REOPTIMIZATION AND REOPERATION OF THE AKOSOMBO AND KPONG DAMS PROJECT

REPORT:

"Literature Review- Environmental flow, Livelihood flow and Adaptive Management"

March, 2013

Presented by the Institute for Environment and Sanitation Studies (IESS), University of Ghana

To

The Water Resources Commission

Contributors:

Dr. Daniel Nukpezah
Dr. Opoku Pabi
Dr. Benjamin Ofori
Dr. Jesse Ayivor
Prof. Chris Gordon

EXECUTIVE SUMMARY

Damming of rivers to generate electricity contributes to the growth of an economy as a result of the multiplier effects it creates by providing power for industry and for domestic use. However damming of rivers also results in the erosion of quality of the standard of living of downstream communities. This occurs as a result of the fact that damming creates situations where ecosystem functions and processes downstream are impaired.

The damming of the Volta River at Akosombo has for example resulted in the drastic reduction in floodplain agriculture as natural flooding no longer leaves rich alluvial deposits that improve soil fertility in the overlying upland areas. In addition, the damming has distracted the natural flow of the river thereby changing the natural ecology and by promoting the growth of exotic weeds that have choked off the once lucrative shell fishery and increased the snail vectors of the schistosome parasite. The overall effect of the loss of agriculture, clam picking, deteriorating health due to bilharzias infestation and fishing activities has created intense poverty in the lower Volta and led to a dramatic shift in income generating activities.

Through advances in science, knowledge and technology, it is now possible to optimize and reoperate dams to restore downstream ecosystem functions and livelihoods.

The goal of the Akosombo and Kpong Dams Reoptimisation and Reoperation Project is to contribute to economic growth and poverty reduction through restoration of downstream ecosystems, food systems and livelihoods. As part of the reoptimization and reoperation efforts, the IESS was contracted to among other things:

- Carry out literature review on environmental and livelihood flows and design an adaptive management programme for environmental and livelihood flows downstream. This report documents finding related to the literature review. A separate report on design of adaptive management is being prepared.

The key findings of the literature review include the following:

- The concept of environmental flows describes the quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and wellbeing that depend on these ecosystems
- Increment in minimum flow due to alteration of the natural mean discharge affects the average velocity of a river’s minimum flow. This artificial changes induced by dams cause a significant change in fish community suggesting that changes in flow can have a significant impact on ecosystem structure and function
- Optimal flows help limit adverse ecological impacts to acceptable levels (Stewardson and Gippel, 1997).

- Major criteria for determining environmental flows includes the maintenance of flow variability which affects the structural and functional diversity of rivers and their floodplains and which in turn influences the diversity of aquatic species (WANI, 2011)
- Flow regime is the key driver of the processes that sustain river and floodplain biodiversity and is demonstrated by four key principles:

Principle 1

Flow is a major determinant of physical habitat availability which in turn is a major determinant of biotic composition

Principle 2

Aquatic species have endured life history strategies primarily in direct response to the natural flow regimes

Principle 3

Maintenance of natural patterns of longitudinal and lateral connectivity is essential to the viability of populations of many riverine species

Principle 4

The invasion and success of exotic and introduced species in river is facilitated by the alterations of flow regimes

- Flow regimes influence the ecology of a river and if a natural ecosystem is desired, the flow regime will need to be natural. Thus so many ecosystem function depends on the flow regime (Dyson et al., 2008)
- Flow drives fluvial processes such as channel widening and meandering
- Flow regime is an overriding factor governing the nature and stability of communities along a river although biotic interactions do take place and have their influence on the species composition and abundance (Marchland, 2003; King et al., 2000)
- All major riverine processes such as flooding, moderation of salt water intrusion, sediment transport etc are dependent on certain aspects of the discharge characteristics of a river (Marchland, 2003)
- Flow regime is the most important determinant of ecosystem function and services provided by these functions
- Five main components of the flow regime including the rate of change of flow, flow frequency, flow duration, timing of flows and quantity of flows are important to help restore ecosystem functions and livelihood downstream
- Minimum flows in a river have been fixed, often arbitrarily at 10% of the main annual runoff (World Commission on Dams, 2000).

Further this report establishes that riverine ecosystems are sustained by environmental flows which ensures ecological balance and maintains healthy aquatic ecosystems that support human livelihood.

1. INTRODUCTION

Damming of rivers to generate electricity contributes to the growth of an economy considering the positive cascading effects it has for the development of any nation. However the development of rivers for hydropower has conventionally come at a high cost in terms of riverine livelihoods and ecosystems. Inspite of the clearly documented benefits that hydro power generation due to damming of rivers contribute to any economy, hydropower dams have also devastated the livelihoods of the downstream communities and the physical ecosystem processes on which they depend.

The damming of the Volta River at Akosombo has resulted in a drastic reduction in floodplain agriculture as natural flooding no longer leaves rich alluvial deposits that improve soil fertility in the overlying upland areas. In addition stakeholders have realized that the damming of the Volta River has distracted its natural flow, ecology and has brought about certain challenges like the growth of exotic weeds that have choked off the once lucrative shell fishery and increased the snail vectors for the debilitating bilharzias. Furthermore the sediment poor water flowing downstream due to the fact that much of the sediments have been trapped in the lake has resulted in net increased shoreline erosion which has been estimated at 10 metres per year compared to an estimate of 2-5 metres per year when the dam was built.

The overall effect of the loss of agriculture, clam picking, deteriorating health due to bilharzias infestation and fishing activities has created intense poverty in the lower Volta and led to a dramatic shift in income generating activities. The goal of the Ghana Dam reoptimization and Reoperation Project is to contribute to economic growth and poverty reduction through restoration of downstream ecosystems, food systems and livelihoods by reoperating the Akosombo and Kpong dams.

As part of the reoptimization and reoperation efforts, the IESS was contracted to among other things:

1. Carry out literature review on environmental flows, livelihood flows and adaptive management
2. Estimate the effects of reoperation of Akosombo and Kpong dams on public health

3. Carry out an analysis of governance and institutional structures within the study area and produce a report on the effectiveness of governance and institutional structures to manage the change that would occur
4. Design an adaptive management programme for the Lower Volta

This report focuses on the first term of reference (TOR) for this assignment namely "Literature review; environmental and livelihood flows"

2. PROCESS AND METHODS USED FOR THE LITERATURE REVIEW

In order to report on the assigned terms of reference, the project team met on several occasions to discuss the key issues to be included in the literature review. A systematic literature search then followed on key themes like "environmental flows", "livelihood and livelihood flows", "integrative model of environmental and livelihood flows" and also on "adaptive management". The articles were then read and the key points reviewed. Sources of the literature search included the internet, the electronic resources of the Balme library, Universiy of Ghana and the Volta Basin Research Project (VBRP) secretariat at the University of Ghana as well as print journal articles and published books on the Volta basin.

3. LITERATURE REVIEW

<u>3.1 Environmental flows</u>

3.1.1 Concept of environmental flows

Increasingly, concerns over environmental sustainability and maintaining ecosystem integrity in rivers have persuaded water resources managers to recognize the need of allowing certain amount of flow with an acceptable level of quality in rivers which is often regarded as environmental flow (EF) (Tharme, 2003).

The origins of the environmental flows concept can be traced to work undertaken in the 1940s in the western USA, following the recognition that a loss of flow in rivers was responsible for reduced numbers of game-fish species. Subsequently, the concept of environmental flows has advanced considerably in the last 20 years from a focus on individual aquatic species (although there are circumstances where this continues to be relevant) to a much broader concern about aquatic ecosystem protection or restoration (King et al., 1999; Hirji and Davis, 2009; Arthington et al., 2004; Moore, 2004). In the literature, the three most common terms, environmental flow, minimum flow and in-stream flow, showed relatively equal frequencies, and other common terms included natural flow regime, ecological reserve and environmental water allocation. Brown and King (2003) however, point to an important distinction between in-stream flows and environmental flows. They were of the view that in addition to releases for environmental needs, in-stream flows encompass all releases for non-environmental purposes, including hydropower, irrigation, navigation, dilution of pollution and inter basin transfers. These releases do not constitute environmental flows, as they do not take into account the natural variability of the flow regime.

According to Dyson et al. (2008), the concept of environmental flows is part of a broader notion of taking an ecosystem approach to integrated water resources management. They maintain that the concept of environmental flows is adaptive and essential to the wider Integrated Water Resource Management (IWRM) approach. In view of this, it is argued as having a close link to the concept of ecosystem services.

