the import of engines and pumps, and standardisation restrictions limiting the makes and models available, were both withdrawn, resulting in a drastic fall in price of equipment. By early 1989, the cost of a STW to irrigate 4 to 5 hectares of land had fallen below taka 20,000 (US$600). This was about 60% of the subsidised price for such equipment through BADC. Ahmed (2000) argues that this was one of the most significant aspects of agricultural input market liberalisation, as irrigation is the leading factor for growth based on seed-fertiliser technology. He also observes that between 1988 and 1996, irrigated area expanded at roughly twice the rate that had been achieved between 1978 and 1986. The significance of the reforms was confirmed by the results of a multi-simultaneous equation model. Liberalisation of markets for irrigation equipment had both direct and indirect impacts on total rice production. Positive direct impacts resulted from increased irrigated rice area and higher yields from this land. Positive indirect impacts were due to the fact that irrigated rice area was the dominant factor influencing fertiliser consumption, and hence again yields. It was estimated that liberalisation led to an annual growth rate in net rice production 0.9 percent higher than it would otherwise have been.

Ahmed (2000) also notes that the rapid expansion of irrigation and HYV rice had a direct negative impact on rainfed rice production by encouraging farmers to change the crop rotation involving all crops. Because irrigated rice is of longer duration (120-140 days compared to 60-100 days for other crops), and because of labour constraints in the peak season, farmers generally made changes by cutting down on the area of rainfed rice. Lower rice prices resulting from increased irrigated production may also have negatively affected the area of rainfed production. It was estimated that liberalisation resulted in a net addition to rice production in the post liberalisation period (1976-97) of 1.3 million tons (2 million tons of incremental irrigated production, and a reduction of 0.7 million tons rainfed production). It was also noted that the reduction in rainfed rice area could have caused an increase in areas of other crops, so that the net gain in the crop sector would be larger than estimated for rice alone.

From a review of micro-level data collected from five villages representing different agro-ecological zones and socio-economic characters in N.W. Bangladesh, Hamid et al. (1998) conclude that the agricultural production system is heterogeneous at the micro-level. Land level, soil type and water availability are key determinants of productivity and incomes. Droughts due to irregular rainfall and non-availability of irrigation water are the factors making poor farmers most vulnerable to production loss and to poverty. Expansion of irrigation has thus been beneficial. However, they argue that an excessive dependence on paddy rice, which has been reinforced by the adoption of modern seed and irrigation technology, threatens the stability and diversity of traditional agricultural systems, and the diversity and sustainability of livelihood activities of some poor groups. Though modern technology has contributed to increased foodgrain production, the stability and sustainability of the system was observed to have deteriorated in many areas. Established practices of soil, water and other resources conservation originating from indigenous technical knowledge have been abandoned by farmers adopting modern agriculture. Examples of negative livelihood impacts for the poor are conflicts between richer farmers trying to drain bheel lands and poorer households trying to conserve water bodies for fish growth. Similarly, cultivation of marginal lands by removing 'weeds' and wild species for paddy culture may reduce livelihood activities of the poor who collect wild vegetables, medicinal plants, fruits and fuel.

Despite the abundance of aquifers in Bangladesh, abstraction of groundwater for irrigation can have environmental consequences. Khan (1988) reported that in the northern districts of Rajshahi and Bogra, groundwater levels had been depleted to a level of 9 to 13 metres below the static water table. As a result, most shallow and hand tubewells installed for irrigation and drinking purposes had failed because the pumping head had gone beyond the maximum suction lift limit. Furthermore, about 50,000 ponds, tanks and ditches in the Barind areas, within the northern districts, had almost dried up. Soil moisture available to rainfed crops was reduced, and fruit and deep-rooted trees were also affected. Overall, the region was facing an acute shortage of water for surface irrigation, drinking and fish culture (Khan 1988).

