STRENGTHENING ETHIOPIAN UNIVERSITIES IN INTEGRATED RIVER BASIN MANAGEMENT PROJECT (NUFFIC NPT/ETH/205)

Integrated River Basin Management

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FOREWORD

This lecture note has been prepared as part of the Ethiopia NPT project, entitled “Strengthening Ethiopian Universities in Integrated River Basin Management Project”. The lecture note has been prepared by Ethiopian authors from six universities under the guidance and supervision of Dr. Yasir Mohamed of UNESCO-IHE.

The objective of the lecture note is to provide a comprehensive theoretical material and practical skills for the integrated management of river basins, with emphasis on the Ethiopian case. The course has been designed to maximize benefits from all other courses prepared under the Ethiopia-NPT project.

The lecture note is divided into six chapters covering all aspects of IRBM. Chapter 1 is an introduction presenting basic principles and theories. Chapter 2 gives quick information about river systems and interaction with mankind. Chapter 3 presents background information about water resources planning and related economical aspects. Chapter 4 show the tools and methods used in IRBM. The water governance issues related to IRBM are given in Chapter 5. The last Chapter gives a brief description of 4 major river basins in Ethiopia: Blue Nile/Abay, Awash, Omo-Ghibe, and Rift valley basin.
Table of Contents

TABLE OF CONTENTS .................................................................................................................................. VII

LIST OF TABLES .......................................................................................................................................... XI

LIST OF FIGURES ...................................................................................................................................... XIII

1. INTRODUCTION ........................................................................................................................................ 1

1.1 Definition of Terminologies and Basic Concepts .................................................................................. 1

1.2 Theories and Principles of IRBM ........................................................................................................... 6

1.2.1 The Need for River Basin Management ........................................................................................... 6

1.2.2 The Need for Integration ................................................................................................................... 7

1.2.3 Objectives and Benefits of IRBM ................................................................................................... 9

1.2.4 Key Activities and challenges in IRBM ........................................................................................ 10

1.2.5 Principles of IRBM .......................................................................................................................... 11

1.3 Processes/Phases of IRBM .................................................................................................................. 14

1.3.1 The Planning Phase (steps 1-6) ...................................................................................................... 15

1.3.2 The Implementation Phase ............................................................................................................. 19

1.3.3 The Monitoring and Evaluation Phase (Steps 8 and 9) .................................................................. 20

1.3.4 Cross cutting issues and points to tote in the processes of IRBM .................................................. 20

1.3.5 Key Elements for Effective IRBM ............................................................................................... 21

1.4 Questions/Tutorial .................................................................................................................................. 24

2. RIVER SYSTEMS .................................................................................................................................... 26

2.1 Chapter Overview ............................................................................................................................... 26

2.2 Hydrology and Water Resources ....................................................................................................... 27

2.2.1 Introduction ................................................................................................................................... 27

2.2.2 Hydrological cycle .......................................................................................................................... 28

2.3 River functions .................................................................................................................................... 36

2.3.1 River basins and catchments ......................................................................................................... 36

2.3.2 Stream corridors ............................................................................................................................ 36

2.3.3 Stream Channel ............................................................................................................................... 37

2.3.4 Structural Changes in the Stream Corridor .................................................................................. 39

2.3.5 Stream Order Models .................................................................................................................... 40

2.3.6 Longitudinal Changes in Stream Ecosystems ............................................................................. 41

2.3.7 Key Stream Processes and Other Important System Characteristics ......................................... 43

2.3.8 Functions of the river system ....................................................................................................... 49

2.4 Human interventions and impacts .................................................................................................... 52
### Table of Contents

2.4.1 Man's attitude towards nature and development ................................................................. 52  
2.4.2 Engineered River Systems ..................................................................................................... 56  
2.4.3 Impacts of land-use practices .............................................................................................. 58  
2.4.4 Discharge and transport of materials .................................................................................... 60  
2.4.5 Impacts on water quality ....................................................................................................... 61  

2.5 River Basins in Ethiopia ............................................................................................................ 62  
2.5.1 Introduction ......................................................................................................................... 62  
2.5.2 Surface Water Resources .................................................................................................. 62  
2.5.3 Groundwater Resources System ....................................................................................... 66  

2.6. Exercises/Tutorials and Project ............................................................................................... 68  
2.6.1 Exercises/Tutorials ............................................................................................................. 68  
2.6.2 Project ............................................................................................................................... 69  

3. RIVER BASIN PLANNING AND MANAGEMENT .................................................................... 72  
3.1 Water Resources Planning in River Basins ............................................................................ 72  
3.1.1 The Need for Planning ...................................................................................................... 72  
3.1.2 Planning and Management Aspects .................................................................................. 74  
3.1.3 Types and Approaches of Planning and Management ....................................................... 75  
3.1.4 Planning Process ............................................................................................................... 76  

3.2 Operational Management ....................................................................................................... 85  
3.2.1 What is operational management? .................................................................................... 85  
3.2.2 Instruments of operational management .......................................................................... 85  
3.2.3 Operational Infrastructure ............................................................................................... 86  
3.2.4 Water Quality Management ............................................................................................. 86  
3.2.5 Water charges and cost recovery ...................................................................................... 87  
3.2.6 Water right ......................................................................................................................... 88  
3.2.7 Water allocation ............................................................................................................... 89  

3.3 Economics and Finance ......................................................................................................... 91  
3.3.1 General .............................................................................................................................. 91  
3.3.2 The time value of money and discount rates .................................................................... 91  
3.3.3 Project economics and evaluation .................................................................................... 93  
3.3.4 Economic analysis and multiple alternatives ..................................................................... 95  
3.3.5 Cost and value of water ...................................................................................................... 98  
3.3.6 Finance ............................................................................................................................. 100  

3.4 Examples, Case studies and Tutorials .................................................................................... 103  
3.4.1 Examples- Time value of money and project analysis ..................................................... 103  
3.4.2 Case study ....................................................................................................................... 106  
3.4.3 Tutorials and assignments ............................................................................................... 109  

4. TOOLS AND METHODS FOR IRBM ..................................................................................... 112  
4.1 Monitoring and Water Resource Information System ............................................................. 112
4.1.1 Monitoring, Acquisition and processing of Water Resource Data ....................................... 112
4.1.2 Water Resource Information System ................................................................................... 115

4.2 Statistical Methods .................................................................................................................. 120
4.2.1 Statistical Data Summary and Description ........................................................................... 120
4.2.2 Regression Analysis .............................................................................................................. 122
4.2.3 Frequency Analysis .............................................................................................................. 125
4.2.4 Time Series Analysis ............................................................................................................. 129

4.3 Decision Support Systems ....................................................................................................... 135
4.3.1 Optimization ........................................................................................................................ 135
4.3.2 Simulation ............................................................................................................................ 143
4.3.3 Multi-criteria and Evaluation Techniques ............................................................................ 145
4.3.4 EIA ........................................................................................................................................ 148
4.3.5 Decision support tools ......................................................................................................... 148
4.3.6 Example Models in Decision Support System (DSS) ............................................................ 151

4.4 Tutorials/Examples/Case studies .............................................................................................. 155

5. GOVERNANCE ISSUES (POLICY/INSTITUTIONS) ................................................................. 156

5.1 Introductory Background ........................................................................................................ 156
5.1.1 Water governance ............................................................................................................... 156
5.1.2 Why is river basin (Water) governance important? ............................................................ 158
5.1.3 Fundamental requirements for good river basin governance ............................................. 161
5.1.4 Rules, regulations/ Policies and laws ................................................................................... 162

5.2 Institutional Setups and ROBs ................................................................................................. 165
5.2.1 Introduction ......................................................................................................................... 165
5.2.2 Functions of institutions in river basin environment ........................................................... 165
5.2.3 Institutional structures in IRBM ........................................................................................ 166
5.2.4 River Basin Organizations (RBOs) ..................................................................................... 176

5.3 Trans-boundary Issues ............................................................................................................ 178
5.3.1 Introduction ........................................................................................................................ 178
5.3.2 The challenges in trans-boundary river basin management ............................................. 179
5.3.3 The water courses convention and alternatives ................................................................. 182

5.4 Conflict Resolution ............................................................................................................... 184
5.4.1 Why conflict over resources? .............................................................................................. 184
5.4.2 Conflict resolution .............................................................................................................. 187

5.5 Tutorials/Examples/Case studies .............................................................................................. 194

6. ETHIOPIAN STUDY CASES OF IRBM .................................................................................. 203

6.1 Abay Basin ............................................................................................................................. 203
6.1.1 General basin characteristics ............................................................................................... 203
6.1.2 Current Developments and their impacts in the basin ....................................................... 206
6.1.3 Conclusions .......................................................................................................................... 209

6.2. Awash Basin ........................................................................................................................... 210
  6.2.1 General Basin characteristics .............................................................................................. 210
  6.2.2 Current developments and their impacts in the basin ......................................................... 213
  6.2.3 Conclusions .......................................................................................................................... 216

6.3 Omo-Ghibe Basin ..................................................................................................................... 218
  6.3.1 General basin characteristics .............................................................................................. 218
  6.3.2 Current developments and their impact in the basin ............................................................. 221
  6.3.3 Conclusions .......................................................................................................................... 222

6.4 Rift Valley Basin ....................................................................................................................... 223
  6.4.1 General basin characteristics .............................................................................................. 223
  6.4.2 Current developments and their impacts in the basin ......................................................... 225
  6.4.3 Conclusions .......................................................................................................................... 227
List of Tables