Added to this, the environmental flows concept recognizes that there are needs of freshwater systems to maintain their ecological integrity and to continue to provide goods and services to society (Moore, 2004). This implies that rivers, wetlands, aquifers and other water systems require a certain fraction of water at sufficient quantities and times to ensure their integrity is not undermined. It is unrealistic and undesirable in many cases to return modified rivers, wetlands and estuaries to their natural state or pristine condition (Schofield, Burt & Connell 2003). This recognition of flow as a key driver of aquatic ecosystems has led to the development of the environmental flows concept. The environmental flows concept now serves to enhance informed, equitable and sustainable decision making in water management (Dyson et al., 2003).

Stewardson & Gippel (1997, pp. 92–93) provided a definition for environmental flows as: “a set of operational rules for water resource schemes to limit adverse ecological impacts to acceptable levels” which “may be designed for a river subject to a new water resource development or more commonly, a historical development for which insufficient consideration has been given to the ecological impacts”. Dyson et al., (2008) posit that the goal of environmental flows is to provide a flow regime that is adequate in terms of quantity, quality and timing for sustaining the health of the rivers and other aquatic ecosystems. This description is in line with the IUCN's definition that it is the water regime provided within a river, wetland or estuary to maintain ecosystems and their benefits where there are competing water demands/uses and where flows are regulated (IUCN 2000). The Nature Conservancy (2006), along similar lines, define it as the quality, quantity, and timing of water flows required to maintaining the components, functions, processes, and resilience of aquatic ecosystems which provide goods and services to people.

Several features of these definitions have universal appeal. The descriptions signal that the "quality" of water is an important dimension alongside water quantity and temporal flow patterns, and it also highlights the continuity of rivers and estuaries and their dependence on freshwater flows. Furthermore, it explicitly links environmental flows, river and estuarine ecosystems, and the livelihoods and well-being of people and societies.

Mathematically, Environmental flows are usually given as a percentage of average annual flow or as a percentile from the flow duration curve, on an annual, seasonal or monthly basis (Korsgaard, 2006).

Environmental flows have been shown to be important in restoring downstream ecosystem processes and functions. For example, Lamouroux et al., (2006) reported that the Pierre-Be´nite, a reach of the Rhone River in France has a natural minimum flow rate of 10 m^3 $s\text{-}^1$ in the months of August. However, increment in the minimum flow due to alteration of the natural mean discharge also affected the average velocity of the river's minimum flow. This artificial changes induced by dams caused a significant change in the fish community within the river. This finding suggests that changes in flow can have significant impact on ecosystem structure and function. This may well imply a threshold flow for optimal ecosystem function making the concept of flow significant for ecosystem sustainability.

3.1.2 Flow as a driver of aquatic ecosystems functions and processes

There are four distinct principles that demonstrate how the flow regime is the key driver of processes that sustain river and floodplain biodiversity (Bunn and Arthington, 2002; Korsgaard, 2006). *Principle 1*: Flow is a major determinant of physical habitat availability, which in turn is a major determinant of biotic composition. *Principle 2*: Aquatic species have evolved life history strategies primarily in direct response to the natural flow regimes. *Principle 3*: Maintenance of natural patterns of longitudinal and lateral connectivity is essential to the viability of populations of many riverine species. *Principle 4*: The invasion and success of exotic and introduced species in rivers is facilitated by the alterations of flow regimes.

The objective in implementing environmental flows is not to return rivers or any other water system to their natural state. Rather, the flow concept aims to estimate the environmental needs of aquatic ecosystems so that these needs can be considered alongside the social and economic needs when decisions are being made with respect to water use and allocations (Moore, 2004).

The flow regime as discussed by Shafroth and Beauchamp (2006) is often the driving variable in these systems, strongly affecting other aspects of the riverine environment such as fluvial processes (e.g., channel widening, meandering) and alluvial groundwater dynamics. These factors, overlaid on the geologic and climatic setting, form the physical "stage" on which vegetation dynamics play out. All major processes that sustain river functions, such as flooding, moderation of salt water intrusion, sediment transport etc., are dependent on certain aspects of the discharge characteristics of the river (Marchand, 2003). For river and wetland ecosystems, the flow regime is the most important determinant of ecosystem function and services provided by these functions. Flow features are determined by river size, geology, climate variation, topography and vegetation cover.

The objective of environmental flows is to maintain or partly restore important characteristics of the natural flow regime (i.e. the quantity, frequency, timing and duration of flow events, rates of change and predictability/variability) required to maintain or restore the biophysical components and ecological processes of in-stream and groundwater systems, floodplains and downstream receiving waters (Arthington & Pusey, 2003).

3.1.3 Environmental Flow Regime and Component

According to Marchland (2003, cited in King et al., 2003) although biotic interactions do take place and have their influence on the species composition and abundance, it is now commonly assumed that flow regime is an overriding factor governing the nature and stability of communities along a river. The flow regime is the pattern or variation of flow needed throughout the year to maintain essential ecosystem functions and processes. Many factors, such as water quality, sediments, food-supply and biotic interactions, are important determinants of riverine ecosystems. However, the overarching master variable is the river's flow regime that is the natural flow paradigm (Poff et al., 1997).

The flows in many rivers may vary throughout a year and between years. This pattern of flow (termed the flow regime) typically consists of low flows during the drier months, small peaks (freshets) when rains return, and occasional high floods in unregulated rivers (Hirji and Davis, 2009). River flow regimes and their relevant events can be described by hydrological indices derived from these components, which must adequately represent the main facets of the regime and the events that determine the biological functioning, geomorphologic processes, and the transportation of nutrients and sediment (Poff & Ward, 1989; Richter et al., 1996; Olden & Poff, 2003).

Environmental flow regime influences not only water quality, energy cycles but also biotic interactions, and habitat of rivers (Naiman et al., 2002). There are five elements of the flow regime which support specific ecological functions (Matthews and Richter, 2007):

- **Extreme low flows** which occur during drought; these are associated with reduced connectivity and limited species migration. During a period of natural extreme low flows, native species are likely to out-compete exotic species that have not adapted to these very low flows. Maintaining extreme low flows at their natural level can increase the abundance and survival rate of native species, improve habitat during drought, and increase vegetation.

- **Low flows,** sometimes referred to as base flows, occur for the most part of the year. Low flows maintain adequate habitat, temperature, dissolved oxygen, and chemistry for aquatic organisms; drinking water for terrestrial animals; and soil moisture for plants. Stable low flows support feeding and spawning activities of fish, offering both recreational and ecological benefits.

- **High flow pulses** occur after periods of precipitation and are contained within the natural banks of the river. High flows generally lead to decreased water temperature and increased dissolved oxygen. These events also prevent vegetation from invading river channels and can wash out plants, delivering large amounts of sediment and organic matter downstream in the process. High flows also move and scour gravels for native and recreational fish spawning and suppress non-native fish populations, algae, and beaver dams.

- **Small floods** which occur every two to ten years; these events enable migration to flood plains, wetlands, and other habitats that act as breeding grounds and provide resources to many species. Small floods also aid the reproduction process of native riparian plants and can decrease the density of non-native species. Increases in native waterfowl, livestock grazing, rice cultivation, and fishery production have also been linked to small floods.

- **Large floods** which take place infrequently; they can change the path of the river, form new habitat, and move large amounts of sediment and plant matter. Large floods also disperse plant seeds and provide seedlings with prolonged access to soil moisture. Importantly, large floods inundate connected floodplains, providing safe, warm, nutrient-rich nursery areas for juvenile fish.

It is important however, to note that the different components of an environmental flow regime contribute significantly to different ecological processes (Postel & Richter 2003).
In addition to elements of the flow regime, five components are recognized that regulate physical and biological processes in fluvial ecosystems (More, 2004). These five components include:

- Rate of Change of flow,
- Flow Frequency,
- Flow Duration,
- Timing of flows and
- Quantity (magnitude) of water flows.

The five components according to Poff et al. (1997) comprise the elements of the natural flow regime that draw attention to the fundamental scientific principle behind the ecological integrity of flowing water systems. As mentioned earlier, these components regulate physical and biological processes in fluvial ecosystems. Thus maintaining or restoring the natural range of variation of hydrological regimes is a fundamental element for protecting fluvial ecosystem integrity (Poff et al. 1997).

Hirji and Davis (2009) noted that, there are two broad methods for providing environmental flows regimes. On regulated rivers, those with water storages in their headwaters, the agreed environmental flows can be delivered through specific releases of water from the storages at the right times to mimic some of the natural patterns of flows. Further, on all rivers-regulated and unregulated-and in all groundwater systems, controls over abstractions can also be used to retain certain components of flows (Hirji and Davies, 2009). For example, cease-to-pump rules during dry periods are widely used to ensure that low flows are protected. A wide variety of instruments are used to provide these flows, including separate entitlements for environmental water, conditions on abstraction licenses, and dam operating rules (Hirji and Davis, 2009). However it has been observed that the recognition of the importance of the flow regime in maintaining a healthy ecosystem has been virtually ignored in a management context (Poff et al. 1997). On the other hand, the Akosombo and Kpong Dams reoptimization and reoperation project seeks to embrace the flow concept and apply it in restoring downstream ecosystem function and processes.