In the south-western parts of the country and also in Pataukhali and Barisal Districts in the south, the main issue is groundwater quality. Northward movement of salinity has increased due to a reduction in dry season river flows in the Ganges. This is attributed to the Farrakka barrage upstream in India. Pumping from the aquifer, makes the saltwater interface move inwards, leading to contamination of aquifers. Salinity is also a constraint in many parts of the south-east regions, such as in Brahmanbaria, Chandpur and Noakhali Districts. Increased salinity of groundwater used for irrigation may degrade soil properties and hamper crop yields. In some central districts, a high iron content in the groundwater has led to the formation of a hardpan. This hardpan can be impermeable and restrict root development, soil aeration, permeability and drainage. Other mineral concentrations in groundwater can also degrade soils, and the problem of arsenic contamination in Bangladesh is well known. Furthermore, groundwater utilisation can create the need for complex soil and water management practices. Application of fertilisers can add nitrate to the groundwater through leaching or direct percolation. In the major rivers, flows in the dry season have declined drastically due to groundwater withdrawals in the upstream regions. Groundwater abstraction from tubewells, particularly shallow tubewells near the river, is at the expense of river flow. Maintenance of minimum acceptable river flows is necessary for fisheries, inland transport and navigational purposes, and also to control problems such as salinity and pollution by sewage effluents. Reduction in streamflows can have a negative impact on fish, population growth rates and migratory patterns, resulting in a complex impact upon the aquatic ecosystem. Changes in groundwater levels or subsurface moisture conditions may cause subsidence. This can damage buildings and create problems in the design and operation of structures for drainage, flood protection and water conveyance (Khan 1988).

7. NEPAL: IRRIGATION DEVELOPMENT AND IMPACTS

7.1 Review of irrigation development in Nepal

Nepal is amongst the world's poorest countries. Because of its rugged terrain, only 17% of Nepal's total land area is suitable for farming, yet 81% of the population relies mainly on subsistence farming (CARE 2001). Many communities, especially in the rural areas, suffer from problems associated with poverty, including low levels of parental care, low literacy rates, widespread nutritional deficiencies, and scant access to safe drinking water and sanitary waste disposal.

Roughly half of the population of Nepal live below the poverty line. Based on the Human Development Report (1998), Nepal is ranked 144 (amongst 174) in the Human Development Index Value (HDI) (UNDP 1998). This is below all its South Asian neighbours, with the exception of Bangladesh. The Nepal Living Standards Survey (NLSS), conducted by the Central Bureau of Statistics (CBS) provides the most recent estimate of poverty both at national and regional levels using household consumption expenditure data. Using the NLSS data, the National Planning Commission (NPC) estimated that around 42% of the population is living below the poverty line. The poverty line was estimated to be NRs 4,404, based on a daily per capita calorie requirement of 2124 (average price level prevailing in 1995/96 and a factor to account for non-food expenditures) (CBS 1996). Another definition, which fixes the poverty line at US$150 per capita per annum, suggests that 71% live in poverty, and even up to 78% in rural hill areas. The Living Standards Survey reports that there are 9 million people in Nepal living in absolute poverty. This number has nearly doubled in the last 20 years, with the net increase in poverty being 2.6% higher in rural areas than urban areas (CBS 1996).

There has tended to be a gradual shift in the distribution of population from rural to urban areas. The urban population in 1981 was 6.3% of the total population, increasing to 9.2% by 1991. Apart from rural-urban migration to the Kathmandu valley, internal migration is characterised mainly by movement of population from the hill region to the inner terai and terai regions (Task Force on Migration 1999). Prior to 1961, the terai was characterised by a preponderance of international immigrants as compared to internal migrants. However, since then, internal migrants, mainly from the adjoining hill districts, have dominated migration to the terai. This followed the malaria eradication programme in the Terai in the late 1950s. Other factors were development of a market for land as a commodity, implementation of landholding ceilings and a policy of encouraging settlement. This was illustrated by the implementation of the Rapti Valley Development Project in Chitwan District. Expansion of the cultivated area created a large-scale demand for agricultural labour (Mishra et al. 2000). Internal migrants are engaged mostly in agriculture, while international immigrants are mainly engaged in non-agricultural activities, either running businesses or providing unskilled and skilled labour (Task Force on Migration 1999). Internal migrants tend to follow the same occupation as in their source place.

The Task Force on Migration (1999) list the push factors from the hill regions as:

- natural calamities,
- loss of land ownership,
- insufficient land,
- lack of employment opportunities,
- poor educational and health facilities,
- increasing population pressure,
- low agricultural productivity; and
- lack of economic opportunities.

Pull factors in the Terai are:

- availability of land,
- food surplus,
- re-settlement programmes,
- industrial and trade activities,
- higher development investment,
- opportunity for forest encroachment,
- better transport,
- marketing,
- education and health facilities, and
- access to urban life and employment in non-agricultural sectors.

Relatives and friends residing in the Terai were an important factor that influenced 32% of the households surveyed in 1983 to migrate.