<table>
<thead>
<tr>
<th>Table</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-1</td>
<td>Classification of Drainage Unit based on Size of the Area</td>
<td>2</td>
</tr>
<tr>
<td>1-2</td>
<td>Differences between Developing and Developed Countries Basin Realities</td>
<td>12</td>
</tr>
<tr>
<td>1-3</td>
<td>Recent Studies into Trends in River Flows (McCarthy, 2001)</td>
<td>35</td>
</tr>
<tr>
<td>2-1</td>
<td>Commonly Observed Changes Associated with River Consortium Concept</td>
<td>42</td>
</tr>
<tr>
<td>2-2</td>
<td>Ecosystem Services Provided by Rivers</td>
<td>50</td>
</tr>
<tr>
<td>2-3</td>
<td>Ecological Functions of Different River Flow Levels (Postel &amp; Richter, 2003)</td>
<td>50</td>
</tr>
<tr>
<td>2-4</td>
<td>The Influence of Man on Water Quality and Quantity</td>
<td>53</td>
</tr>
<tr>
<td>2-5</td>
<td>Function, Criteria and Possible Operation Measures (Douben et al., 2003)</td>
<td>57</td>
</tr>
<tr>
<td>2-6</td>
<td>River Basins, Annual Runoff and Specific Discharge</td>
<td>63</td>
</tr>
<tr>
<td>2-7</td>
<td>Recent Studies into Trends in River Flows (Mccarthy, 2001)</td>
<td>35</td>
</tr>
<tr>
<td>2-8</td>
<td>Commonly Observed Changes Associated with River Consortium Concept</td>
<td>42</td>
</tr>
<tr>
<td>2-9</td>
<td>Ecosystem Services Provided by Rivers</td>
<td>50</td>
</tr>
<tr>
<td>3-1</td>
<td>Types of Plan and Policies Relevant to RBM (cf. Online Course Material – UNESCO-IHE, 2011)</td>
<td>75</td>
</tr>
<tr>
<td>3-2</td>
<td>Suggested Roles and Responsibilities (GWP, 2005)</td>
<td>78</td>
</tr>
<tr>
<td>3-3</td>
<td>Instruments of Operational Management</td>
<td>85</td>
</tr>
<tr>
<td>3-4</td>
<td>Regulatory Approach to Pollution Control</td>
<td>86</td>
</tr>
<tr>
<td>3-5</td>
<td>Summary of Discounting Factors</td>
<td>92</td>
</tr>
<tr>
<td>3-6</td>
<td>Some Common Targets and Decision of Cost-Benefit Analysis</td>
<td>95</td>
</tr>
<tr>
<td>3-7</td>
<td>Description of Components of Full Cost Given in Figure 3-5</td>
<td>98</td>
</tr>
<tr>
<td>3-8</td>
<td>Description of the Components of Full Value Given in Figure 3-6</td>
<td>100</td>
</tr>
<tr>
<td>4-1</td>
<td>Recommended Minimum Densities of Stations (Area in km²) [WMO, 2008]</td>
<td>115</td>
</tr>
<tr>
<td>4-2</td>
<td>Some Commonly Used Plotting-Position Formulas</td>
<td>127</td>
</tr>
<tr>
<td>4-3</td>
<td>Extreme Points and Values of Objective Functions</td>
<td>141</td>
</tr>
<tr>
<td>4-4</td>
<td>Extended Pay-Off Table with Weights and Scales</td>
<td>147</td>
</tr>
<tr>
<td>5-1</td>
<td>International Conferences Relevant to Freshwater</td>
<td>180</td>
</tr>
<tr>
<td>5-2</td>
<td>Features of La Plata River Basin</td>
<td>195</td>
</tr>
<tr>
<td>6-1</td>
<td>Population by Region as Projected in the 1994 Population Census for Abay Basin</td>
<td>203</td>
</tr>
<tr>
<td>6-2</td>
<td>Irrigation Potential in the River Basins of Ethiopia</td>
<td>206</td>
</tr>
<tr>
<td>6-3</td>
<td>Population by Region as Projected in the 1994 Population Census for Awash Basin</td>
<td>210</td>
</tr>
<tr>
<td>6-4</td>
<td>Population by Region as Projected in the 1994 Population Census for Omo-Ghibe Basin</td>
<td>218</td>
</tr>
<tr>
<td>6-5</td>
<td>Population by Region as Projected in the 1994 Population Census for Rift Valley Basin</td>
<td>223</td>
</tr>
<tr>
<td>6-6</td>
<td>Basic Hydrological Data of Lakes and Reservoirs in the Rift Valley Lake Basin</td>
<td>225</td>
</tr>
</tbody>
</table>
List of Figures

FIG. 1-1 (A) BLUE NILE RIVER BASIN AND (B) AWASH RIVER BASIN ...................................................... 1
FIG. 1-2: THE CONCEPT OF INTEGRATED APPROACH IN RIVER BASIN MANAGEMENT .......................... 7
FIG. 1-3: LEARNING-BY-DOING MANAGEMENT CYCLE (SOURCE: GWP, 2009) .................................... 14
FIG. 2-1: COMMON CHARACTERISTICS OF A RIVER SYSTEM ............................................................ 28
FIG. 2-2: EXAMPLE OF A STANDARD DEFINITION OF HYDROLOGICAL CYCLE ................................. 29
FIG. 2-3: THE HYDROLOGICAL CYCLE, WITH ‘WHITE’, ‘GREEN’ AND ‘BLUE’ WATER ............................ 30
FIG. 2-4: THE MAJOR CROSS-SECTONAL COMPONENTS OF THE STREAM CORRIDOR ......................... 37
FIG. 2-5: 5 CHANNEL EQUILIBRIUM (HTTP://WWW.PUBS.ASCE.ORG.) ................................................ 38
FIG. 2-6: TYPICAL CHANGES IN THE STREAM CHANNEL CHARACTERISTICS ALONG ITS LENGTH .......... 40
FIG. 2-7: STREAM ORDERING IN A DRAINAGE NETWORK .................................................................... 41
FIG. 2-8: HE RIVER CONTINUUM CONCEPT .......................................................................................... 42
FIG. 2-9: SEDIMENT TRANSPORT. (MARY AND SUSANNA, 1999) .......................................................... 44
FIG. 2-10: TYPES OF CHANNEL PLAN FORMS (DANIEL P. LOUCKS AND EELCO VAN BEEK, 2005) ...... 45
FIG. 2-11: RELATION BETWEEN FLOW RATE AND SEDIMENT EROSION AND TRANSPORT .......... 46
FIG. 2-12: INTERACTIONS AMONG AQUATIC ORGANISMS AND THEIR SOURCES OF ENERGY .......... 48
FIG. 2-13: DECISION DIAGRAM FOR CORRECTIVE AND PREVENTIVE MAINTENANCE ...................... 58
FIG. 2-14: THE EFFECTS OF DEFORESTATION ON THE CONCENTRATION OF SOME IONS IN STREAMS; ARROWS INDICATE TIME OF DEFORESTATION ................................................................. 59
FIG. 2-15: CHANGES IN SEDIMENT YIELD RELATED TO CHANGES IN LAND USE IN MARYLAND PIEDMONT .................................................................................................................................... 59
FIG. 2-16: ANNUAL CHANGES IN WATER DISCHARGE FROM THE RIVER NILE AND ANNUAL SARDINE AND SHRIMP CATCHES IN THE SE MEDITERRANEAN SEA ............................................. 61
FIG. 2-17: THE SEQUENCE OF WATER QUALITY ISSUES ARISING IN INDUSTRIALISED COUNTRIES ......... 61
FIG. 2-18: ETHIOPIAN RIVER BASINS MAP (AWLACHEW ET. AL. 2007) ................................................... 63
FIG. 3-1: INTERACTION BETWEEN SUBSYSTEMS (LOUCKS AND EELCO VAN BEEK, 2005) .................... 73
FIG. 3-2: ELEMENTS OF THE INTEGRATED RIVER BASIN MANAGEMENT (TEODOSIU ET AL., 2003) .... 73
FIG. 3-3: CYCLE FOR DEVELOPING AND ADJUSTING PLAN FOR WATER RESOURCE MANAGEMENT .... 77
FIG. 3-4: CATEGORIES OF WATER RIGHTS (AFTER BIRD ET AL., 2009) .................................................. 88
FIG. 3-5: GENERAL PRINCIPLES FOR COST OF WATER (AFTER ROGERS ET AL., 1998) ......................... 98
FIG. 3-6: GENERAL PRINCIPLES FOR THE VALUE IN USE (ROGERS ET AL., 1998) ............................... 99
FIG. 4-1: MANAGEMENT AND USE OF HYDROLOGICAL DATABASE ................................................... 117
FIG. 4-2: SYMMETRICAL AND SKEWED DISTRIBUTIONS ...................................................................... 121
FIG. 4-3: CORRELGRAM OF ANNUAL FLOWS OF SABARMATI RIVER .................................................. 125
FIG. 4-4: VARIATION OF TWO OBJECTIVE FUNCTIONS WITH DECISION VARIABLES ...................... 136
FIG. 4-5: ILLUSTRATION OF THE PRINCIPLE OF OPTIMALITY ............................................................ 138
FIG. 4-6: THE FEASIBLE REGION IN DECISION SPACE X AND THE SET OF NON INFERIOR SOLUTIONS X*142
FIG. 4-7: THE FEASIBLE REGION IN OBJECTIVE SPACE Z(X), THE NON INFERIOR SET (Z(X*), AND THE BEST COMPROMISE SOLUTIONS ......................................................................................... 142
FIG. 4-8: A SIMPLIFIED BLOCK DIAGRAM SHOWING THE RELATIONSHIP BETWEEN DSS COMPONENTS150
FIG. 5-1: LEVELS IN RIVER BASIN MANAGEMENT ................................................................................ 166
FIG. 5-2: DISPUTE AVOIDANCE MECHANISM ...................................................................................... 188
1. Introduction
By: Mr. Tewodros Zenebe

1.1 Definition of Terminologies and Basic Concepts

In this course, a number of terms that are related to IRBM and that frequently arise with a variety of meanings in discussions, proceedings, publications and other communications will be used. The most important and frequently used terms will be described not as statements but for the sake of streamlining the discussion.

River basin is to be defined as the geographical area determined by the watershed limits of the system of waters, including surface and underground waters, flowing into a common terminus (cf. Helsinki Rules, International Law Association, 1966, article II). It can also be defined as an area that drains via a specific river; an area where the surface runoff flows towards and passes through the mouth of a specific river; for example, the Nile Basin and Awash Basin (Figs. 1.1 a and b)

![Nile River Basin](image1.png)  ![Awash River Basin](image2.png)

Fig. 1-1 (a) Blue Nile River basin and (b) Awash River basin

Watershed: A line in the landscape (e.g. a ridge) that delineates a catchment. The surface runoff on each side of the watershed will proceed towards different locations. In American English, a watershed is sometimes the same as a catchment or a drainage basin.
Catchment: An area, delineated by watersheds, within which the surface runoff flow towards a specific location. (A river basin is a catchment, but a catchment can also be a smaller part of a river basin). Based on size of the area, a drainage unit can be classified as below

Table 1-1: Classification of drainage unit based on size of the area

<table>
<thead>
<tr>
<th>Drainage Area, ha</th>
<th>Unit</th>
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<tbody>
<tr>
<td>Greater than 100,000</td>
<td>Basin/Catchment</td>
</tr>
<tr>
<td>40,000–100,000</td>
<td>Sub-basin/Sub-catchment</td>
</tr>
<tr>
<td>4,000–40,000</td>
<td>Watershed</td>
</tr>
<tr>
<td>2,000–4,000</td>
<td>Sub-watershed</td>
</tr>
<tr>
<td>400–2,000</td>
<td>Mini-watershed</td>
</tr>
<tr>
<td>Less than 400</td>
<td>Micro-watershed</td>
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</table>

Management can (for our purpose) be described as the attainment of organizational goals and objectives in an effective and efficient manner through planning, organizing, leading and controlling the organizational resources (Malano & van Hofwegen, 1999).