3.2 Livelihood and Livelihood flows

3.2.1 Categories of Livelihood Assets

Livelihood may be defined as adequate stocks and flows of food and cash to meet basic needs. It comprises the capabilities, assets (including both material and social resources) and activities required for a means of living (Chambers and Conway, 1992).

The livelihoods approach is about people and seeks to gain an accurate and realistic understanding of people's strengths (assets or capital endowments) and how they endeavour to convert these into positive livelihood outcomes. The approach is founded on a belief that people require a range of assets to achieve positive livelihood outcomes and that no single category of assets on its own is sufficient to yield all the many and varied livelihood outcomes that people seek. This is particularly true for poor people whose access to any given category of assets tends to be very limited. As a result they have to seek ways of nurturing and combining what assets they do have in innovative ways to ensure survival (DFID, 1999).

Five categories of livelihood assets, which development workers draw on to explore the various dimensions of well-being and the means for achieving it, have been identified. These are natural capital, social capital, human capital, financial capital and physical capital (DFID, 1999; FAO, 2006).

Natural capital relates to access to land and resources including air, water, living organisms and all formations of the earth's biosphere that provide humans with ecosystem goods and services. Social capital refers to the institutions, relationships, and norms that shape the quality and quantity of a society's social interactions.

Human capital is the stock of competencies, knowledge, social and personality attributes, including creativity, embodied in the ability to perform labor so as to produce economic value.

Financial capital relates to assets that are considered to be liquid in nature, which can be used to make purchases of various goods and services or to acquire other types of assets.

Physical capital is the collection of the tangible items that are used for actual production of the good or service (FAO, 2006).

3.2.2 The Asset Pentagon

The assets pentagon is a schematic illustration of people's access to assets. The pentagon was developed to explain the important inter-relationships between the various assets as shown in figure 1.

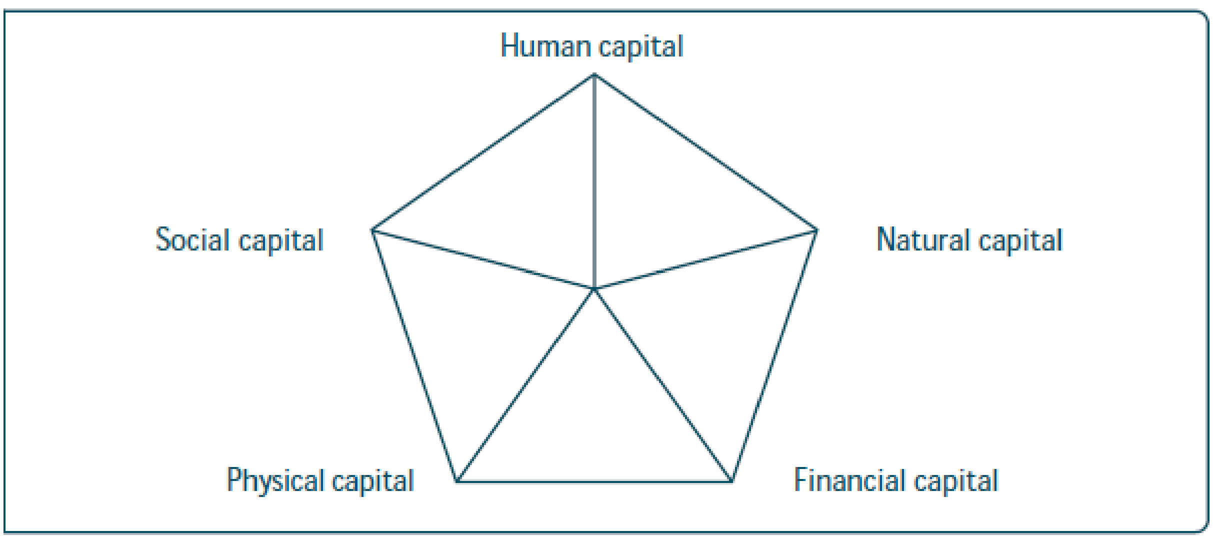


Fig. 1: The asset pentagon (Source: DFID, 1999)

The pentagon shows that a single physical asset can generate multiple benefits. If someone has secure access to land (natural capital) they may also be well-endowed with financial capital, as they are able to use the land not only for direct productive activities but also as collateral for loans. Similarly, livestock may generate social capital (prestige and connectedness to the community) for owners while at the same time being used as productive physical capital (think of animal traction) and remaining, in itself, as natural capital. In order to develop an understanding of these complex relationships it is necessary to look beyond the assets themselves, to think about prevailing cultural practices and the types of structures and processes that 'transform' assets into livelihood outcomes (DFID, 1999)

3.2.3 Livelihood Flows

Livelihood flows are processes that enable livelihoods to function. A range of dynamic flows and processes, referred to as elements of livelihood flows, enable livelihoods to function. These include energy, food, water, information, motivation, social and income (FAO, 2006).

3.2.3.1 Energy

Rural people for example, find it harder to access reliable supplies of electricity and fossil fuels. Fuelwood and animal traction may fill this gap for subsistence purposes, but the lack of energy constrains opportunities for new businesses that could lift people out of poverty.

3.2.3.2 Food

Availability of food may not be a key problem, but food security can be an issue in lean seasons and bad years, or when external markets for cash crops adversely affect local food production.

3.2.3.3 Water

Scarcity of water means that critical trade-offs must be made between using it for drinking and washing, for livestock or for irrigation. Because many poor people do not have access to safe drinking-water, they are more exposed to water-borne diseases.

3.2.3.4 Information

Inadequate flow of information is a major cause of rural poverty, especially when people can no longer rely on traditional knowledge to understand ecology and plant growth, disease and markets.

3.2.3.5 Motivation

Uncertain rights, expropriation of common resources, conflict and change often leave rural people indifferent about the fate of the natural resources on which they rely. This mind-set reduces their disposition to cooperate and their chances of escaping from poverty.

3.2.3.6 Social

When rural institutions are strong, people are often able and willing to share labour, redistribute resources and pool risk. However, rapid changes in the use and management of forests, especially by States or external businesses, adversely affect traditional management and cooperative arrangements (FAO, 2006).

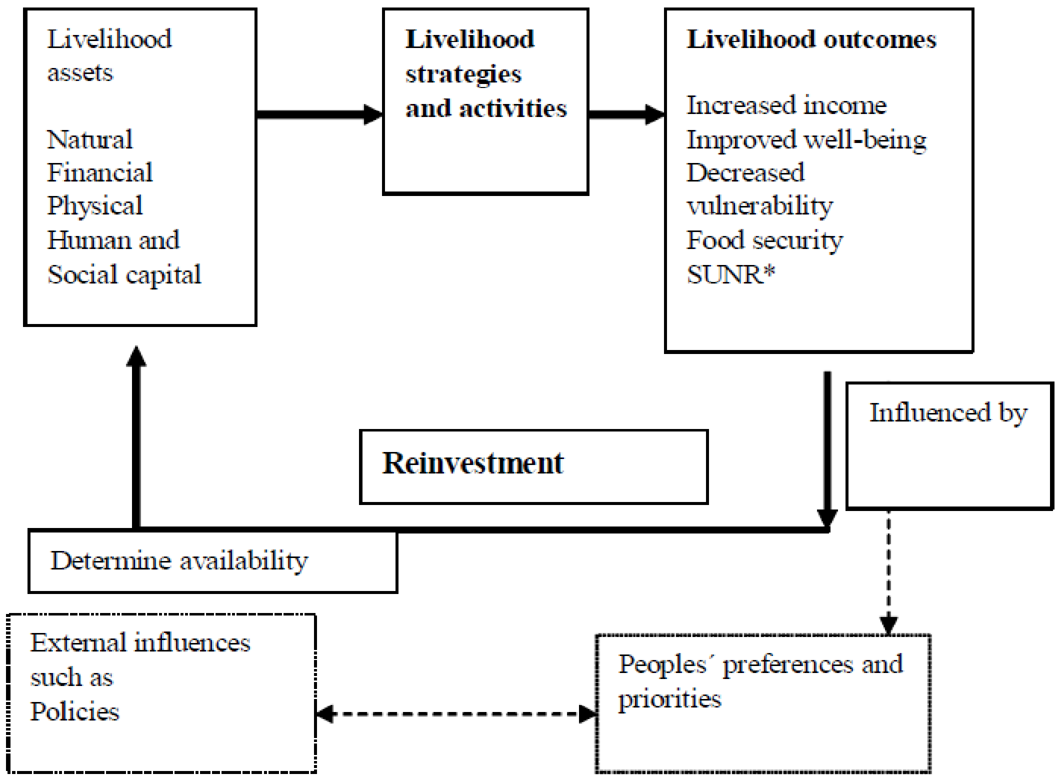
3.2.3.7 Income

Rural people usually have much lower incomes than urban dwellers. This may not matter for meeting subsistence needs, but matters when money is needed to purchase goods and services from the outside. While poverty can be alleviated without additional income, low income makes people unable to move out of poverty. It also leaves them vulnerable in times of crisis and when expropriation and commercialization for external markets deprive them of public goods such as forest products, food crops and water.