Nepal has surplus water resources for both surface and groundwater development. According to Koirala and Thapa (1997), of 1.8 million ha available for irrigation, surface water infrastructure covers about 0.9 million ha and groundwater use, 168,000 ha. Thus Nepal is making use of less than 8% of its water resource potential, but in some hill regions pressure on land and water use may already be limiting.

The development of irrigation in Nepal can be categorised into four phases of development (Shah 2001):

1) Prior to the mid-1950s, farmers developed numerous irrigation facilities in the hills and in the Terai using their own resources. These systems were primarily for supplementing irrigation of main crop paddy during the monsoon season, and were managed by informal community groups who developed their own rules and norms.

2) From 1956 to 1970, emphasis was on construction of infrastructure in the form of government-financed medium and large projects. Extensive development of diversion weirs and main canal distribution systems followed the traditional farmer-developed model of run of the river diversions to provide supplementary irrigation in the monsoon season.

3) The 1970s and early 1980s saw more intensive development of command areas through expansion of irrigation infrastructures and rehabilitation of farmer built and managed systems.

4) From the mid-1980s to the present, emphasis has been placed on more integrated development of land and water resources. This has incorporated the following:

    - renovation and expansion of farmer-managed systems with beneficiary participation,
    - groundwater development where surface supplies were seasonal,
    - use of other forms of improved agricultural technology; and
    - involvement of NGOs as implementing agencies.

Land use management strategies seek to integrate agriculture, forestry and irrigation into a common platform for rural development.

The current policy framework for agricultural development in Nepal has been prescribed by the Agriculture Perspective Plan (APP) of 1995, which is based on the following strategy:

- A technology-based green revolution in agriculture becomes the initial engine of accelerated growth.
- Accelerated agricultural growth creates a demand-pull for the production of high value commodities in agriculture, as well as for non-agriculture commodities, with consequent large multiplier effects on other sectors of the economy.
- Broadly-based, high rates of growth in employment, then become the mechanism for achieving societal objectives.
- Public policy and investment focus on a small number of priorities, building on past investment in human capital, physical and institutional infrastructure.
- A package approach to development is introduced, which in Nepal's case would be different for the Terai, hills, and mountains and would recognise the powerful complementarity between public and private investment and priorities, and would ensure their co-ordination.
- To achieve broad participation, the strategy is regionally balanced and explicitly ensures the participation of women (APROSC and JMA Inc. 1995).

It can be seen that this strategy relies very much on agriculture as the "engine" of both economic growth and poverty alleviation. It follows that irrigation is included in the prioritised or 'packaged' approach to public policy and investment, along with fertiliser, roads, power, credit and agricultural technology. In fact, more than half of the total public investment in APP's priority inputs was allocated to irrigation, but with emphasis that the type and quality of irrigation is critical to achieving the growth objectives.

Although irrigation has been the main focus of investment programmes in agriculture in Nepal for more than forty years, the APP argues that the emphasis has been on expanding supplementary monsoon irrigation. It cited that a "mere" 18% of Nepal's arable land had year-round well-controlled water. This was identified as being essential to the high-intensity agriculture underlying the green revolution and its strong multipliers on growth in other sectors. The relative lack of well-controlled, year-round water supplies was thus given as a prime reason why agricultural growth rates in Nepal have been low. The very low rate of adoption of both year-round irrigation and fertiliser use means that although individual adopters experience improved yields there is little impact on aggregate production (APROSC and JMA Inc. 1995).

It is argued that well-controlled water is essential to reduce risks and to introduce the water regimes of the high-yield crop varieties that drive the green revolution. Year-round irrigation is also a pre-requisite of the high cropping intensities that drive rapid output growth. Both are necessary to shift to high value commodities that become the most effective source of agricultural growth. This emphasis on high value commodities represents a major proportion of the 4 to 6% agricultural growth rates that characterise the most successful cases of development (APROSC and JMA Inc. 1995).

The APP also argues that under Nepal's rainfall regimes, the returns to other key public investments such as roads, or farmer investment in inputs such as fertiliser will remain low and potentially uneconomic. This will be the case as long as land is unirrigated, or only seasonally irrigated and hence still heavily dependent on annual rainfall. It is proposed that it is the high density of income generation in a modernising agricultural sector that makes infrastructure investment profitable.

In the APP's strategy, irrigation development is more important in the Terai than in the hills and mountains. Shallow tube wells are the core of the irrigation strategy for the Terai, and groundwater plays a far larger role in the strategy than its share of investment. The cost of developing shallow tube wells, per hectare, was estimated to be one seventh that of a new surface scheme, less than half that of rehabilitation of terai surface schemes, and a quarter of that required for hill rehabilitation schemes. Although there was seen to be some scope for improving the existing surface schemes, only a small proportion of that would provide the year-round well-controlled water essential for the large increase in production required by the APP. Thus, since the APP's publication, institutional priorities have relied far more on shallow tube well development than on other aspects of irrigation.