River basin planning: The process of collecting and analyzing river basin data and evaluating management measures in order to achieve the objectives within prescribed timescales. The river basin planning process is followed by implementation of the program of measures.

River basin management is Management of water resources, water-related resources and water-related development in a river basin. It can, from case to case, involve a variety of tasks, depending on the geographic, social and economic context and the surrounding institutional landscape.

Integrated water resources management (IWRM) is the management of surface and subsurface water in a qualitative, quantitative and environmental sense from a multi-disciplinary and participatory perspective. There is a focus on the needs and requirements of society at large with regard to water at the present and in the future, thus aiming at maximum sustainability in all senses (van Hofwegen & Jaspers, 1999).

Integrated river basin management (IRBM) can be understood as the management of all surface and subsurface water resources of the river basin in its entirety with due attention to water quality, water quantity and environmental integrity. A participatory approach is followed, focusing on the integration of natural limitations with all social, economic and environmental interests. It is a concept developed since the early 1900s and gained prominence in the last 20 or 30 years as a potentially valid management approach. Different terminologies are interchangeably used to describe IRBM including: Integrated Water Management (IWM) and Integrated Water Resource Management (IWRM). Consensus similarly varies over a definition of what IRBM actually means and the following are definitions given to IRBM by various organizations.

**Global Water Partnership (GWP) 2000:** A process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.
Motueka River Catchment, New Zealand: A process that recognizes the catchment as the appropriate organizing unit for understanding and managing ecosystem processes… in a context that includes social, economic and political considerations, and guides communities towards an agreed vision of sustainable land and water resource management for their catchment.”

Murray-Darling Basin Ministerial Council, Australia: A process through which people can develop a vision, agree on shared values and behaviors, make informed decisions and act together to manage the natural resources of their catchment. Their decisions on the use of land, water and other environmental resources are made by considering the effect of that use on all those resources and on all people within the catchment.

Division of Water, Environment & Forestry Technology, CSIR, South Africa: A process which recognizes the need to integrate all environmental, economic and social issues within (or related to) a river basin into an overall management philosophy, process and strategy or plan, and is aimed at deriving the greatest possible mix of sustainable benefits for future generations and the communities in the area whilst protecting the natural resources upon which these communities rely.

World Wildlife Fund: The process of coordinating conservation, management and development of water, land and related resources across sectors within a given river basin, in order to maximize the economic and social benefits derived from water resources in an equitable manner while preserving and, where necessary, restoring freshwater ecosystems.

According to Easter et al., (1985), Integrated river basin management is defined as the process of formulating and implementing a course of action involving water and related land resources of a watershed, taking into account related social, economic, environmental, and institutional factors, with special emphasis on the linkages between upstream and downstream parts of a watershed and their respective human and physical endowments.

River Basin Organizations (RBOs) are organizations that deal with the management of rivers, lakes, wetlands, aquifers, and land within the hydrological boundaries of a basin. There are many different types of RBOs and these are:

Type 1: Advisory Committee: A formalized or quasi-formal organization in which individuals take responsibility for undertaking action planning and provide advice; governments ‘hand over’ strategic planning to such organizations; they frequently have no or limited legal jurisdiction.

Type 2: Authority: An organization which makes planning decisions at a central or regional government level; may set and enact regulations, or have development consent authority; authorities are founded on democratic principles and a framework of law to which all relevant individuals and institutions are subject in a basin setting.

Type 3: Association: Similar to an Advisory Committee, this is an organization of like-minded individuals and groups with a common interest. In a river basin they have varying roles: providing
advice, stimulating basin awareness, education and ownership of basin natural resources management issues; educational functions and information exchange.

Type 4: **Commission:** An organization which is delegated to consider natural resources management matters and/or take action on those matters. A basin commission’s powers vary, and include advisory/education roles, monitoring roles, undertaking works, fulfilling goals of a specific government’s charter or an international agreement. Commissions normally are instituted by a formal statement of a command or injunction by government to manage land and water resources; commissions may also have regulatory powers.

Type 5: **Council:** A formal group of experts, government ministers, politicians, NGOs and lay people brought together on a regular basis to debate matters within their sphere of basin management expertise, and with advisory powers to government. A council is contrasted with a commission which, although also a body of experts, is typically given regulatory powers in addition to a role as advisor to the government.

Type 6: **Corporation:** A legal entity, created by legislation, which permits a group of people, as shareholders (for-profit companies) or members (non-profit companies), to create an organization, which can then focus on pursuing set objectives, and empowered with legal rights which are usually only reserved for individuals, such as to sue and be sued, own property, hire employees or loan and borrow money. It is also known as a "company". The primary advantage of a for-profit corporation is that it provides its shareholders with a right to participate in the profits (by dividends) without any personal liability because the company absorbs the entire liability of the organization.

Type 7: **Tribunal:** A basin entity which has formalized procedures and quasi-judicial powers; a heavy emphasis on bureaucratic decision making; stakeholders may formally participate through hearings; major decisions are taken by independent bodies, like a water pricing tribunal. A Tribunal acts as a special court outside the civil and criminal judicial system that examines special problems and makes judgments, for example, a water tribunal, which resolves disputes between water users. Very few such entities exist purely for river basins management purposes but rather for special purposes, for example, government pricing tribunals. Some tribunals have specific water functions which are a component of a broader river basin's management process, where an RBO may or may not exist. These entities have limited traditional powers of civil government and do not report to other government agencies, except where a local government body may oversee entities such as ‘country’ drainage districts, which charges for water. They play an important role in developed countries and many developing countries.

Type 8: **Trust:** A trust is legal device used to set aside money or property of one person for the benefit of one or more persons or organizations. It is an organization which undertakes river basin works; develops and implements a strategic plan; its mandate is to be the river basin ‘advocate’; it co-ordinates local programs through Memoranda of Understanding or other agreements; it raises local levies (funds) for its works and programs. A Trust keeps monies raised in ‘trust’ for the benefits of its citizens.

Type 9: **Federations:** Collaboration of organizations or departments within one government or between state and national governments to establish and undertake actions for river basin
management. Local government groupings have emerged in some locations in the USA for regional natural resources governance. Governance actions at various levels (national, state and local) include: agreements on water sharing and water quality management, shared statements of intent; shared policy development; information exchange; joint actions for management of ecosystem degradation. Collaboration is expressed in terms of framework directives, cost-sharing arrangements, joint statements of intent, partnerships, joint programs and agreed policy.
1.2 Theories and Principles of IRBM

1.2.1 The Need for River Basin Management

The river basin is a functional region that includes the key interrelationships and interdependencies of concern for water and land management from upstream to downstream.

From the earliest civilizations up till now, river basins have played an important role in sustaining communities of people and other forms of life. A quick glance at history demonstrates the intimate connection between the stability of a group of people, its economic and social development, and the availability and reliability of water. This has rightly led many authors to define the first developed social groupings as hydraulic civilizations (Caponera, 1992). All major human migrations and the birth of towns and communities have been closely correlated with the search for, and the settlement around, naturally irrigated areas and valleys adequately supplied with water.

River basins are the natural entities in which freshwater appears, the ultimate source of nearly all water used and nowadays also the receptors of most wastewater. River basins play a pivotal role not only in the water cycle, but also in nearly all other life cycles as a crucial source of bio-diversity. Multiple sector interests are predominantly served and covered by the resource base of river basins: drinking water supply, agriculture, hydropower generation, recreation, transport, etc.

River basins are used ever more intensively and many of them are under pressure. In some cases human pressure is reaching the maximum sustainable level or has already surpassed this level. Severe water competition is resulting between users, sectors and countries. Conflicts between upstream and downstream are on the increase. Such conflicts may be exacerbated in international river basins, where socioeconomic inequities among them are often much greater, as are differences in power, and where conflicts may lead to loss of life and a reduced capacity of governments to respond to domestic needs (Murphy, 1997). The slightly exaggerated term “water wars” is appearing now and then in newspapers (Jaspers, 2000). The incidence of floods in quantity and in severity is also considered to be increasing. Causal links with unbalanced human occupation and watershed destruction are also likely.

Management of river basins becomes necessary as freshwater and other services provided by basins become scarce and competition increases for their use. Appropriate measures to overcome these problems can be achieved by considering hydrological functions of river basins. Hydrological unit or hydrological cycle is wide and complex encompassing land, water and atmosphere in one single relation, which determine the quality and quantity of water in this relation. To address several environmental problems that are associated in hydrological function in a certain area, it is appropriate to use a specific natural system, where as much decisive factors as possible are included. People have adopted river basin as the most understandable natural system that links all water-related decisive factors, such as forest, soil, river and coast.

Policies for the use and protection of water resources in a country are set by national governments. Although the implementation of these policies is effective at many scales, where policies are implemented at the basin scale, there is the opportunity to deliver ‘whole basin’ solutions and to resolve upstream-downstream (for a river) and region-to-region (for a lake or groundwater resource)
controversies. The 'whole basin' approach allows the assessment of impact at a system level. In other words, national policies, as well as international agreements and regional conventions for transboundary waters, are applied to natural basins.

In addition, Water policies and new legal frameworks are prepared in order to embody new principles and strategies for integrated water resources management (Global Water Partnership, 2000) as there is a broad consideration that water is a finite and vulnerable resource (ICWE, 1992). Whenever implementation of water policies and strategies is at stake, it is unavoidable to consider river basins as logical units for water and environmental resources management (Savenije, 2000).

1.2.2 The Need for Integration

To prevent or solve problems and conflicts and to meet social and natural demands in river basins, integrated approaches are indispensable. The complexity of the physical river system, the exchange of groundwater and surface water and vice versa and the continuous interaction between environmental elements is a physical imperative. To be effective, river basin management should consider all these interactions (Fig 1.2).

![Fig. 1-2: The concept of integrated approach in river basin management](image)

It difficult to develop effective management responses from within particular jurisdictions or economic sectors, because many impacts occur as a result of cumulative impacts of numerous and diverse activities over large spatial scales, or only become obvious over long periods of time. The fact that different elements of the river basin management function are implemented by different sectors and through different disciplines is a complicating factor, which can only be tackled by a holistic approach (cf. Savenije, 2001).