3.2.4 The Sustainable livelihoods framework

The framework attempts to establish a link between the policy environment and access to resources such as forestry and water, besides the impact of such access on the strategies adopted by the rural population (Hobley & Shields 2000).

Figure 2: Sustainable Livelihoods framework, with explanatory notes



Source: Nhantumbo *et al.*, (2003).

Since the 1990s governments and development agencies have increasingly being employing the sustainable livelihood approach (SLA) as a tool for tackling poverty reduction. This followed the expansion of the concept of sustainable livelihood at the 1992 United Nations Conference on Environment and Development that, among other things, advocated for eradication of poverty (Krantz, 2001). The issue of sustainable livelihood borders on poverty-focused development activities which aim at building the capacities of groups of people to improve upon their living status (DFID, 1999). Thus, promotion of sustainable livelihoods seeks to address the conditions of vulnerable groups by taking into consideration the factors and processes that create and perpetuate poverty.

According to the Department for International Development (DFID), SLA "provides an analytical framework that promotes systematic analysis of the underlying processes and causes of poverty" (DFID, 1999). It draws on the main factors that affect poor people's livelihoods and the typical relationships between these factors. It focuses on the strengths within the group and takes advantage of the knowledge, skills and abilities as well as the structures that are needed to take people out of poverty. (DFID,1999). Though SLA framework is used variously by different agencies the main focus is on poverty reduction on sustainable basis by dealing with the underlying resources and capacities – it is a capacity building model. It provides a holistic way of thinking through complex issues at various levels for designing programmes and evaluating the strategies (DFID, 1999).

The model highlights the variety of assets at the disposal of the group which support their livelihood (Fig. 2). The vulnerability context is understood as the factors that create and perpetuate poverty which is conceived at the level of the individual and in the broader social context. Understanding of the context–specific processes is necessary for the design of appropriate policies and strategies to enhance progress towards poverty reduction and elimination. The strategies adopted are expected to transform existing structures and processes that create the conditions of poverty. The structures and conditions include institutional arrangements and power relations that define access to livelihood assets, help shape individual creativity to cope with stresses, build trust and confidence among people and ensure mutual support and cooperation. These human organizational systems define the strategies that are adopted to develop the assets in order to achieve certain outcomes to support human livelihoods.

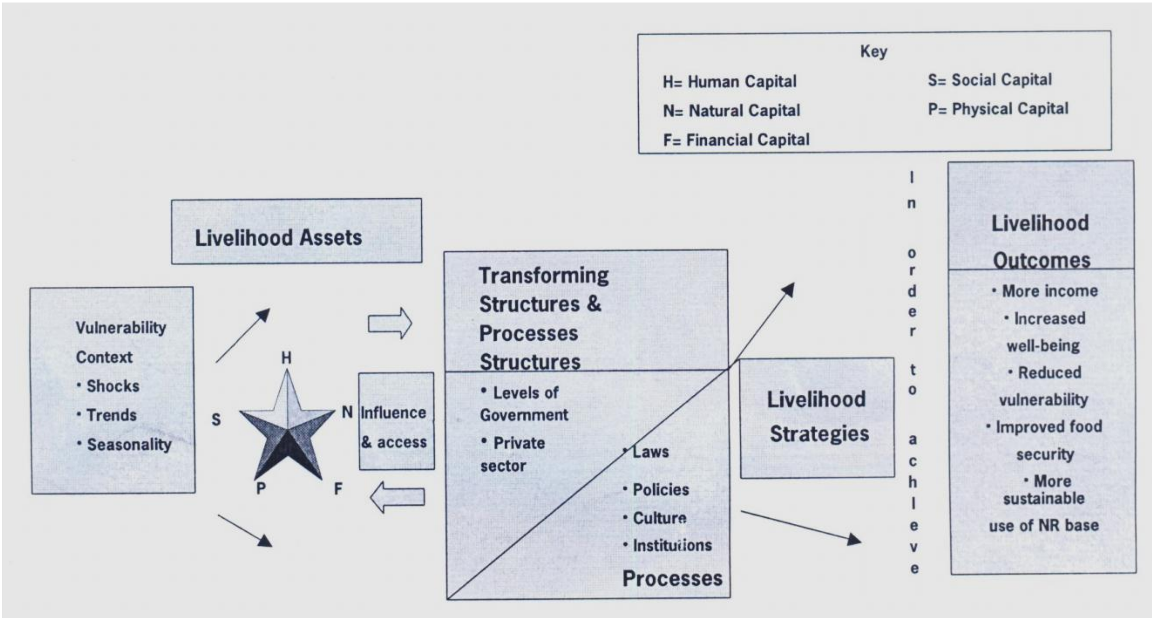


Fig.3: Sustainable livelihood framework with vulnerability context (Source: DFID, 1999)

The SLA is viewed as versatile and can be used under different circumstance and at different levels. At the lowest level it lends itself to the adoption of participatory approaches in understanding the causes and dimensions of poverty, thereby enabling people to examine their circumstances and provide their own definition of poverty. When employed at the level of programme planning and policy analysis it unravels the impacts of different policy and institutional arrangements upon households and the dimensions of poverty.

In spite of its usefulness Krantz (2001) contends that there are some difficult methodological and practical issues relating to definition of poverty and who the poor are. This is essential for prescribing and designing interventions. Though the 'poverty line' and 'wealth ranking' methods could be adopted in defining poverty, DFID suggest that it should be part of the very process of analysing livelihoods. The understanding here is that the whole socio-economic, cultural and institutional milieu of the group should be clear before the identity, characteristics and circumstance of the poor is established. This difficulty is underscored by the fact that there are complicated informal structures and relationships, though difficult to observe from outside, that influence access to resources and livelihood opportunities. The challenge is that these issues are sensitive to talk about during participatory discussions. For example it is sometimes difficult to get vulnerable groups including women to genuinely express their conditions (Moses, 1994).

3.3 Environmental flow and sustainable livelihood: An integrative model

Riverine ecosystems (and riparian communities) are sustained by environment flows, in this case water, which ensures ecological balance and maintains healthy aquatic ecosystems that support human livelihoods. Environmental flows replenish water in river and stream channels to reduce the effect of abstraction and diversion. The natural seasonal flows dictate the rising and falling water levels necessary for maintaining aquatic life and other life-forms that depend on riverine ecosystems and riparian habitats.

Environmental flows are however modified by dam construction across river channels to impound water and regulate water flow mainly for electricity generation, water supply for domestic and industrial use and irrigation. According to the World Commission on Dams (WCD), dam construction increased after the 1950s particularly in developing countries and by the end of the 20th century, there were over 45,000 dams in over 150 countries (WCD, 2000).

Dam construction has long lasting and profound impact on the environment and the total economic, social and environmental cost is enormous. Many people including displaced populations, host communities and downstream riverine communities are affected by dams, particularly large scale ones. It is estimated that 472 million people located downstream of 7000 largest dams in the world have been affected (Richter et. al, 2010). Dam construction alters the natural flow pattern of rivers and change downstream ecological conditions which has implications for livelihood support. It blocks movements of fish and other aquatic animals and disrupts flood-recession agriculture upon which riparian communities depend. Altogether, dam construction dramatically changes the established response of downstream communities to natural seasonal flow regimes that define their livelihoods.

Very often dam affected downstream populations are given less attention by dam development authorities and governments and this worsens their livelihood conditions even though they may benefit from flood protection and irrigation and other opportunities provided by the dam (Richter et. al, 2010). The nature, severity and duration of the adverse impacts of damming on downstream communities vary from one dammed river to the other.