7.2 Evidence of irrigation impacts in Nepal

Given the population pressure on cultivable land resources in Nepal, one indicator of the livelihood impact of irrigation is provided by estimates of the minimum landholding (ha) necessary to earn a poverty line income from agriculture (see Table 2).

Table 2 Minimum landholding (ha) necessary to earn a poverty line income from agriculture in Nepal

Condition	Valley floor (ha)	Hill slopes (ha)
Rainfed	1.39	2.08
Partial irrigation[1]	0.63	1.21
Full irrigation[1]	0.41	0.85

[1] Assuming current technology (1989)

Source: Master Plan for Irrigation, 1989, cited in (Koirala and Thapa 1997).

Neupane (1991) reports that many micro-level irrigation evaluation studies, conducted in the late 1970's by the Agricultural Projects Services Centre (APROSC), reported an increase in food productivity and cropping intensity in irrigated areas.

In a detailed study of Mohana village in southern Nepal, Tomita et al. (1992) found that introduction of irrigation led to the replacement of rainfed rice with paddy rice and also the introduction of more crops, thereby increasing food resources and available cash.

For the south-eastern Terai, Shakya and Flinn (1985) established that the adoption of modern rice technology was higher where irrigation existed. Tenure status and access to credit were also significantly related to varietal adoption, whereas family and farm size, and educational status were not. Fertiliser use was also influenced by similar factors.

The Asian Development Bank (1999) provides details on farm production and incremental improvements achieved in Chitwan District as a result of irrigation rehabilitation under the East Rapti irrigation project. The project interventions included strengthening of WUAs, river flood protection works and intensification of extension services. Compared to the without project situation, there were significant improvements in yields and cropping intensity, diversification from cereals to cash crops and from local to improved varieties, and estimated incremental annual employment of 298,000 person-days.

The Bhorletar irrigation scheme was built in an area that was suffering from out-migration of males (>20%), irrigation could only take place in the monsoon season and there was also a food deficit. Apart from agriculture, there were very few employment opportunities. The irrigation scheme became operational in 1983 and had an enormous impact on agricultural output. Annual cropping intensity rose from 128% before the project to 212% in 1985. Before the project was implemented, 80% of Bhorletar's population was considered poor. Their agricultural surplus was insufficient to even meet basic food requirements. In 1985, it was found that less than 45% of the population could be classified as poor. Employment in agriculture increased and the project also created considerable economic potential in agro-processing, trade and transport of agricultural products and in the construction industry. However, after two years, it was found that some erosion had occurred in the command area, which needed attention (Martens 1989).

The Kankai irrigation project aimed to establish sustainable irrigated cropping using water from the Kankai River. It also aimed to improve the low levels of agricultural output, farm incomes and living conditions in an area totalling 8,000ha. The project comprised the provision of a river diversion weir, intake structure, irrigation, drainage and roads. Overall, the social and poverty reduction impact of the project is estimated to have been positive. More people were living in the area than would otherwise have been possible and average net farm incomes, though still modest, had doubled. By providing migration opportunities to impoverished hill farmers, the project reduced environmental pressure on the hills. Less degradation resulted in better hydrological conditions on which the project critically depends. Settlement of more industrious migrants from the hills has ensured higher productivity levels than if the project area had been cropped by local farmers alone. The massive migration and rapid settlement of hill people in the scheme alleviated poverty amongst poor migrant farmers. However, in this process, the new settlers, with a different social background, have progressively marginalised the indigenous farmers (ADB 1993).

From surveys of 42 villages in the central and eastern areas of Nepal, Upadhyaya et al. (1993) found that, despite the adoption of Modern Varieties (MVs), increases in paddy yields have not been as significant as those achieved in other Asian countries. The most popular of the MVs adopted in Nepal did not respond to the use of fertiliser as well as others, although they could withstand a wider range of production environments. However, yield gains were modest. It was concluded that the lack of, or poor quality of, irrigation facilities, led to relatively poor output performance in Nepal.