Moreover, as basic elements of these integrated approaches are a basin-wide planning scope, attention to management of surface and subsurface water and to water quantity, water quality and environmental integrity as an inseparable entity, there should be an emphasis on the relations between land use and water resources and to the integration of natural limitations, social and economic demands and legal, political and administrative processes (Savenije, 2000).
Besides, water resources planning should consider and prioritize all relevant societal water uses in their spatial distribution. A fine-tuning between consumptive uses (domestic, industrial, agricultural water supply) and non-consumptive uses (power supply, fishery, recreation, and nature conservation) is indispensable in more complex systems. A system of integrated planning is needed in which water quality; water quantity and environmental integrity are managed in an integrated way.

IRBM is distinguished from the coordination of uses in multiple sectors and systems approaches because it implies the “integration of water planning and management with environmental social and economic development concerns”, and has an explicit objective of improving human welfare. Poverty alleviation and livelihood concerns are therefore implicit. IRBM is also inclusive of management at sub-basin catchment or watershed levels, which focuses on problems that are difficult to address at the larger scales, such as relationships between land use and water flow for purposes of stabilizing stream flows, controlling erosion and sedimentation, and improving groundwater recharge. It is at this level also that stakeholders may become more directly engaged (Barrow, 1998).

Integrated river basin development with the aim stated involves the coordinated and harmonious development of the various works in relation to all the reasonable possibilities of the basin. These may include irrigation and drainage, electric power generation, navigation, flood control, water treatment, industrial and domestic uses of water, recreation and wildlife (Gunnar, 1983).

Ten specific items are listed as important in the integration process:

- Integration of environmental objectives, combining quality, ecological and quantity objectives for protecting highly valuable aquatic ecosystems and ensuring a general good status of other waters;
- Integration of all water resources, combining fresh surface water and groundwater bodies, wetlands, coastal water resources at the river basin scale;
- Integration of all water uses, functions and values into a common policy framework, i.e. investigating water for the environment, water for health and human consumption, water for economic sectors, transport, leisure, water as a social good;
- Integration of disciplines, analyses and expertise, combining hydrology, hydraulics, ecology, chemistry, soil sciences, technology engineering and economics to assess current pressures and impacts on water resources and identify measures for achieving the environmental objectives of the Directive in the most cost-effective manner;
- Integration of water legislation into a common and coherent framework. The requirements of some old water legislation have to be reformulated to meet modern ecological thinking. Other pieces of must be coordinated in river basin management plans where they form the basis of the programs of measures;
- Integration of all significant management and ecological aspects relevant to sustainable river basin planning including those which are beyond the scope of flood protection and prevention;
- Integration of a wide range of measures, including pricing and economic and financial instruments, in a common management approach for achieving the environmental objectives. Programs of measures are defined in River Basin Management Plans developed for each river basin district;
Integration of stakeholders and the civil society in decision making, by promoting transparency and information to the public, and by offering an unique opportunity for involving stakeholders in the development of river basin management plans;

Integration of different decision-making levels that influence water resources and water status, be local, regional or national, for an effective management of all waters;

Integration of water management from different member States, for river basins shared by several countries, existing and/or future States.

1.2.3 Objectives and Benefits of IRBM

The main objective of IRBM is to establish a balance between the existing natural functions of the river system and the developed aspects of the system. The management actions should fulfil the expectations of the society for industrial use, recreation, nature management, and agricultural purposes. Primarily, coordination of multiple activities and resolving conflicts, particularly those stemming from negative externalities are the key functions of integrated river basin management. These are in addition to the traditional objectives of allocation of water, sustainable water supply, waste treatment, and water quality management. These activities involve financing and development of infrastructure in a manner that ensures sustainability of the ecosystem and therefore, of water.

In addition, the objectives of IRBM also include:

− Protection of all waters
− Insuring good ecological and good chemical status
− Prevention of degradation of water bodies
− Stepwise reduction/elimination of the emission hazardous substances.
− Revoking some abstraction licenses to improve the water environment;
− Enhancing public water supply by a program of improvement and development;
− Enhancing and build waste water treatment plan
− Promoting water-use efficiency

The above mentioned objectives should be set to reduce potential risks related to the uncertainties about future. In addition, activities in addressing these objectives should consider present and future water demand and water availability, water quality for proper uses, the potential effects of climate change and changes in different societal values. River basin management does also have a variety of benefits, such as the ones listed below.

Social benefits:

− Basic access to water, sanitation - and electricity
− Livelihoods; reduced urban migration
− Reduced risk exposure (floods, drought)
− Cultural aspects of water availability

Income generation and livelihoods:

− Water efficiency and economic efficiency of production systems
− Timely and appropriate response to new (external) opportunities and threats - lower trade barriers, commodity prices, climate change, ...
Economic revenue:
- Value chains building on primary production: Agriculture, fisheries, hydropower, etc.
- Value generated by tourism and navigation

Other benefits:
- Habitat conservation
- Peaceful relations within the basin
- Investment climate supported by good governance

1.2.4 Key Activities and challenges in IRBM

Key activities related to water resources development:
- Water resources management studies
- Master planning and policy development
- Investment planning/feasibility studies
- Soil erosion assessment and planning of soil erosion control strategies
- Water supply and demand assessment
- Water resources system modeling.
- Key activities related to environmental management:
  - Environmental impact assessment
  - River and floodplain ecology and rehabilitation.

Key activities related to information management:

Information management systems, mathematical models and a user interface are often combined in a Decision Support System (DSS). In such a DSS the data and modelling systems help to assess the impacts of promising scenarios and managerial policies and to evaluate them. Such systems allow water managers and their staff to get a better picture and understanding of their system and the surrounding areas. It also helps them to present this picture and the consequences of proposed measures or strategies to others, for example government officials and the interested public.

The activities are:
- Data base development and management
- Key challenges in IRBM

IRBM is also inclusive of management at sub-basin catchment or watershed levels, which focuses on problems that are difficult to address at the larger scales, such as relationships between land use and water flow for purposes of stabilizing stream flows, controlling erosion and sedimentation, and improving groundwater recharge. It is at this level also that stakeholders may become more directly engaged (Barrow 1998), and the key challenges in IRBM are:
− To insure that local livelihood and environmental concerns are reflected in basin-wide management plans and development objectives, and considered in decision-making;
− To identify management actions that are effective for insuring that ecosystem services continue to be provided;
− To develop equitable economic and institutional arrangements that allow those in upper basin areas to share the benefits of adopting management practices that are consistent with providing ecosystem services, and for those who benefit from them to share their costs; and
− To develop compatible approaches for monitoring outcomes and for reporting information needed to support stakeholder negotiations.

1.2.5 Principles of IRBM

The above discussions illustrate the complexity of river basin management. There is a danger that promoters of IRBM lapse into high levels of conceptualization, rather than recognizing the realities of this complexity. This is particularly the case with naive advocates of sustainable development who frequently rely on doctrinaire statements, rather than workable solutions. In this regard, the following principles are provided to offer some reality to river basin management. The principles were derived by the author’s review of material published on current IRBM, reviews of past practices and the literature on evaluation of river basin management, and interviews and his own professional experience in the field. The general principles intended to guide Integrated River Basin Management (IRBM) are (IWR, 2006):

Principle 1: Engagement and ownership by decision-makers as specified in a formal agreement. River basin management design is enhanced if relevant river basin decision-makers own the process and participate under a formal, contractual arrangement, rather than ad-hoc, voluntary arrangements. The issue of multiple players and distant participants can be addressed by the use of Internet-based river basin information systems, with supportive local meetings and face-to-face contacts.

Principle 2: Improved river basin management design informed by scientific, social and economic information. Sound scientific information guides effective integrated river basin management. It should describe resource condition and trend, the causes of resource degradation and the likely impacts of resource management options. Economic analysis and social impact assessment should be used to provide ex-ante and ex-post evaluations of river basin management plans. This is supported by accurate modeling of river basin management options.

Principle 3: Application of unique institutional arrangements to suit the specific needs of individual basins based on differences in hydrology, capacity and stakeholders. There are many institutional arrangements to enact IRBM. These include cost-sharing programs, tradable discharge permits and voluntary actions, as well as more regulatory practices such as environmental regulation, zoning laws and environmental standards for best practice. Developing countries require different approaches to institutional strengthening for river basin management than those of developed countries, relating to their difference in hydrology, administrative capacity and vast numbers of stakeholders (Table 1.2).
Table 1-2: Differences between developing and developed countries basin realities

<table>
<thead>
<tr>
<th>Developed Countries</th>
<th>Developing Countries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperate climates, humid, higher river-stream density</td>
<td>Rainfall low, climate extreme, higher mean temperatures, lower stream density, water scarcity an emerging constrain</td>
</tr>
<tr>
<td>Population concentrated in the valleys, downstream</td>
<td>Densely populated in both valleys and catchment areas; population high both upstream and downstream of dams</td>
</tr>
<tr>
<td>Water rights based on riparian doctrine and prior appropriation</td>
<td>Water rights based on rights to rainfall or ground-water; people's notions of ownership relate more easily to rain than to large-scale public diversions</td>
</tr>
<tr>
<td>Focus on blue surface water: water found in rivers, and lakes</td>
<td>Focus on green water: water stored in the soil profile or blue water stored in aquifers</td>
</tr>
<tr>
<td>Most water users get water from 'service providers'; most water provision is in the formal sector-making water resources governance feasible</td>
<td>Most water users get their water directly from rain and from private or community storage without any significant mediation from public agencies or organized service providers. Because the bulk of water provision takes place in the informal sector, it is difficult to pass enforceable water legislation</td>
</tr>
<tr>
<td>Small numbers of large-scale stakeholders</td>
<td>Vast numbers of small-scale stakeholders</td>
</tr>
<tr>
<td>Low transaction costs for monitoring water use and collecting water charges</td>
<td>High transaction costs for monitoring water use and collecting water charges</td>
</tr>
</tbody>
</table>

Source: [http://www.iwmi.cgiar.org/home/integrated_river_basin.htm](http://www.iwmi.cgiar.org/home/integrated_river_basin.htm), (Hooper 2005)

**Principle 4: Clear definition of the role and structure of the river basin organization (RBO).** An RBO requires a clear management role and jurisdiction which involves:
- A skills-based, independent membership of its board of directors/oversight group
- A democratic process - members elected by the regional community
- An accountability procedure of its management departments-reporting to an independent board of directors
- Being linked to high levels of government for political influence and support
- Responsible for the core basin management business of social and economic inventories of the river basin, management of river basin information, provision of resource management planning guidelines to Local Government, implementation of plans of action and co-ordination of other agencies’ actions in the river basin.