Alteration of downstream ecological conditions means that the riparian communities have to adjust to post-dam conditions and redefine their livelihood strategies and this continues to be a major challenge. The adaptation responses to dam-induced alterations of downstream ecosystems are also expected to vary depending upon a variety of reason. Apart from specific intervention programmes to improve upon the livelihoods of riparian populations the idea has been mooted that dams can be re-operated to allow for ecological gains and social benefits (Richter et. al, 2010). This could be achieved through controlled environmental releases that would try to mimic the natural condition of rivers and capable of restoring downstream river ecosystems (The Nature Conservancy, 2010). "The challenge is determining the quantity and timing of water flows required to maintain the components, functions, processes and resilience of aquatic ecosystems and sustain the goods and services they provide to people" (The Nature Conservancy, 2010).

3.4 <u>Adaptive management</u>

Environmental and socio-economic outcomes of management policy decisions on complex natural-human systems are often uncertain. To be effective, decision-making processes must be flexible and designed to be adjusted in the face of uncertainties as outcomes from management actions and other events become better understood. Adaptive management encourages an ecosystem–level, rather than disjointed, approach to natural resource management that encourages close collaboration among scientists, managers, and other stakeholders and promotes sectoral integration on key policy decisions (Jacobson 2003).

Adaptive management is a formal process for continually improving management policies and practices by learning from their outcomes, and incorporates natural variability in evaluating the results of management actions. Effective adaptive management is not trial and error, which evidently portrays incomplete understanding of the system. It does not focus solely on tracking and reacting to the fast, immediate variables; this leads to perpetual reactive, crisis management. Light and Blann (2001) explain adaptive management as a planned approach to reliably learn why policies (or critical components of policies) succeed or fail. Restoration fails when managers do not learn from actions and policies and, ultimately, miss restoration goals.

3.4.1 Emergence, Characteristics and Relevance

Adaptive management emerged from a multiple study background, including business (Senge, 1990), experimental science (Popper, 1968), systems theory (Ashworth, 1982), and industrial ecology (Allenby and Richards, 1994). Adaptive management for natural resources was first described by Holling (1978). Fundamentally, the recognition that resource systems typically are only partially understood, and that there is value in tracking resource conditions, and using what is learned as resources are being managed from the evolution of the concept and practice. Learning in adaptive management occurs through the informative practice of management itself, with management strategy adjusted as understanding improves.

One of the earliest discussions in the natural resource literature was by Beverton and Holt (1957), as he related it to the management of fisheries. Subsequent to that, Holling (1978) and Walters and Hilborn (1978) provided the name and conceptual framework for adaptive management of natural resources, and Walters (1986) gave a more complete technical treatment of adaptive decision making. Lee’s (1993) book expanded the context for adaptive management with comprehensive coverage of its social and political dimensions.

A number of formal definitions have been advanced for adaptive management. For example, the US National Research Council (2004) defines it as a decision process with flexible decision making that can be adjusted in the face of uncertainties as outcomes from management actions and other events become better understood. The council stresses careful monitoring of outcomes that advances scientific understanding and helps adjust policies or operations as part of an iterative learning process. One of the most popular definitions that may provide a suitable guide for this project comes from Jacobson (2003). He defines adaptive management as a cyclic, learning-oriented approach to the management of complex environmental systems that are characterized by high levels of uncertainty about system processes and the potential ecological, social and economic impacts of different management options. As a generic approach, adaptive management is characterized by management that monitors the results of policies and/or management actions, and integrates this new learning, adapting policy and management actions as necessary.

Published discourses portray it as a concept with some basic set of indispensable elements and characteristics, especially, in its practice and implementation. In an adaptive management approach, resource management and restoration policies are viewed as scientific experiments (Lee 1993). The presumed uncertainty inherent in its implementation associated with managing complex systems has been emphasized by Williams and Johnson (1995), whereas its scientific orientation has been addressed by Bormann et al. (2007). The complexity of the strategy (Allen and Gould 1986, Ludwig et al. 1993), the need for adjustments (Lessard 1998, Johnson 1999, Rauscher 1999), monitoring (Allen et al. 2001, Bormann et al. 2007), and the necessity for stakeholder involvement (Norton 1995) have been adequately pointed out and explained.

Principally, adaptive management is seen as an evolving process involving learning (the accumulation of understanding over time) and adaptation (the adjustment of management over time). The sequential cycle of learning and adaptation leads naturally to two beneficial consequences: better understanding of the resource system, and better management based on that understanding. The feedback between learning and decision making is a defining feature of adaptive management. Thus, learning contributes to management by helping to inform decision making, and management contributes to learning by using interventions to investigate resources. Management interventions in adaptive management can be viewed as experimental "treatments" that are implemented according to a management design. However, the resulting learning should be seen as a means to an end; namely, effective management, and not an end in itself (Walters 1986). The ultimate focus of adaptive decision making is on management, and learning is valued for its contribution to improved management.

A distinction is often made between "passive" and "active" adaptive management (Salafsky et al. 1991, Bormann et al. 1996, Schreiber et al. 2004). Though there is considerable variability in the use of these terms (Williams 2011*b*), usually based on how uncertainty and learning are treated. Active adaptive management pursues the reduction of uncertainty actively through management interventions that emphasize rapid learning. On the other hand, passive adaptive management focuses less on the reduction of uncertainty and more on the status of the resource, with learning as a useful by-product (Walters 1986). In practice, though, the main difference between passive and active adaptive management is the degree to which management objectives emphasize the reduction of uncertainty (Williams 2011*b*).

There are several approaches to both active and passive adaptive management. For example, a common (but not the only) form of active adaptive management involves experimental management, in which rapid learning involves the simultaneous application of different interventions at different sites in the spirit of designed experiments, with experimental learning outcomes used to guide future decision making. On the other hand, a common (but not the only) form of passive adaptive management involves decision making based on a single parameterized model. Here the focus is on achieving resource objectives, with little emphasis on learning per se. Different parameter values essentially represent different hypotheses about the effects of management, and learning occurs as data from post-decision monitoring are used to update the parameter distributions over repeated cycles.

Whatever the treatment of uncertainty, the heart of adaptive decision making is a recognition of alternative hypotheses about resource dynamics, and assessment of these hypotheses with monitoring data. These same features are shared with scientific investigation. That is, both science and adaptive management involve (*i*) the identification of competing hypotheses to explain observed patterns or processes; (*ii*) the use of models embedding these hypotheses to predict responses to experimental treatments; (*iii*) the monitoring of actual resource responses; and (*iv*) a comparison of actual versus predicted responses to gain better understanding (Williams 1997*a*, Nichols and Williams 2006). This overlap is the main reason that adaptive management is often referred to as a science-based approach to managing natural resources. Of course, a key difference between scientific investigation and adaptive decision making is that the treatments in adaptive management are management interventions chosen to achieve management objectives as well as learning, as opposed to experiments chosen for the pursuit of learning through hypothesis testing.

Finally, it is useful to distinguish between adaptive management and the trial-and-error approach of “try something, and if it doesn’t work try something else,” which involves an ad hoc revision of strategy when it is seen as failing. In contrast to trial and error, adaptive management involves the clear statement of objectives, the identification of management alternatives, predictions of management consequences, recognition of uncertainties, monitoring of resource responses, and learning (National Research Council 2004). Basically, learning by ad hoc trial and error is replaced by learning through careful design and testing (Walters 1997). Adaptive management can be seen as a process of structured decision making (Williams et al. 2007), with special emphasis on iterative decisions that take uncertainty and the potential for learning into account.

We describe adaptive management as the interplay of decision and assessment components, in an iterative process of learning by doing and adapting based on what's learned. Adaptive management involves key activities such as stakeholder engagement, resource monitoring, and modeling, none of which is sufficient by itself to make a decision process adaptive. The integration of these components is what defines an adaptive approach to natural resource management.

3.4.2 Conditions suitable for adaptive management applications

Not all resource management decisions require adaptive approach. Thus, the question of whether a management problem calls for adaptive management must be addressed at the very outset of a project. Largely, some preconditions are necessary requirements. Obviously, if there is insignificant uncertainty involved in decision choices, or no contradictory disagreements about objectives to achieve, there will be no need for its adoption. In many instances, though the approach has been applied almost indiscriminately, leading to no improvements in management performance. High management uncertainty is a fundamental requirement for the adoption of adaptive management. Here, management decision must be made, though its consequences cannot be predicted with certainty.

Second, clear and measurable objectives are required to guide decision making for monitoring. Articulation of clear objectives plays a critical role in performance evaluation, as well as making decisions. Without useful objectives and metrics by which they can be evaluated, it is difficult to determine what actions are best, and whether they are having the desired effect. Again, there must be an opportunity to apply learning to management. It means that there should be a range of acceptable management alternatives from which to make a selection, and a flexible management environment that allows for changes in management as understanding accumulates, over time.