Gill (1996) reached similar conclusions with regard to production and productivity trends in the Terai. He listed the four main advantages of irrigation in the Terai as: risk reduction, potential for increased yields, earlier planting and establishment, and reduced growing period (for varietal reasons). The last two factors help to increase the flexibility of cropping patterns, and in particular, facilitate production of an ‘early’ paddy crop in advance of the main monsoon season crop. Hence, the most fundamental change in cropping patterns accompanying the intensification process occurs when irrigation is introduced. Expansion or contraction of paddy production is largely a function of irrigation, particularly with early paddy, and to a lesser extent spring paddy. The area of wheat has also been increasing due to irrigation and modern short duration varieties, which are easier to fit into the cropping pattern after the main monsoon crop of paddy.

Results from Participatory Rural Appraisal (PRA) surveys showed that yields under irrigation were 30-60% higher under irrigation than rainfed conditions. In addition, the contribution of varietal change was greater as MVs yielded between 66-100% more than local varieties of the same crop in the same season (Gill 1996). Yield trends reported by rainfed villages were negative or static, and while more mixed, those of irrigated villages were similar in tending to show stagnation in productivity, although at a higher level. It was concluded that productivity growth in aggregate in the Terai was being maintained by farmers who were switching to a superior production environment (i.e. irrigation) and/or to a superior technology (i.e. improved seed). These two processes were mutually reinforcing, and as not all villages, or even farms in a village, make the switch at the same time, the aggregate result was a succession of upward shifts in production at the micro level, which aggregated to produce modestly increasing yields at the macro level. However, the shift was being made to varieties whose productivity was already tapering off or even diminishing. It is a concern that these upward shifts are masking the fact that yields in almost all production environments have been static or declining. Farmers’ explanations for this decline or stagnation in yields in the absence of technical change were: declining soil fertility as organic matter from prior forest cover was used up, difficulties in obtaining sufficient and correct fertiliser on time, lack of water control and reliability of irrigation supply, and declining performance of retained MV seed coupled with shortages in supply MV seeds for purchase (Gill 1996).

With regard to employment impacts, Mishra et al. (2000) argue that a competitive seasonal labour market was emerging throughout the Gangetic delta region in Nepal and India. Circulating patterns of seasonal migrant labour were responding to hierarchized markets, and wage levels and rates. Green revolution areas offered higher wage rates and levels, a longer duration of work, and higher savings. Irrigated areas, which had not truly entered the GR phase, were the next preferred areas. Unirrigated areas dominated by smallholdings and extensive-agriculture orientated areas were the least attractive because the wage levels, savings and work duration were the lowest and shortest.

Data gathered from 162 STW owners and 162 non-owner households in the Terai region of Nepal, showed that STW irrigation had a significant positive effect on cropping intensity, rice productivity, farm income, and employment Bhandari (2001). Furthermore, it promoted cropping patterns dominated by cash crops, expedited adoption of modern crop varieties, and provided irrigation security during drought. STW ownership was skewed towards the large farmers, who reaped the major benefits of STW irrigation.

A survey of 273 STW owners and 237 non-owners in 6 selected Terai districts, was undertaken by Koirala (1998). STWs were mostly used for paddy and wheat crops. In paddy, STWs were mostly used during the nursery stage in April-May, before the monsoon. In the crop stage, their use was dependent on the performance and spread of the monsoon. For wheat, irrigation was provided 2-3 times at critical stages. Irrigation was also used for pulses, sugarcane and vegetables. Vegetables were particularly profitable. For farmers in Bara district, net profits per ha for the following crops were: bitter gourd NRs 99,958, potato NRs 75,253, cucumber NRs 73,858, cauliflower NRs 154,146. According to Koirala (1998), this was "a level of profit beyond imagination in the traditional cereal crop cultivation". Irrigation costs ranged from 10-42% of total production cost. In paddy-wheat rotation, STWs were also profitable because of the increase in cropping intensity, increased use of fertiliser and increase in yield of 150-300%. Given the incremental costs of irrigation, even a 50% increase in yield was found to be profitable. Vegetable production was recommended to increase utilisation of STWs, which would otherwise be idle for 8 months of the year.

It was observed that STW owners tended to be wealthier than non-owners. In particular, eligibility for an Agricultural Development Bank (ADBN) STW loan required the farmer to own 1.5 *bigha* (approximately 1 hectare) of contiguous land. It was concluded that the survey data confirmed that STW loans, and hence the benefits of irrigation, had been disproportionately gained by relatively wealthy, literate and better-off farmers (see table 3).