**Principle 5: Strong river basin advocacy** driven by strong leadership. Successful river basin management is driven by strong leadership. Individual advocates and organizations with a strong river basin advocacy are needed to engage both willing and recalcitrant resource managers.

**Principle 6: Prioritizing actions specified** within a River Basin Management Plan implemented over the short-term. River basin management will be more likely to succeed when short-term actions (say within three years) are implemented, visible results change the landscape, and water quality improves. This requires clear identification of these actions and immediate commitment to action by river basin managers. These actions need to be specified within a River Basin Management Plan. It is unlikely that this Plan will develop within a short time period, so interim river basin management actions
should be designed and implemented immediately. Longer term river basin management planning can commence simultaneously with a goal of developing an agreed, cost-shared plan of action in three year’s time.

**Principle 7: Accountability** to monitor the implementation and effectiveness of a River Basin Management Plan. A process of accountability is required to monitor the effectiveness of a river basin management plan and the organization responsible for its implementation. This task can be implemented at the commencement of a river basin management plan and be linked to a river basin-based State of the Environment report. In this way regular reports (say every 2 years) chart the progress of river basin health, using critical water quality and ecosystem indicators. Similar organizational performance indicators can be developed and used to analyze the effectiveness of an RBO.

**Principle 8: Local government partnerships** for effective implementation. Local government has a key role to play in local governance - decisions which can have a more immediate impact on resource conditions. Planning and local zoning mechanisms are useful tools which to implement broader river basin management goals.

**Principle 9: Integrating functions for collaboration** enables horizontal and vertical coordination between varieties of stakeholders in different sectors. Lack of coordination between and within government agencies, NGOs, the general public and locally and regionally significant water stakeholders is a constant problem in IRBM. The solution lies in identifying collaboration mechanisms and driving collaboration throughout the RBO and with and between its strategic stakeholders. The starting point for collaboration and coordination mechanisms is to establish a joint vision for the basin and an ethic of willingness to cooperate, coordinate and jointly manage. This requires clear specification of the roles and responsibilities of partners in any joint action. Frequently, coordination stops at the level of agreed values whereas what is needed, once an agreed vision is achieved, are actual collaborative plans of action and a monitoring and review program to account for and report to the collaborators on progress and pitfalls.
1.3 Processes/Phases of IRBM

IRBM is a cyclic process. It involves taking account of the interdependence of natural and human factors within a catchment. In this process, water resources development in a basin, along with management principles and objectives, evolves over time, as new demands and needs emerge, and innovative solutions are added at each stage. A river basin continuously adapts to those demands as part of an orderly IWRM process. This approach consists of a comprehensive set of analysis steps; supported by mathematical tools for the analysis of natural resource systems in a socio-economic context. The Global Water Partnership (2009a) developed a "Handbook for Integrated Water Resources Management in Basins". The handbook identified generalized sequential steps for basin management, including: Outline broad policy goals as a vision for water management Identify specific water management issues and problems Evaluate potential solutions to resolve these issues Implement the most appropriate strategy(s) Evaluate the outcomes of implementing these strategies Integrate the lessons learned from evaluating the outcomes into future work The critical stage of this approach is revising future programs and activities based on past experiences in water planning and management, and incorporating new knowledge and information. This conceptual model is demonstrated in the "Learning-by-Doing Management Cycle" as shown in Figure 1.3.

![Learning-by-Doing management Cycle](Source: GWP, 2009)

Policy making, planning and management might be considered as a series of sequential steps in basin management. The first step is to draw up broad policy goals (where we want to get to). The next steps are to specify water management problems to be solved (identify issues), list potential strategies (how we are going to get there), evaluate each of these, select a strategy or combination of strategies, implement the strategy, evaluate the outcomes, learn from these outcomes and revise our plan to make it work better in the future. These steps form a cycle. Of course, in practice this cycle may be interrupted by external forces, but the 'learning-by-doing management cycle' helps us incorporate what we learn in the process of planning and managing river basins and take into account new
information as it comes to hand. This means we can adapt how we manage basins to changing circumstances, for example political changes, natural catastrophes and changes in demography.

In general, these generalized steps can be categorized under three processes/phases for IRBM. These categories of processes are: the Planning process/phase, the Implementation process/phase and the Strategic process/phase. In these phases, there are various steps to be followed.

1.3.1 The Planning Phase (steps 1-6)

River Basin Management Plan (RBMP) is an inventory and documentation mechanism for the information gathered including environmental objectives for surface and ground waters, quality and quantity of waters, and the impact of human activity on water bodies and will indicate the quality and quantity objectives to be achieved. They also coordinate programs of measures and other relevant programs. The basin planning process should promote enhanced dialogue, negotiation, and participation mechanisms, resulting in transparent decision making.

In the planning process, basin description and characterization or inventory is very important as it gives a clear picture of the basin condition. Sufficient information on physical features of the basin and problems encountered should be included to describe it. The following items are included for basin description.

River basin delineation: The delineation of basins is marking the boundaries of the basins. It can be performed by reconnaissance survey and study of topo-sheets. But this technique is slow and does not provide much accuracy. Demarcation of priority areas and improving the quality of work can be achieved by using areal photograph and Digital Elevation Map (DEM) analysis.

Bio-physical data collection: includes the collection and analysis of the following data.

**Location:** The information such as name of river basin tributary, physiographic region, and principal communication lines associated, latitude and longitude should be collected.

**Size and shape:** The size of the watershed in ha or km² and shape of watershed such as how long it is, narrow or fan shaped should be known.

**Climate:** About the climate the following information are needed.
1. Precipitation: forms, annual, seasonal and monthly distribution, storm pattern, rainfall intensity, duration and its aerial distribution.
2. Temperature: maximum and minimum, soil temperature.
3. Evaporation,
4. Relative humidity,
5. Wind velocity and its distribution,

**Geology:** The geologic characteristics of the watershed such as nature of parent rocks, fractures, faults, weathering, ground water recharge etc. are considered as important factors.

**Slope:** It includes the degree of slope, length of slope, and mean slope of the land surface and proportion of different areas of watershed falling under different slope groups.

**Surface Drainage:** The following information is to be collected
1. Nature of stream flow: whether perennial, intermittent, seasonal, spring fed etc.
2. Drainage network: stream orders, density and length of streams, etc.
3. Morphological characteristics of streams.

**Soils:** The information about major soil groups existing in the watershed and their hydrological grouping, physical and chemical properties of soils are to be collected.

**Physiography:** It includes detailed elevation of different parts of the watershed, mountainous range etc.

**Landuse/land Cover Condition:** It includes the followings:
Forest lands, range lands, cultivated lands, waste lands, habitations & miscellaneous uses.

**Socio-economic Data:** Economic conditions of the people, source of income and social customs must be known for successful watershed planning. For successful implementation and continuation of the river basin management program, it is essential that major responsibility should be taken by the people residing in the area. Therefore, peoples’ participation in the program should be made mandatory.

This requires the sponsorship of the concerned people and can help in formulating and achieving the best possible program for river basin management. It is also necessary that the beneficiaries share a part of the cost. At least they should provide free labour. In addition to the data mentioned under the previous section, the following additional economic and social data should be collected.

- Population under different income groups
- Source of income: main and subsidiary
- Educational background of the residents
- Social and religious customs
- Return from natural resources e.g. forest, range land, orchards, water bodies etc.
- Work force available for manual labour
- Stigma of women working in the field
- Willingness of the farmers to change cropping pattern and land use
- Marketing facility and expected effect of yield increase on market price
- Communication facility and possibility of marketing the excess produce outside the area
- Existence of any cooperative society and its functioning or possibility of forming any such society
- Existence of local government at the village level and its role in rural development
- Existing irrigation sources and possibility of further development
- Availability of technical manpower for repair of pumpsets, tractor, power tiller and farm implements.
- Status of electric power availability and 3-phase power supply.
- Food habits of the people, e.g. raw material required for their food.

Other important issues to be included in the descriptions should include the following:
Food requirement, housing, education, medical facilities, irrigation requirement, fertilizer, seed and other inputs for agriculture, agro-service centre and processing unit, marketing facility, water for domestic use and cattle, fodder and fuel requirement and Road and electricity.

There are two important features of the planning process before the river basin management plans can be finalized.
− Stakeholders and the general public must be consulted on their content and the proposals in them
− The appropriate government minister must approve them

The key issues to be included in the plan are:
− General description of characteristics of the river basin districts
− Summary of significant pressures and impacts of human activity
− Map identifying protected areas and monitoring network
− Environmental monitoring data showing the status of surface water, groundwater and protected areas

List of environmental objectives
− Summary of the economic analysis of water use
− Summary of the Program of Measures
− Summary of the public information and consultation measures taken

Here under are major steps to be followed in the planning process for IRBM. The activities in Steps 1 (policy, regulatory and institutional contexts), 2 (stakeholder participation process), 3 (inventory, assessment and technical studies), 4 (setting priorities) and 5 (setting objectives) are arranged in a general sequence of initiation. However, in practice most of these steps can be undertaken in parallel, as long as all are at an adequate level of completion prior to Step 6 (water and land use management plan for the basin).

A bottleneck can occur if the activity of agreeing on, and setting priorities in a basin (Step 4) does not include all the relevant stakeholders, including water and land users, as well as responsible agencies or authorities, in a legitimate decision-making process. Thus it is essential that policy, regulatory and institutional issues be resolved such that the relevant authorities can work together, and that a credible, inclusive stakeholder participation process is well under way (with stakeholders having been helped to understand the relevant technical and strategic issues).

Inventories and specialist desk and field studies, covering ecological, hydrological, economic and social aspects (Step 3), can commence at an early stage in the process. However, it should be recognized that the level of detail and resolution required in these studies will be influenced by the process of determining quantitative objectives, which in turn will require a certain degree of numerical confidence, depending on the sensitivity and importance of basin components and the associated water resources. Hence there can be some iteration required between Steps 3, 4 and 5.

**Step 1: Policy, regulatory and institutional contexts**

It is generally necessary to ensure that the policy, regulatory and institutional arrangements are supportive of efforts to river basin management. Reviewing policy and legislation can be a lengthy process, and although it can be undertaken in parallel with the other implementation steps 1 to 5, implementation (Steps 7) will definitely be compromised if this step is not sufficiently advanced, and preferably substantially completed, by the time implementation begins. A specific bottleneck can occur in relation to the legal status of water allocations and entitlements. Complete revision of
existing laws and policies is not always necessary, and also can be difficult and very slow if not supported at the political level. It is often sufficient to identify and analyze:

Policies and laws from various national sectors (such as water, agriculture, environment, economic development, social development) that positively support the river basin management, and that generally contain shared principles and objectives;

Policies, laws and regulations from various national sectors that conflict with the objectives of river basin management, and where revision or reform may be necessary;

Policies, laws and regulations that can be used for sanctions or enforcement purposes during the implementation phase if necessary, such as pollution prevention, land use planning controls, resource exploitation limitations.