This opportunity for progressive enhancement in decision making is the reason for justifying adaptive management. On the contrary, an adaptive approach is not warranted if the potential for improvements in management is limited to justify the costs of generating the requisite information needs.

Dialogues on adaptive management acknowledge the essence of a sustained commitment by stakeholders, including, but certainly not limited to, decision makers. Stakeholders should be actively involved and participate throughout an adaptive management, from project conception and implementation activities: namely, the identification of objectives and management alternatives, determination of uncertainty, data collection and monitoring. Stakeholders are often diverse groups with different social, cultural, or economic perspectives and stakes. Active stakeholder involvement means an ongoing commitment of time and resources (Lee 1999), among other things. Stakeholder engagement in discussions from the beginning of a project can help to reconcile conflicting perspectives and facilitate collaboration in decision making.

3.4.3 Phased Development Process of ADM

3.4.3.1 Set-up Phase of Adaptive Management Process

Two main phases are involved in ADM process. These are the Set-up and the iterative phases. The elements in the set-up phase generally include stakeholder involvement, objectives setting, development of management alternatives, predictive models, and monitoring protocols. These are a series of sequential structured processes as indicated below.

Stakeholders bring different perspectives, preferences, and values to decision making. It is important to have at least some stakeholder engagement in all the set-up elements of a project, and to continue that engagement throughout the project. A critical challenge is to find common ground that will promote decision making despite disagreements among stakeholders about what actions to take and why. Failure to engage important stakeholders, and disagreement about how to frame a resource problem and identify its objectives and management alternatives, are common stumbling blocks. Successful implementation of adaptive management depends on a clear statement of project objectives. Objectives represent benchmarks against which to compare the potential effects of different management actions, and serve as measures to evaluate the effectiveness of management strategies.

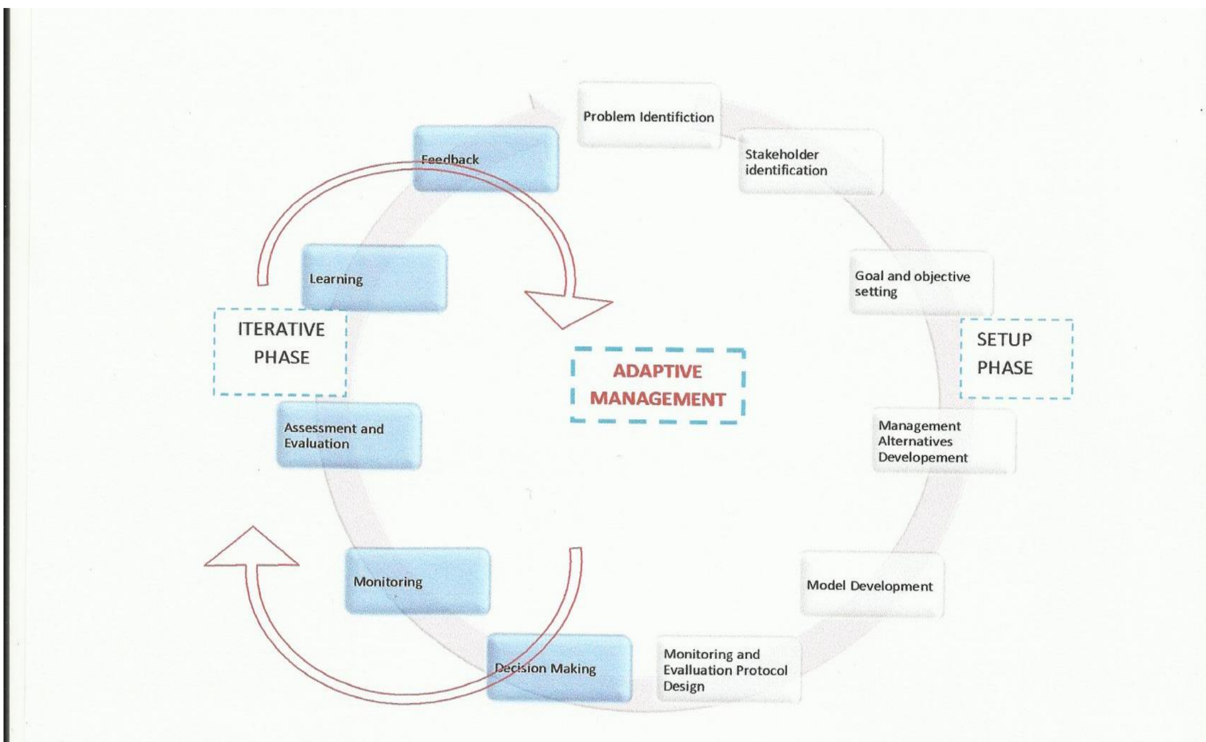
Adaptive decision making requires the clear identification of a set of potential alternatives from which to select an action at each decision point. Some actions might affect the resource directly; others might have indirect effects. Learning and decision making both depend on our ability to recognize differences in the consequences of different actions, which in turn offers the possibility of comparing and contrasting them in order to choose the best action. Models play a critical role in adaptive management, as expressions of our understanding of the resource, as engines of ecological inference, and as indicators of the benefits, costs, and consequences of alternative management strategies. Importantly, they can represent uncertainty (or disagreement) about the resource system. Models are used to characterize resource changes over time, as the resource responds to fluctuating environmental conditions and management actions.

Monitoring provides the information needed for both learning and evaluation of management effectiveness. The value of monitoring in adaptive management is inherited from its contribution to decision making. To make monitoring useful, choices of what ecological attributes to monitor and how to monitor them (frequency, extent, intensity, etc.), must be linked closely to the management situation that motivates the monitoring in the first place, as well as practical limits on staff and funding.

3.4.3.2 Components of the iterative phase of adaptive management

The iterative phase of adaptive management is folded into a recursive process of decision making, follow-up monitoring, assessment, learning and feedback. The actual process of adaptive decision making entails decisions at each point in time that reflect the current level of understanding and anticipate the future consequences of decisions. Decision making at each decision point considers management objectives, resource status, and knowledge about consequences of potential actions. Decisions are then implemented by means of management actions on the ground. Monitoring provides information to estimate resource status, underpin decision making, and facilitate evaluation and learning after decisions are made. Monitoring is an ongoing activity, conducted according to the protocols developed in the set-up phase.

The data produced by monitoring are used along with other information to evaluate management effectiveness, understand resource status, and reduce uncertainty about management effects. Learning is promoted by comparing predictions generated by the models with data-based estimates of actual responses. Monitoring data can also be compared with desired outcomes, in order to evaluate the effectiveness of management and measure its success in attaining management objectives. The understanding gained from monitoring and assessment helps in selecting future management actions. The iterative cycle of decision making, monitoring, and assessment, repeated over the course of a project, leads gradually to a better understanding of resource dynamics and an adjusted management strategy based on what is learned. Periodically it is useful to interrupt the technical cycle of decision making, monitoring, assessment, and feedback in order to reconsider project objectives, management alternatives, and other elements of the set-up phase. This reconsideration constitutes an institutional learning cycle that complements, but differs from, the cycle of technical learning. In combination, the two cycles are referred to as "double-loop" learning.



Set-up and Iterative phases of Adaptive Management

Literature on adaptive management identifies many impediments to its success (Walters 1997, Gregory et al. 2006). Cost involved in complex decision-making structures, technical expertise and support for people who implement adaptive management can be considerable.

Institutional resistance to acknowledging uncertainty by managers who consider it as an admission of incompetence is crucial. Some believe that they are already using adaptive management, even when they are not. This occurs most often with projects that involve some ongoing monitoring, in the mistaken belief that monitoring by itself is enough to make a project "adaptive." There is extreme risk aversion by many managers, which leads to strategies that are risk-aversive in the near term, with little or no opportunity for learning. Management often is short-sighted, emphasizing near-term gains and losses and devaluing long-term management benefits and costs. If the future is heavily discounted, there is little incentive to use adaptive management to learn how to manage better in the future. Stakeholders are not engaged in a meaningful way. Without involvement, stakeholders can become disillusioned with management practices, withhold support for a project. Yet many managers are reluctant to include stakeholders in decision making. There is a lack of institutional commitment to follow through with the necessary monitoring and assessment after an initial start-up of adaptive decision making. Monitoring activities include sampling design, data collection and summarization, database management, and data assessment. Many managers are unable or unwilling to continue these activities for extended periods of time.