Table 3 Characteristics of STW owners compared to non-owners

Characteristic	**STW owners**	**Non-owners**
Sample size	273	237
Average landholding, ha	3.38	1.81
Average % of holding irrigated	75	40
Average number of plots	3	2
Average land value (NRs per ha)	574,000	442,000
Average homestead area, ha	0.09	0.08
% of concrete houses	47	27
% owning cattle	88	78
% owning buffalo	74	34
Literacy, %	47	34
Gap in male v female literacy, %	34	48

Source: (Koirala 1998)

A cross-sectional survey of an irrigated village (Anandban) and an unirrigated village (Ramapur) was conducted in the Terai in 1987 by Thapa (1989). Considerable inequality was observed in income distribution in both villages, with rice income contributing most to income inequality, together with size of operational holdings. Wider adoption of new agricultural technology in the irrigated village led to less equitable income distribution, mainly through rising returns to land. The new technology also had a positive impact on employment, particularly for hired labour, although inter-regional migration led to an equalisation of wage rates between villages. However, despite an increase in returns to labour due to the technological change, share of returns to labour declined in the irrigated village. Thus it appears that irrigation was equity reducing. Although the landless poor and small farmers gained in absolute terms, large farmers gained more from the increasing returns to land. The conclusions to this study emphasised the need for continued development and dissemination of new technology in Nepal. This would be through: investment in irrigation, research and extension and an improved input delivery system. It also concluded that the unfavourable income distribution impact of new technology could only be mitigated through a land tenure policy which encourages efficiency but discourages land concentration.

Based on a farm household survey in Nepal, Yadav et al. (1992) found that farm size and irrigation were major determinants of borrowing from formal institutions, whereas family size was the most decisive factor in borrowing from informal sources. Formal sector borrowing per hectare of cultivated area initially increases and then decreases with farm size. While very small farmers tend to be excluded from the formal financial market because of a lack of collateral, very large farmers choose to borrow less from that source because of lower production efficiency.

It is a common finding of time allocation studies that women work longer hours than men, and low income women work longer hours than better-off women. Nepalese women are equally involved in both field and post-harvest work in crop production. Ploughing is considered a man's job, whereas, all other work, although shared by men, is mostly undertaken by women (Katuwal 1990). Women's involvement is also greater in production of the main staple crops of rice, maize and wheat (Regmi and Weber 1997). Acharya and Bennett (1981) found that, in Nepal, women spend almost the same amount of time on production/income generating activities as men (4.62 hours/person/day by women and 5.8 hours/person/day by men). They also spend significant additional amounts of time on food and forage gathering, fuel and water collection, food processing, home construction and other domestic activities. Taking all activities together, women worked for about 44% more time than men (10.8 compared to 7.5 hours/person/day). When this time input was valued, women were contributing 15% more to household income than men (Acharya and Bennett 1981). The time allocation of women compared to men also varies by income group, by terai, hill or mountain location, by season and by ethnic group (Acharya and Bennett 1981), (Nepal Rastra Bank 1988). According to Sharma (1995), in both rainfed and irrigated agriculture, time spent working by women is higher compared to men. In rainfed areas women devote 12.36 hours per person per day, whereas for men it is only 9.03 hours. In irrigated zones, women spend 11.61 hours per person per day, and men only 7.85 hours (Sharma 1995).

Neupane (1991) studied households with and without irrigated land in two areas in southern Nepal (both in Chitwan District). The interrelationships between household income and women's time allocation were examined, as well as the implications for the health and nutritional status of children. Data was collected for a sample of 90 households in both an irrigated and control area. In the irrigated area, irrigation was introduced in 1967, with the main canal constructed in 1972, and rehabilitation in 1974. Compared to other districts of the country, Chitwan is relatively better off in terms of education and health services.

Investigation was based on the assumption of two possible pathways by which irrigation could effect child health and nutrition:

i) a positive impact from increased household income and food consumption as a result of additional production and increased food availability;
ii) a negative impact if increased demand for women's time from increased cropping intensity or changed cultivation practices is compensated by decreased time spent on child-care and household activities.

Kumar and Hotchkiss (1988) and Popkin (1983) have presented evidence linking time allocation and workload of women to child nutritional status. In addition, child development may be hindered by an increase in morbidity from exposure to water-borne diseases associated with irrigation. Neupane (1991) also reports that the association between childrens' nutritional status and parents' education, especially maternal education, is frequently cited by nutrition researchers. There appears to be a strong positive correlation when income is higher and a negative correlation during periods of intense food shortage. Thompson (1979) found severe growth stunting in children in the rural hills of Nepal to be more prevalent amongst poor compared to wealthier households, especially during a bad harvest year. In a nutritional study, Martorell et al. (1984) found higher values for crop production in Nepal to be associated with better growth, height for age, and weight for age among children.