Policies and laws can be formal and based in the statutory legal system of a country, or they can be customary and based in particular community systems of practice and law. The principles of identifying the supporting and conflicting elements of policy and law apply equally to statutory as to customary law, although the challenges of integrating statutory and customary systems, and providing for a pluralistic legal environment, can be significant.

New institutional arrangements, at international, national or local levels, are likewise sometimes politically difficult to implement from scratch, and it is necessary and generally better to begin working with the existing range of responsible and interested institutions. Memoranda of cooperation, or cooperative policy, can be used to formalize relationships when necessary. As relationships and understanding grow, the structure and function of new institutions that would be more appropriate to the task should emerge, and institutional reform and restructuring will then have more support.

**Step 2: Stakeholder participation process**

Although, for convenience, this is noted as a single discrete step, in fact participation of interested, affected and accountable stakeholders is a process that should continue throughout the cycle. At different steps, different stakeholders need to be involved, and the process may take various forms from awareness-raising, through participatory appraisal, consultation, participation and formal negotiation. Participation is included as Step 2 because the participatory process must be designed early in the cycle and properly resourced. Training, as well as the preparation of information and learning materials, may be needed well ahead of the key planning step of setting priorities (Step 4). In addition, it is important to allow enough time to identify all the relevant stakeholders, well before key implementation decisions are taken.

**Step 3: Technical studies (inventory, assessment and hydrological function)**

This is a step that can be initiated early in the process, and it can run in parallel with policy and institutional development as well as participatory and consultation efforts. The scope of work and the level of technical detail required for these studies are partly influenced by priority-setting in Step 4; it may be necessary to undertake more detailed or intensive field studies. Nevertheless, Step 3 can begin with desktop studies, later progressing to much more detailed field work, according to a fieldwork and measurement program which is informed by planning priorities.

**Step 4: Setting agreed priorities**

It is vitally important that this step includes all stakeholders, and that it is well structured and formalized, with appropriate records of decision on the relative priorities in the river basin. Some issues may be afforded a higher protection status than others, due to their importance in conservation,
economic, social or cultural terms, their sensitivity, or the dependence of local populations upon their benefits/services. Ensuring that this step is formalized, participatory and well-informed will greatly assist in prioritizing implementation actions later, including the use of financial resources as well as the allocation of water.

**Step 5: Setting quantitative management objectives**

This is primarily a scientific task, but it still requires the participation of responsible agencies as well as affected stakeholders. The agreed priorities assigned in Step 4 must be translated into practical, measurable, implementable and enforceable management objectives. These objectives need to then be integrated into the business planning of the responsible land, water and environmental management agencies, as well as into any community or customary use agreements. These objectives also form a very important baseline against which to assess environmental impacts at later stages.

**Step 6: Integrated land and water management plan**

This is a very important step in the cycle, and one at which it is essential that the different sectoral planning and management processes are synchronized and integrated. Whether it is an initial concept plan or a comprehensive operational plan for land and water management in the basin, ideally there should be a formal plan, signed off by all the responsible agencies, and with one agency formally accepting the lead role in implementation. There is no single best way to set out such an integrated plan, and each country or basin should consider what format and structure would be most appropriate for their own situation.

### 1.3.2 The Implementation Phase

**Step 7: Parallel and integrated implementation at basin level**

Countries or basin authorities may have considerable experience in implementing either site-level management plans or basin-level water resource management plans. However, the challenge generally lies in the implementation of these two instruments in parallel, while ensuring integration, consistency and synchronization at particular times and places.

Spatial and temporal planning scales are often very different, depending on the sector and the objectives; separate agencies may be responsible for the lead in each case; business planning cycles may not be matched; effective communication channels for data, information, policy and problems may not have been established.

Sometimes the problems of working in parallel can be addressed through a joint working group which is fully inclusive of the various agencies and interest groups. This could have the status of, for example, the governing board of a basin authority, or it may be a much less formal working group of technical officials who meet often to discuss and resolve operational problems.

Whatever the level at which the joint working group is established, it needs political support from the highest levels of all the organizations and agencies that are members of the working group. If this political support is not forthcoming, then committed technical field officials can often address most operational problems, but their work can be greatly hampered by legal challenges (for example, related to water allocations) and lack of organizational policy guidelines.
1.3.3 The Monitoring and Evaluation Phase (Steps 8 and 9)

**Step 8: Monitoring and reporting**
Sustainable adaptive ecosystem management approaches generally rely on the inclusion of explicit monitoring and reporting steps to close the cycle. This step provides the “glue” which holds the whole Critical Path together. Yet monitoring and reporting activities are often those for which the least time and money is budgeted, and they are often the first to be cut back when budgets are tight. Monitoring programs need to be designed against the priorities and objectives set in Steps 4 and 5. There is little value in monitoring if the resulting information cannot be used to assess achievement of or progress towards the agreed management objectives for the river basin.

It is likely that some of the management objectives will be social or economic, related to livelihood protection and enhancement. For these, the monitoring program will then also need to provide information to track progress on these objectives, as well as on more widely-understood hydrological and ecological objectives. Performance criteria against which to evaluate the progress and management of planning and implementation activities are also necessary.

Information on status, trends and progress may need to be packaged in different ways for different audiences such as politicians, agency managers, stakeholders, and community interest groups.

**Step 9: Review, reflect and revisit plans and priorities**
Like monitoring, this is a critical strategic step whose importance is generally greatly underestimated. There are two levels of review:

− At the operational level, monitoring results can feed back very quickly into refined management objectives or remedial actions, without necessarily requiring substantive review of the formal basin management plans;

− Formal strategic review of basin management plans should be conducted on a regular basis (5 to 10 years is an appropriate time period, but it can be matched to business planning cycles). As a result of this review, management priorities and objectives may be substantively revised (rather than just refined) to take account of changing ecological, social or economic conditions.

If carried out properly at both operational and strategic levels, this review step closes the Critical Path Cycle and ensures effective “learning-by-doing”, which is the foundation principle of adaptive management of ecosystems.

1.3.4 Cross cutting issues and points to tote in the processes of IRBM

A number of key issues are not linked to any specific step, but can cause problems anywhere in the Critical Path if they not attended to. These include:

− Ensuring adequate technical, institutional and infrastructural capacity, in good time to prevent bottlenecks. This includes specialist hydrological and ecological expertise, as well as expertise in policy, legal and institutional matters. Institutional capacity may be needed in the form of budgets, if not actual delegations, secondments or assignments of responsible staff where no institutions at all exist to initiate the process.
− The value of sustained, credible leadership. This often comes down to a single, committed individual with strong leadership skills and the ability to mobilize people into integrated teams. Political leadership of this kind is just as important as the facilitation-style leadership of the person or group who manages to get all the stakeholders, agencies and interested groups to reach consensus at various stages of the process.

− Providing a continual flow of information into the process. Integrated, adaptive approaches, such as the Critical Path approach described here, are being applied in many different situations around the world. Ensuring a continual flow of information on best practices, new developments and new scientific tools and techniques, will improve application “on the ground”.

− Ensuring a continual flow of information out of the process. The importance of communication and awareness initiatives, at various levels from policy and technical through to the general public, cannot be overestimated. A free flow of information, appropriately packaged, greatly reduces resistance to change and helps people to see the benefits of working towards multiple social, environmental and economic objectives in a river basin.

1.3.5 Key Elements for Effective IRBM

A long-term vision for the river basin, agreed by all the major stakeholders. River basin-scale objectives cannot be tackled seriously within the scope of a typical three- or five-year project. IRBM requires long-term financial and ‘technical’ investment. It also takes time to build sufficient trust and levels of understanding among stakeholders before implementation of IRBM activities can begin. While it is important for those involved in the river basin planning process to share a common long-term vision, it must also be recognized that different stakeholders will have different and sometimes conflicting expectations, and that complete consensus may not be achievable. However, there should be sufficient agreement over priorities to ensure that scarce resources are used effectively. This can be achieved through a step-by-step process of identifying the basin values to be conserved, setting environmental targets, and establishing the actions needed to meet those targets.

Integration of policies, decisions and costs across sectoral interests such as industry, agriculture, urban development, navigation, fisheries management and conservation, including through poverty reduction strategies. Integration between organizations, economic sectors and disciplines dealing with water management issues is required for ensuring efficient and cost-effective river basin planning. This is especially relevant for international river basins. Also, other legislations, policy and financial instruments are to be integrated with water policy to remove or minimize obstacles to sustainable river basin management.

The river basin is clearly recognized as the basic planning scale for water management measures. The great diversity in river basin sizes means approaches suitable to one location are not automatically transferable elsewhere, although the same basic planning principles must apply. Coherence is required between the processes developed at different spatial scales, i.e. reconciling top down and bottom up approaches to ensure environmental objectives are effectively met.
Effective **timing**, taking advantage of opportunities as they arise while working within a strategic framework. Timing of implementation is considered as critical. Deadlines for achieving the objectives of the IRBM are extremely challenging. But they must not be seen as a step-by-step timetable for implementation as many tasks will effectively be required before such deadlines. Better start implementing early but imperfectly.

Active **participation** by all relevant stakeholders in well-informed and transparent planning and decision-making. The main purpose of public participation is to ensure that decisions are based on common understanding, shared knowledge, experiences and scientific evidence. Information, consultation and participation of the public and stakeholders are key elements of the process that will lead to successful river basin planning. Provision of transparent and accessible information, together with genuine opportunities for participation in planning and decision-making, should be prioritized from the start. Participation needs to be adapted to the appropriate scale, target groups and activities, and managed carefully to ensure expectations from all sides are clear and can be fulfilled.

Adequate investment by governments, the private sector, and civil society organizations in **capacity** building for river basin planning and participation processes. Capacity among all relevant actors needs to be maximized. Capacity building, starting with awareness rising, is required for officials, planners and administrators, but also for economic sectors, local authorities and NGOs. Allocating adequate financial and human resources to capacity building and participation process will be key to implementing IRBM plans.

In addition, the following a few specific recommendations are given by Sylvia (2002) for effective IRBM.