4. CONCLUSIONS AND RECOMMENDATIONS

Rivers have great influence on the landform, physiography, livelihood as well as floras and faunas. Given the present degraded condition, environmental flow requirement would be most useful for many rivers (Bari and Marchand, 2006). Environmental flows are essential for freshwater ecosystem health and human well-being. The overarching reason why there is the need for flow requirements for the lower Volta River is due to the fact that the creation of the dams have impacted negatively on ecosystem function, services and livelihoods downstream of the dam. Defining flow requirements for key species and processes is an important step towards restoration of downstream ecosystem function and livelihoods. Key issues such as important flow variables such as magnitude, frequency, duration, timing and rate of change of flow influences the flow requirements and must be considered in setting restoration flow targets. In the face of data paucity, the need for adaptive management through incremental adjustment and learning has become ever more justifiable.

The review of the literature has established that there is a relationship between environmental flows and sustainable livelihood. Environmental flows tend to establish important ecological processes and functions that restore livelihood flows downstream. Thus to the extent that adequate flows are established many of the livelihood activities would be restored. Environmental flows can serve as an important link between environmental conservation and poverty alleviation for communities riparian to the Volta River.

Additionally the literature review has shown that, there is a need for an environmental flow requirement for the Volta River because Environmental flows have the potential to increase connectivity between pools, improve water quality within pools (reducing salinity and improving dissolved oxygen), cover low lying bars and woody debris, which provides instream habitat, and provide for the growth of aquatic plants and increase macroinvertebrate diversity thereby contributing to a more balanced aquatic ecosystem health.

The challenge for the Lower Volta River is defining the flow requirement for restoring ecosystem function and processes downstream. From the literature review and from field work, the current flow regime has not been adequate to get rid of the aquatic weeds infestation. The choices available include ongoing work that would help the setting of restoration flow targets to have an empirical basis. On the other hand, where further work would be less feasible, and where there are high uncertainty regarding data and model predictability, the use of passive adaptive management framework as an alternative should be considered.

Finally field observations and interviews by other project partners (consultation with downstream communities) have shown that, 50 years after dam construction, there have been changes and developments along the river and lake front. Reoptimization should therefore be done in such a way that in establishing the desired flow regime, important tradeoffs such as whether the developments along the river and lake front would be affected should be well considered and communicated to the communities downstream of the dam.

5. REFERENCES

Acreman, M. & Dunbar, M. J. (2004): "Defining environmental river flow requirements - a review". *Hydrology & Earth System Sciences* 8[5], 861-876.

Arthington, A. (2013): Environmental Flows; Saving Rivers in the Third Millennium, the Regents of the University of California

Arthington, A. and Pusey, B. (2003): Flow restoration and protection in Australian rivers. River Research and Applications 19: 377-395.

Arthington, A. H. and Zalucki J.M. (Eds) (1998): Comparative Evaluation of Environmental Flow Assessment Techniques: Review of Methods', LWRRDC Occasional Paper 27/98. Land and Water Resources Research and Development Corporation

Allen, W.J., O.J.H. Bosch, M.J. Kilvington, D. Harley, and I. Brown. 2001. Monitoring and adaptive management: Addressing social and organisational issues to improve information sharing. *Natural Resources Forum* 25:225-233.

Allenby, B.R., and D.J. Richards. 1994. *The Greening of Industrial Ecosystems.* Washington, DC: National Academy Press.

Ashworth, M.J. 1982. *Feedback Design of Systems with Significant Uncertainty*. Chichester, UK: Research Studies Press.

Bandaragoda, D.J. (2000): A framework for Institutional Analysis for Water Resources Management in a river basin context. *IWMI Working paper 5*.

Bari, M. F. and Marchand M. (2006): Management of Rivers for Instream Requirement and Ecological Protection; a Multidisciplinary Collaborative Research WL|Delft Hydraulics BUET, Dhaka-1000, Bangladesh

Brown, C. and King, J. (2003): Environmental Flows: Concepts and methods. In Davis, R. and Hirji, R. (Eds); Water Resources and Environment Technical Note C.1., Washington, D.C.: The World Bank.

Bunn, S. E. Arthington A. H. (2002): Principles and ecological consequences of altered hydrological regimes for aquatic biodiversity. Environmental Management 30: 492–507

,Beverton, R.J.H., and S.J. Holt. 1957. *On the Dynamics of Exploited Fish* Beverton *Populations.* London: Her Majesty's Stationery Office.

Bormann, B.T., P.G. Cunningham, and J.C. Gordon. 1996. Best management practices, adaptive management, or both? In *Proceedings of the 1995 National Society of American Foresters Convention.* Conference held at Portland, ME.

Chambers, R. and Conway, G. (1992). Appraoch to sustainable livelihood for the rural poor: Practical concept for the 21st Century. IDS Discussion Paper 296, IDS, Brighton, UK.

Department for International Development (1999). Sustainable Development Guidance Sheet: Introduction. hpttp://www.livelihoods.org/info/info_guidancesheets.htm1tm1

DFID (Department for International Development) (1999). Sustainable livelihoods guidance sheets. Issues. (Department for International Development. London.

De Groot, R.S. (1994): Evaluation of environmental functions as a tool in planning, management and decision making. PhD Wageningen University

Dyson, M., Bergkamp, G. and Scanlon, J., (Eds) (2008): Flow – The essentials of environmental flows, 2nd Edition. Gland, Switzerland: IUCN. Reprint, Gland, Switzerland: IUCN

Dyson, M., Bergkamp, G. and Scanlon, J. (Eds) (2003): The Essential of Environmental Flows. IUCN, Gland, Switzerland and Cambridge, UK

FAO, (Food and Agricultural Organization) (2006). Better forestry, less poverty: A practitioner's guide. FAO's Forestry Paper 149. FAO, Rome.

Forslund, A., et al. (2009): Securing Water for Ecosystems and Human Well-being: The Importance of Environmental Flows; Swedish Water House Report 24. SIWI

Holling, C.S. 1978. Adaptive Environmental Assessment and Management. John Wiley and Sons. London, United Kingdom.

Hobley, M. and Shields, D. (2000) 'The reality of trying to transform structures and processes: forestry in rural livelihoods'. *Working Paper 132*, Overseas Development Institute, London.

Hirji, R. and Davis R. (2009): Environmental Flows in Water Resources Policies, Plans, and Projects: Case Studies. Environment Department-Washington, DC: World Bank.

Hirji, R. and Panella T. (2003): "Evolving Policy Reforms and Experiences for Addressing Downstream Impacts in World Bank Water Resources Projects." River Research and Applications 19 (5-6): 667–81

IUCN (International Union for the Conservation of Nature) (2000): Vision for Water and Nature. A World Strategy for Conservation and Sustainable Management of Water Resources in the 21st Century. Gland, Switzerland: IUCN

Jager, H.I. and Smith B.T. (2008): Sustainable reservoir operation: Can we generate hydropower and preserve ecosystem values? River Research and Applications 24: 340-352.

Jacobson, C. 2003. Introduction to Adaptive Management. PhD dissertation. (Online) URL:

http://student.lincoln.ac.nz/am-links/am-intro.html

Johnson, B.L. 1999. Introduction to adaptive management: Scientifically sound, socially challenged? *Conservation Ecology* 3:8. http://www.consecol.org/Journal/vol3/iss1/art10

Kerger, F., Dewals B., Erpicum, S. Archambeau, P. and Pirotton M. (2010): Modelling Flows in Environmental and Civil Engineering, New-York: Nova Science Publishers

Kerger, F., (2010): Modelling Transient Air-water Flows in Civil and Environmental Engineering, PhD Thesis, University of Liège, Faculty of Applied Science, Liège, Belgium, pp 315

King, J. M., R.E. Tharme & M.S. de Villiers (Eds.) (2000): Environmental Flow Assessments for Rivers: Manual for the Building Block Methodology; WRC Report No. TT 131/00, University of Cape Town

King, J., Tharme, R., and Brown, C. (1999): Definition and Implementation of Instream Flows; World Commission on Dams WCD Thematic Report Environmental Issues II.1 Cape Town

Korsgaard, L. (2006): Environmental Flows in Integrated Water Resources Management: Linking Flows, Services and Values; Ph.D. Thesis, Institute of Environment & Resources Technical University of Denmark; Available Online [www.er.dtu.dk]

Krantz, L. (2001). The Sustainable Livelihood Approach to Poverty Reduction: An Introduction. Swedish International Development Cooperation Agency (SIDA)

Lee, K.N. 1993. *Compass and Gyroscope: Integrating Science and Politics for the Environment.* Washington, DC: Island Press.

Lee, K.N. 1999. Appraising adaptive management. *Conservation Ecology* 3:3. http://www.consecol.org/Journal/vol3/ iss2/art3/

Lessard, G. 1998. An adaptive approach to planning and decision-making. *Landscape and Urban Planning* 40:81-87.