Neupane's (1991) findings were that mean landholding size and distribution were similar between the irrigating and non-irrigating groups. However, irrigating households had a greater tendency to cultivate additional land as tenants. Farmers reported that before irrigation, the cropping pattern was the same for both groups with maize and mustard as the dominant spring and winter crops. After the introduction of irrigation, the irrigating group had three crops: first paddy, then mustard, wheat and potatoes as winter crops, and finally maize in spring. The non-irrigating group continued to have only two crops: maize or upland paddy (or a mixed stand) in summer, and mustard, wheat or winter maize in winter (paddy was grown by only 27% of non-irrigating households).

With regard to livestock, there was no difference in buffalo ownership, but the mean number of all animals owned was higher for irrigating households. Paddy straw was the main source of fodder, therefore paddy area cultivated may have been a limiting factor for small and non-irrigating households. For expenditure, irrigating households spent less on food and more on crop inputs. No clear pattern was evident for other items.

There was no significant difference between the mean total household incomes of irrigated and non-irrigated households, but there were notable differences in the composition of income. Farm income was significantly higher in irrigating households, and was the main source of income for both groups, followed by income from government and non-government employment, then business income, and finally casual waged labour. Off-farm income contributed up to 60% of total income for non-irrigating households and only 44% for irrigating households. Waged labour income was 100% higher for non-irrigating households. Family size, total landholding size, number of livestock and mother's education status were found to be more significant determinants of total household income than irrigation. The distribution of total income was similar for both groups, while that for off-farm income was more equal for non-irrigating households, and that for farm income more equal for irrigating households (Gini coefficient of 0.3 compared to 0.4). It was concluded that irrigation had not increased disparity in income distribution between the irrigation beneficiaries, particularly for farm income. With regard to food consumption, there were also no significant differences in per capita caloric consumption between irrigating and non-irrigating households. However, non-irrigating households spent 200% more than irrigating households on purchasing food.

The allocation of womens' time to household activities was significantly higher in non-irrigating households (observations taken in 4 months – February, April, July, October). Time spent on agricultural activities was higher in these months for irrigating households. The effect was most pronounced in the peak agricultural months. Women in irrigating households also spent more time on livestock activities, although irrigation was a less significant determinant of time spent than the number of livestock and the ratio of pre-school children to adults. The results did not show that women in irrigating households spent less time on child-care activities, in fact they spent more, but it was concluded that the small sample size and variation in age ratios of children could influence the results and that the actual situation was probably no difference.

With regard to child nutritional status, there were no differences in mean weight gains observed over three month intervals, and no consistent pattern of disparity in weight for age, height for age and weight for height indicators. It was concluded that there was no evidence that children from irrigating households were nutritionally better off.

It was speculated that it is womens' presence at home, rather than the types of activities they are involved in, that affects the nutritional status of children. For staple crops, threshing and processing activities are the most time consuming jobs, but are carried out by women at the homestead. In contrast, livestock activities may take women away for the whole day, if it is necessary to collect fodder in the forest or graze animals there. Regression models suggested that time spent on agricultural and livestock activities away from the home could have a long-term detrimental impact on childrens' weight for age and height for age.

Production of dairy products could contribute significantly to the nutritional status of children, either directly or from the cash income from milk sales. Seasonality also played a role as during the pre-monsoon period when incidence of illness is high, womens' presence at home, regardless of the type of activity performed, was important for the nutritional status of children. No difference was found in the literacy rate between irrigating and non-irrigating households, but for both groups the gender disparity was that 50-55% of males were literate and only 32% of females.

Overall, Neupane (1991) concluded that introduction of irrigation had positive effects on total food production and farm income distribution. However, long term negative effects on child nutrition could also occur because of women's time allocation. She suggested that in the areas studied, incremental income from irrigation was not high enough to achieve a positive effect on child nutritional status sufficient to outweigh the negative impact from the increased agricultural labour demand for women. The positive impact of irrigation on child nutrition may also have been limited by the extent to which the benefits derived from incremental agricultural production were mainly gained in kind rather than in cash, and were consumed by the whole family.

It was also concluded that lack of irrigation need not be a constraint to improved nutrition. If there is no shortage of food and there is good market access and people have income from off-farm activities then their consumption can be at the same level as households who produce staple foods themselves. Clearly, access to off-farm income may be more limiting elsewhere. It is notable that Chitwan District is one of the most favoured in Nepal, in terms of infrastructure and the potential for livelihood diversification.