1. Recognize both protection of ecosystem services and poverty alleviation as explicit objectives of IRBM and develop more specific objectives consistent with these, for particular river basins.
2. Establish effective decision-making processes and institutional arrangements that engage stakeholders at the very beginning, in defining the problems and the objectives and that allow for negotiation and conflict resolution needed to reach agreement on management plans.
3. Give special attention to monitoring the implementation phase of IRBM to insure that the process is inclusive of all significantly affected stakeholders and that they all have access to adequate information.
4. Conduct basin-wide integrated assessment to inform a process of negotiation and to resolve conflicts between new objectives and existing practices. Give special attention to clarifying the roles that ecosystem services play in sustaining livelihoods, to their multiple benefits, and to options for insuring that they continue to be provided – this should include evaluation of potential market-based, voluntary and regulatory arrangements for paying for ecosystem services. Assessments can also help also to increase donor confidence and may help to justify increased funding.
5. In the valuation of ecosystem services, acknowledge areas of uncertainty and ranges of variability in ecosystem processes – this creates a space for stakeholder deliberation which can facilitate mutual learning, meaningful participation in decision-making, and more informed value judgments.
6. Identify all policies relevant to the management of river basins and those that conflict with IRBM objectives, including existing property rights arrangements, and subsidies for inappropriate land uses, to assess their implications and identify ways these could be reformed to better promote IRBM objectives.
7. Given the fundamental relationship between poverty and environmental degradation, an important criterion for sustainable development, and a starting point for analysis of livelihood assets, is to examine whether the needs of the least advantaged and most vulnerable stakeholders are being met.

8. Highlight the contribution of ecosystem services to sustaining livelihoods as a way to help reduce conflict by allowing stakeholders to focus on shared interests.

9. Use IRBM as a framework and as criteria for evaluating development projects and targeting assistance, and to find ways to support alternative livelihood strategies – that increase the flexibility of stakeholders to respond to threats and opportunities. Provide assistance also for the process of assessment.

10. Avoid universal and overly prescriptive policies so as to allow for flexibility in implementation, appropriate to local circumstances, based on consideration of the different ways that different stakeholders are affected.

11. Be prepared to take advantage of trends and opportunities for change – examples are the development of policies for management of the Rhine in response to catastrophic events, opportunities for change that presented themselves with the fall of the apartheid regime in South Africa, and the end of the cold war and collapse of communist governments in Eastern European countries.

12. Develop common standards for monitoring and report but avoid overly centralized decision-making structures that can stifle local initiatives.
1.4 Questions/Tutorial

1. Describe the differences and similarities between watershed, catchment and river basin.
2. Can you give a definition of Integrated River Basin Management?
3. Mention the different RBOs and try to explain the main responsibility under each ROB type.
4. Explain in your own words the term ‘integration’. Please, describe the elements of integration in IRBM.
5. Can you mention 4 key-characteristics for the application of integrated river basin management?
6. Can you give few reasons as to river basin based management is preferred in Ethiopia?
7. How can an integrated planning process support a system of integrated river basin management?
8. Can you list the main objectives, benefits and key activities in IRBM?
9. Describe in your own terms the principles in IRBM
10. What can generally be understood by the sentence ‘IRBM is a cyclic process’?
11. What are the key elements for effective implementation of IRBM?
12. Capacity building can be interpreted in many senses and can be aiming at various fields of development. Can you indicate the most important fields of development for IRBM


2. River Systems
By: Mr. Mengiste Abate

2.1 Chapter Overview
This chapter gives the basic understanding of river system and how it works and explains the dynamic interactions between environmental changes and human development in a river basin. In the first topic, the key concept of hydrological system is discussed.

In the second topic, river functions are analysed. In this topic many environmental problems, including the problems related to river basins, can be understood better if they are analysed from an ecological perspective. Hence, the topic introduces the concept of the ecological perspective related to wetlands and biodiversity. This topic goes deeper into the effects of human development on the environment in river basins and also analyses the feedback of environmental change on human development.

Topic three discusses human intervention and impacts in the river system. This is firstly done from a more ethical and philosophical point-of-view, i.e. what is man’s attitude towards nature and development, and secondly concrete interventions in river basins, such as land use and diversion structures, are being discussed.

The major river basins of Ethiopia are discussed in topic four. In this topic an in depth situation analysis for each major river basins are made.
In the last topic, exercise /tutorial and project are given.
2.2 Hydrology and Water Resources

2.2.1 Introduction

Surface plus ground water is to mean Water Resources. Less than 3% of the water on earth is fresh water. Most of this is locked up in ice caps and glaciers, or is in the form of groundwater. This leaves only about 200,000 km$^3$ for rivers and lakes. The hydrological cycle renewed fresh water by evaporation and precipitation. Average annual global rainfall over land is about 110,000 km$^3$ and approximately 36.36% of which is potentially available for use and the remainder is lost through evaporation before reaching the sea. But, as part of it falls on uninhabited places, the actual quantity of renewable fresh-water is considerably smaller, and is about 9,000 km$^3$ for the human use. The current freshwater consumption is about 800 m$^3$ per person per year. Due to uneven distribution of rainfall (ranging from 120,000 m$^3$ per capita in Canada to 70 m$^3$ in the island of Malta), the availability of freshwater is a critical factor in socio-economic development. Therefore, the full understanding of hydrology of the river (surface and ground) is imperative for the socio-economic development of regions, (UNESCO-IHE Institute for Water Education IRBM online Module, 2011).

River as a watercourse concept of natural drainage network consisting of a main water course and its tributaries and of river basin as a geographically defined area that is drained by a drainage network are certainly quite insightful and have been understood for long time. Less insightful, since not seen from earth surface, are the concepts of aquifer as a water carrying geological stratum or strata and of underground storage as a volume of water stored in geological strata located under the surface. In the area of water resources the concepts of physical, biological and human society systems, its activities and their complex mechanisms of interdependency is unfortunately a relatively new and not always a well digested concept. River basins (regional, inter-regional, national, international according to a geographical and political view) or their subdivisions, have in the past and will continue to play a very relevant role, being clearly identifiable as conceptual units in which a strong interaction of factors important to human society may be expected. It has, however, to be understood that along the line of the system concept many involved factors cannot be limited to the exclusive consideration of the boundaries represented by river divides or their internal physical or socio-political sub divisions. Their area of influence and dependence may by far extrapolate the basin’s geographical boundaries. Typical examples are, for instance, found in cases when two adjacent basins are physically connected by underground aquifers or when the use of water resources has far reaching consequences for human communities not only regionally but also at national or international levels.

A schematic representation of such a system and its main components is shown in Fig. 2.1.
2.2.2 Hydrological cycle

The annual water cycle from rainfall to runoff is a complex system where several processes (infiltration, percolation, surface runoff, recharge, seepage, re-infiltration, moisture recycling) are interconnected and interdependent with only one direction of flow: downstream. A catchment is therefore one single system and more than the sum of a large number of subsystems. Our water use is embedded in the hydrological system. It is therefore important that we consider the hydrological system and locate our water use in it.

The hydrological system is the source of water. Whereas water is finite, it is also renewable through the hydrological cycle. The hydrological system generates the water that we need for drinking and other domestic use, for agricultural production (both rain-fed and irrigated), for industrial production, for recreation, for maintaining the environment, etc.
In addition to the above water, the hydrological system also receives return flows from human water use in a form not often recognised, namely as water vapour from transpiration of crops and evaporation from natural and man-made lakes and “Grey” return flows. Grey return flows normally are more noticeable, such as sewage water from cities and industries that flow back into rivers. Such flows may also percolate into aquifers, often carrying with it pollutants (for instance from irrigation). In heavily utilized catchment areas, downstream users may depend on return flows as the source of their water.

Water demand management measures can change water use patterns and it will always have a downstream impact. Often this impact will be positive, for example when less water is abstracted, and more water remains in the system for downstream users and/or the environment. But some impacts may be unexpected. Leakages from distribution networks may recharge local aquifers, which may be heavily utilised by urban dwellers. These may have come to depend on this source of water. When leakage control has been successful, less water will percolate into the aquifer and with pumping rates remaining the same, water levels may drop.

Another case is increasing the efficiency of irrigation systems, which often leads to a more reliable, more precise and better timed flow to the irrigated crops, translating into higher yields, which are accompanied by higher transpirative water use. The net “gains” from decreased water losses and increased efficiency of irrigation systems may thus be less than superficially calculated. Downstream users who have come to rely on the return flows from inefficient irrigation may face decreased water availability, as much water is lost in the form of evaporation.

From Ecosystem point of view, the hydrological cycle can be studied at different spatial scales. One starts with considering a certain area, such as an individual plant, a farmer’s field, a watershed, a catchment area, an international river basin, an ocean, or the earth. It is crucial for a systems approach to carefully define the boundaries of the area under consideration, and any water fluxes that cross them. These are either inflows into the area under consideration, or outflows. Subsequently all other sources of water into the area are identified, from such uses. It is useful to distinguish three different
types of water depending on their occurrence in the water cycle (UNESCO-IHE IRBM online module, 2011):

- ‘white’ water = rainfall and that part of rainfall which is intercepted and immediately evaporates back to the atmosphere
- ‘green’ water = soil moisture in the unsaturated soil layer, stemming directly from rainfall, that is transpired by vegetation
- ‘blue’ water = water involved in the runoff (sub) cycle, consisting of surface water and groundwater (below the unsaturated zone)

Fig. 2-3: The hydrological cycle, with ‘white’, ‘green’ and ‘blue’ water
(source: UNESCO-IHE IRBM Online Module, 2011)

Fig. 2-3 gives a schematic representation of the hydrological cycle, distinguishing between these three flows. The processes occurring within the three ‘colours’ of water, as well as their interconnections, determine the characteristics of each natural hydrological system.

Effects of Climate Change on the Hydrological Cycle

This section summarizes the potential effects of climate change on the components of the water balance and their variability over time.

I. Precipitation

Precipitation is the main driver of variability in the water balance over space and time, and changes in precipitation have very important implications for hydrology and water resources. Hydrological variability over time in a catchment is influenced by variations in precipitation over daily, seasonal, annual, and decadal time scales. Flood frequency is affected by changes in the year-to-year variability in precipitation and by changes in short-term rainfall properties (such as storm rainfall intensity). The
frequency of low or drought flows is affected primarily by changes in the seasonal distribution of precipitation, year-to-year variability, and the occurrence of prolonged droughts.