Light, S.S. and K. Blann. 2001. Adaptive Management and the Kissimmee River Restoration Project (unpublished manuscript). Implications of Kissimee River Restoration. Unpublished manuscript prepared for the Committee on Restoration of the Greater Everglades Ecosystem.

Marchand, M. (2003): Environmental Flow Requirement; An integrated Approach for River and Coastal Zone Management, WL/Delft Hydraulics (Z2850) 06.02.04-03

Mathews, R., and Richter, B. (2007): Application of the Indicators of Hydrologic Alteration software in environmental flow-setting. Journal of the American Water Resources Association (JAWRA) 43(6): 1400-1413

McMahon, T. A. and Finlayson B. L. (1995): Reservoir system management and environmental flows. *Lakes and Reservoirs: Research and Management* 1: 65–76

Moore, M. (2004): Perceptions and interpretations of environmental flows and implications for future water resource management: A survey study. Master’s Thesis, Department of Water and Environmental Studies, Linköping University, Sweden

Moses, D. (1994). Authority, Gender and Knowledge: Theoretical Reflections on the Practice of Participatory Rural Appraisal. Development and Change, Vol.25.

Nhantumbo, I., Norfolk, S., and Pereira, J. (2003). Sustainable livelihoods in Southern Africa. Institutions, Governance and Policy Processes. Sustainable Livelihoods in Southern Africa Programme. Research Paper 10.

National Research Council. 2004. *Adaptive Management for Water Resources Planning.* Washington, DC: National Academies Press.

Nichols, J.D., and B.K. Williams. 2006. Monitoring for conservation. *Trends in Ecology and Evolution* 21:668-673.

Norton, B.G. 2005. *Sustainability: A Philosophy of Adaptive Ecosystem Management.* Chicago: University of Chicago Press.

Naiman, R. J., Bunn S. E., Nilsson C., Petts G. E., Pinay G., and Thompson L. C. (2002): Legitimizing fluvial ecosystems as uers of water: an overview, Environmental Management 30(4):455-467

Nature Conservancy (2006): Environmental Flows: Water for People, Water for Nature. TNC MRCSO1730; Boulder, CO: Nature Conservancy.

Olden J.D. & Poff N.L. (2003): Redundancy and the choice of hydrological indices for characterizing stream flow regimes. *River Research and Applications*, 19: 101-121

Peart, M.R. (1995): Monitoring of bed load sediment production and movement in a small stream in Hong Kong. In: '*Management of sediment, philosophy, aims and techniques*', Sixth International Symposium on River Sedimentation, New Delhi, India, pp. 343-350.

Postel, S. and Richter, B. (2003): Rivers for Life. Managing water for people and nature; Island Press, Washington D.C

Popper, K.R. 1968. *The Logic of Scientific Discovery*, 2nd ed. New York: Harper and Row.

Rauscher, H.M. 1999. Ecosystem management decision support for federal forests in the United States: A review. *Forest Ecology and Management* 114:173-197.

Poff, N.L., Ward J.V. (1989): Implications of stream flow variability and predictability for lotic community structure: a regional analysis of stream flow patterns. Canadian Journal of Fisheries and Aquatic Sciences 46: 1805–1818.

Poff, N.L., Allan J.D., Bain M.B., Karr J.R., Prestegaard K.L., Richter B.D., Sparks R.E. & Stromberg J.C. (1997): The natural flow regime; Bioscience 47: 769–784

Richter, Brian D., Jeffrey V. Baumgartner, Jennifer Powell, and David P. Braun (1996): "A Method for Assessing Hydrological Alteration within Ecosystems." *Conservation Biology* 10 (4): 1163–74.

Richter, B. D., Postel, S., Ravenga, C, Scudder, T., Lehner B., Churchill, A. and Chow, M. (2010). Lost in Development Shadow: The Downstream Human Consequences of Dams. Water Alternatives 3 (2): 14-42

Salafsky, N., R. Margoluis, and K. Redford. 2001. *Adaptive Management: A Tool for Conservation Practitioners.* Washington, DC: Biodiversity Support Program. http://www.worldwildlife.org/bsp/

Schreiber, E.S.G., A.R. Bearlin, S.J. Nicol, and C.R. Todd. 2004. Adaptive management: A synthesis of current understanding and effective application. *Ecological Management and Restoration* 5:177-182.

Senge, P.M. 1990. *The Fifth Discipline: The Art and Practice of the Learning Organization.* New York: Currency Doubleday.

Slootweg, R., Vanclay, F., & Schooten, M. (2001): Function evaluation as a framework for the integration of social and environmental impact assessment. Impact Assessment and Project Appraisal 19, pp. 19-28.

Scudder, T. (2002): People dependence on environmental flows. In: Conference Proceedings 4th Eco hydraulics Conference 'Enviro Flows 2002, March 3-8, 2002, Cape Town, South Africa.

Schouten, C.J.J, M.C. Rang, B.A. de Hamer & H.R.A. van Hout (2000): 'Strongly polluted deposits in the Meuse river floodplain and their effects on river management', in: New Approaches to River Management, A.J.M. Smits, P.H. Nienhuis & R.S.E.W. Leuven (Editors), Backhuys Publishers, Leiden (NL), ISBN 90-5782-058-7.

Stewardson, M.J. and Gippel C.J. (1997): In-stream environmental flow design: A review. Unpublished draft report by the Cooperative Research Centre for Catchment Hydrology. (Department of Civil and Environmental Engineering, University of Melbourne: Victoria.)

The Nature Conservancy (2010). Sustainable River Projects. www.**nature**.**org**/our**initiatives**/

Stalnaker, C., Lamb B. Henriksen J., Bovee K. and Bartholow J. (1995): The Instream Flow Incremental Methodology: A Primer for IFIM-Biological Report, US Department of the Interior, National Biological Service; Washington, D.C.

Tharme, R. E (2003): A global perspective on environmental flow assessment: Emerging trends in the development and application of Environmental flow methodologies for rivers. River Research and Applications, Vol. 19, pp. 397–441.

The Brisbane Declaration (2007): Environmental Flows are Essential for Freshwater Ecosystem Health and Human Well-Being. Declaration of the 10th International River Symposium and International Environmental Flows Conference, Brisbane, Australia, 3–6 September, 2007.

Victorian Government (2004): *Water Act 1989* S43 & 47 — Bulk Entitlement (Wimmera and Glenelg Rivers- Flora and Fauna) Conversion Order 2004; Government Gazette No. G 24

Victorian Water Quality Monitoring Network (VWQMN), Victorian government, viewed from October 2007 – February 2008.

WCMA (2005): Environmental flows. Report on 2004/2005 releases in the Wimmera and Mackenzie Rivers. WCMA, Horsham.

WCMA (2007): A snapshot of the health of the lower Wimmera River. WCMA, Horsham.

Wilson, A.L., Dehaan, R. L., Watts, R.J., Page, K.J., Bowmer, K.H., & Curtis, A. (2007): Proceedings of the 5th Australian Stream Management Conference. Australian rivers: making a difference. Charles Sturt University, Thurgoona, New South Wales

World Commission on Dams (2000): Dams and Development-A New Framework for Decision-Making. The Report of the World Commission on Dams; Earthscan Publications Ltd., London and Sterling, VA

WCD (2000). Dams and Development: A new framework for decision-Making. The Report of the World Commission on Dams. Earthscan Publications Ltd. London

Walters, C., and R. Green. 1997. Valuation of experimental management options for ecological systems. *Journal of Wildlife Management* 61:987-1006.

Walters, C.J. 1986, *Adaptive Management and Renewable Resources*, Macmillan, New York, NY.

Walters, C.J. and Holling, C.S. 1990. Large-scale management experiments and learning by doing", *Ecology*, Vol. 71, pp. 2060-8.

Walters, C.J., and R. Hilborn. 1978. Ecological optimization and adaptive management. *Annual Review of Ecology and Systematics* 9:157-188.

Williams, B.K. 1997*a*. Logic and science in wildlife biology. *Journal of Wildlife Management* 61:1007-1015.

Williams, B.K. 2011*a*. Adaptive management of natural resources: Framework and issues. *Journal of Environmental Management* 92:1346-1353.

Williams, B.K. 2011*b*. Passive and active adaptive management: Approaches and an example. *Journal of Environmental Management* 92:1371-1378.

Williams, B.K., R.C. Szaro, and C.D. Shapiro. 2007. Adaptive management: The U.S. Department of the Interior technical guide. Washington, DC: U.S. Department of the Interior.

Young, M. D. (1992): Sustainable Investment and Resource Use: Equity, Environmental Integrity and Economic Efficiency. Man and Biosphere Series, Vol. 9, UNESCO and Parthenon Publishing Group, Paris.

[online] URL:www.adaptivemanagement.net/abstracts.htm