With regard to environmental impacts, Brown and Shrestha (2000) report that market-oriented production is a key factor driving land-use intensification in the middle hills of Nepal. The results of a GIS-based case-study indicate that the area under cultivation has increased, but the expansion of irrigation has been limited by water availability. Farming systems have become more intensive, with double and triple crop rotations where water is available. Increased vegetable production and the marketing of milk are indicators of such intensification. For example, 70% of the households surveyed now grow cash crops, and 45% sell buffalo milk. As market-oriented agriculture is more demanding of soil and water resources, concerns about resource degradation are emerging. Agro-chemical use has increased, soil acidification related to the use of ammonium-based fertilisers is a concern, and stream eutrophication is now common during the dry season. Commercial milk production has increased demand for animal fodder, placing additional pressure on forest and rangelands. Fodder shortages during the dry season were reported by 55% of female farmers. Increasing population pressure is also encouraging farmers to change from a single irrigated crop to double irrigation of terraces and from rainfed terraces to irrigated terraces, thus increasing pressure on dwindling water supplies.

A study in the middle hills of Nepal has shown that irrigated terrace risers often experience extensive slope failures (Gerrard and Gardner 2000). Although relatively insignificant in land degradation terms, they are labour intensive to repair and create management problems. Results show that it is recent conversion of rainfed to irrigated terraces that causes most problems. Gerrard and Gardner (2000) conclude that the landscape has reached the point where further expansion of irrigated terraces is unsustainable as irrigation is moving on to more marginal, less suitable areas.

Gill (1995), however, argues that the extent to which population pressure and expansion of the cultivated area is responsible for deforestation and soil erosion in the middle hills of Nepal has been greatly exaggerated. He contends that the conventional view that farmers are to blame for erosion, fails to take account of the severity of the natural processes that occur, independent of action by people. Traditional farm and forest management practices can have beneficial, or at least, less severely damaging effects.

A more specific environmental observation is made by Collins and Neal (1998), who established that stormflow in cultivated catchments is dominated by low-alkalinity rainwater which dilutes the higher-alkalinity stored waters, often causing a decrease in stream pH. In a forested catchment, high infiltration rates maintain stored water flows and reduce the rainfall contribution to stormflow. Drains and irrigation channels for terraced agriculture therefore provide quick flowpaths allowing rainfall to bypass the soil horizons, thus influencing both the volume and pH of stormflow.

Potential management options to minimize the impact of intensification include improved agricultural extension, Nitrogen-fixing plants, improved composting, liming, and increased water use efficiency. According to Brown and Shrestha (2000), market-driven agricultural production provides a source of income to the rural poor, but the sustainability of these intensive systems is dependent on addressing soil and water degradation.

8. CONCLUSIONS

Irrigation can play a central and dynamic role in the improvement of rural livelihoods, but is often subject to criticisms of inefficiency in water use, high capital and recurrent costs, lack of sustainability, and association with inequity in the distribution of both land and water.

Irrigation is an effective, but blunt, instrument for reducing rural poverty, and research is needed on the best means to reduce disparities among landowners and between landowners and other groups, without compromising productivity and wider poverty alleviation gains.

Developing country governments and other stakeholders need better knowledge about irrigation's role in improving and sustaining rural livelihoods to improve decision making in the following areas:

- Policy decisions relating to the degree of support provided to irrigated agriculture compared to rainfed agriculture and other sectors, and to the liberalisation of trade and markets, all with the objective of stimulating pro-poor growth.
- Investment decisions relating to the rehabilitation or expansion of irrigation.
- Water allocation decisions in a context of increasing water scarcity and competition for water from other sectors (what will be the full economic cost and impact on rural livelihoods of transferring water from irrigation to other uses?)
- The potential to improve the design and management of irrigation including both engineering and institutional factors (including water user roles in management) so as to enhance the contribution made by irrigation to rural livelihoods.

This research will contribute to this knowledge by collecting micro or scheme level evidence of the processes at work though which irrigation affects rural livelihoods. Information will be collected and analysed in relation to production, income and employment effects, the likely nature and scale of production and consumption linkages, impacts on water, soil and the environment generally, the extent and nature of livelihood diversification, and multiple uses of water. The research will also explore existence of constraints to the achievement of irrigation led pro-poor growth, and any incidences of negative impacts on rural livelihoods.

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