There are different trends in precipitation in different parts of the world, with a general increase in Northern Hemisphere mid and high latitudes (particularly in autumn and winter) and a decrease in the tropics and subtropics in both hemispheres. Current climate models simulate a climate change-induced increase in annual precipitation in high and mid-latitudes and most equatorial regions but a general decrease in the subtropics (Hulme and Carter, 1999), although across large parts of the world the changes associated with global warming are small compared to those resulting from natural multi-decadal variability, even by the 2080s. Changes in seasonal precipitation are even more spatially variable and depend on changes in the climatology of a region. In general, the largest percentage precipitation changes over land are found in high latitudes, some equatorial regions, and Southeast Asia, although there are large differences between climate models.

Until recently, very few projections of possible changes in year-to-year variability as simulated by climate models have been published, reflecting both the (until recently) short model runs available and the recognition that climate models do not necessarily reproduce observed patterns of climatic variability. Recent developments, however, include the increasing ability of some global climate models to reproduce features such as El Niño (e.g., Meehl and Washington, 1996) and open up the possibility that it may be feasible to estimate changes in year-to-year variability.

Potential changes in intense rainfall frequency are difficult to infer from global climate models, largely because of coarse spatial resolution. However, there are indications (e.g., Hennessy et al., 1997; McGuffie et al., 1999) that the frequency of heavy rainfall events generally is likely to increase with global warming. Confidence in this assertion depends on the confidence with which global climate models are held. More generally, uncertainty in GCM projections of precipitation largely determines the uncertainty in estimated impacts on hydrological systems and water resources.

Increasing temperatures mean that a smaller proportion of precipitation may fall as snow (McCarthy, 2001). In areas where snowfall currently is marginal, snow may cease to occur—with consequent, very significant, implications for hydrological regimes.

II. Evaporation
Evaporation from the land surface includes evaporation from open water, soil, shallow groundwater, and water stored on vegetation, along with transpiration through plants. The rate of evaporation from the land surface is driven essentially by meteorological controls, mediated by the characteristics of vegetation and soils, and constrained by the amount of water available. Climate change has the potential to affect all of these factors—in a combined way that is not yet clearly understood—with different components of evaporation affected differently.

The primary meteorological controls on evaporation from a well-watered surface (often known as potential evaporation) are:

- the amount of energy available (characterized by net radiation),
- the moisture content of the air (humidity—a function of water vapour content and air temperature), and
- the rate of movement of air across the surface (a function of wind speed).
Increasing temperature generally results in an increase in potential evaporation, largely because the water-holding capacity of air is increased. The relative importance of different meteorological controls, however, varies geographically. In humid regions, however, atmospheric moisture content is a major limitation to evaporation, so changes in humidity have a very large effect on the rate of evaporation.

It is important to emphasize, that different evaporation calculation equations give different estimates of absolute evaporation rates and sensitivity to change. Therefore, it can be very difficult to compare results from different studies. Equations that do not consider explicitly all meteorological controls may give very misleading estimates of change.

*Vegetation cover, type, and properties* play a very important role in evaporation. Interception of precipitation is very much influenced by vegetation type (as indexed by the canopy storage capacity), and different vegetation types have different rates of transpiration. Moreover, different vegetation types produce different amounts of turbulence above the canopy; the greater the turbulence, the greater the evaporation. A change in catchment vegetation—directly or indirectly as a result of climate change—therefore may affect the catchment water balance (there is a huge hydrological literature on the effects of changing catchment vegetation).

Although *transpiration* from plants through their stomata is driven by energy, atmospheric moisture, and turbulence, plants exert a degree of control over transpiration, particularly when water is limiting. Different studies showed that there is a large degree of uncertainty over the effects of CO₂ enrichment on catchment-scale evaporation, but it is apparent that reductions in stomatal conductance do not necessarily translate into reductions in catchment-scale evaporation.

**III. Soil Moisture**

The amount of water stored in the soil is fundamentally important to agriculture and is an influence on the *rate of actual evaporation, groundwater recharge, and generation of runoff*. Soil moisture contents are directly simulated by global climate models, albeit over a very coarse spatial resolution, and outputs from these models give an indication of possible directions of change.

The local effects of climate change on soil moisture will vary not only with the degree of climate change but also with soil characteristics. The water-holding capacity of soil will affect possible changes in soil moisture deficits; the lower the capacity, the greater the sensitivity to climate changes. Climate change also may affect soil characteristics, perhaps through changes in *water logging or cracking*, which in turn may affect soil moisture storage properties. Infiltration capacity and water-holding capacity of many soils are influenced by the frequency and intensity of freezing.

**IV. Groundwater Recharge and Resources**

Groundwater is the major source of water across much of the world, particularly in rural areas in arid and semi-arid regions, but there has been very little research on the potential effects of climate change. This section therefore can be regarded as presenting a series of hypotheses. Aquifers generally are replenished by effective *rainfall, rivers, and lakes*. This water may reach the aquifer rapidly, through macro-pores or fissures, or more slowly by infiltrating through soils and permeable rocks overlying the aquifer. A change in the amount of effective rainfall will alter recharge,
but so will a change in the duration of the recharge season. Increased winter rainfall—as projected under most scenarios for mid latitudes—generally is likely to result in increased groundwater recharge. However, higher evaporation may mean that soil deficits persist for longer and commence earlier, offsetting an increase in total effective rainfall.

Various types of aquifer will be recharged differently. The main types are: Unconfined and Confined aquifers

An unconfined aquifer is recharged directly by local rainfall, rivers, and lakes, and the rate of recharge will be influenced by the permeability of overlying rocks and soils. Evaporation, changes of rainfall amount, and structured soils are the factors for the reduction of groundwater recharge.

Shallow unconfined aquifers along floodplains, which are most common in semi-arid and arid environments, are recharged by seasonal streamflows and can be depleted directly by evaporation. Changes in recharge therefore will be determined by changes in the duration of flow of these streams—which may locally increase or decrease—and the permeability of the overlying beds, but increased evaporative demands would tend to lead to lower groundwater storage.

It should be noted from the above discussion that unconfined aquifers are sensitive to local climate change, and abstraction. However, quantification of recharge is complicated by the characteristics of the aquifers themselves as well as overlying rocks and soils.

A confined aquifer, on the other hand, is characterized by an overlying bed that is impermeable, and local rainfall does not influence the aquifer. It is normally recharged from lakes, rivers, and rainfall that may occur at distances ranging from a few kilometres to thousands of kilometres. Recharge rates also vary from a few days to decades. Deep aquifers may not be seriously affected by seasonal or interannual rainfall or temperature of the local area. Attempts have been made to calculate the rate of recharge by using carbon-14 isotopes and other modeling techniques. This has been possible for aquifers that are recharged from short distances and after short durations. However, recharge that takes place from long distances and after decades or centuries has been problematic to calculate with accuracy, making estimation of the impacts of climate change difficult. The medium through which recharge takes place often is poorly known and very heterogeneous, again challenging recharge modeling. In general, there is a need to intensify research on modeling techniques, aquifer characteristics, recharge rates, and seawater intrusion, as well as monitoring of groundwater abstractions.

V. River Flows

By far the greatest numbers of hydrological studies into the effects of climate change have concentrated on potential changes on stream flow and runoff. The distinction between “stream flow” and “runoff” can be vague, but in general terms stream flow is water within a river channel, usually expressed as a rate of flow past a point—typically in m$^3$ s$^{-1}$—whereas runoff is the amount of precipitation that does not evaporate, usually expressed as an equivalent depth of water across the area of the catchment. A simple link between the two is that runoff can be regarded as stream flow divided by catchment area, although in dry areas this does not necessarily hold because runoff generated in one part of the catchment may infiltrate before reaching a channel and becoming stream flow.
Over short durations, the amount of water leaving a catchment outlet usually is expressed as stream flow; over durations of a month or more, it usually is expressed as runoff. This section first considers recent trends in stream flow/runoff and then summarizes research into the potential effects of future climate change.

a) Trends in Observed Stream Flow
There have been many notable hydrological events—including floods and drought-sand. There are different studies which show possible trends in hydrological data. Table 2-1 summarizes some of these studies and their main results.

b) Effects of Climate Change on River Flows
By far the majority of studies into the effects of climate change on river flows have used GCMs to define changes in climate that are applied to observed climate input data to create perturbed data series. These perturbed data are then fed through a hydrological model and the resulting changes in river flows assessed. Since the Second Assessment Report (SAR) (Arnell et al., 1996; Kaczmarek, 1996), there have been several global-scale assessments and a large number of catchment-scale studies. Confidence in these results is largely a function of confidence in climate change scenarios at the catchment scale; although Boorman and Sefton (1997) show that the use of a physically unrealistic hydrological model could lead to misleading results.
Table 2-1: Recent studies into trends in river flows (McCarthy, 2001)

<table>
<thead>
<tr>
<th>Study Area</th>
<th>Data Set</th>
<th>Key Conclusions</th>
<th>Reference(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Global</strong></td>
<td></td>
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<tr>
<td></td>
<td>161 gauges in 108 major world</td>
<td>Reducing trend in Sahel region but weak</td>
<td>Yoshino (1999)</td>
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<td></td>
<td>rivers, data to 1990</td>
<td>increasing trend in western Europe and North America, increasing relative</td>
<td></td>
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<td></td>
<td></td>
<td>variability from year to year in several and semi-arid regions</td>
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<td><strong>Russia</strong></td>
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<td></td>
<td>80 major basins, records from</td>
<td>Increase in winter, summer, and autumn runoff</td>
<td>Georgievsky et al. (1995, 1996, 1997), Shiklomanov</td>
</tr>
<tr>
<td></td>
<td>60 to 110 years</td>
<td>since mid-1970s, decrease in spring flows</td>
<td>and Georgievsky (2001)</td>
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<tr>
<td></td>
<td>196 small basins, records up to</td>
<td>Increase in winter, summer, and autumn runoff</td>
<td>Georgievsky et al. (1996)</td>
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<td></td>
<td>60 years</td>
<td>since mid-1970s, decrease in spring flows</td>
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<td><strong>Baltic Region</strong></td>
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<td></td>
<td>Scandanavia</td>
<td>Increase in winter, summer and autumn runoff</td>
<td>Bergstrom and Carlson (1993)</td>
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<td></td>
<td>Baltic states</td>
<td>Increase in winter, summer and autumn runoff</td>
<td>Turend (1998)</td>
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<tr>
<td><strong>Cold Regions</strong></td>
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<td></td>
<td>Yemen, Saudi</td>
<td>Little change in runoff or timing</td>
<td>Shiklomanov (1994)</td>
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<tr>
<td></td>
<td>Mackenzie, Canada</td>
<td>Little change in runoff or timing</td>
<td>Shiklomanov et al. (2000)</td>
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<td><strong>North America</strong></td>
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<tr>
<td></td>
<td>United States</td>
<td>26 catchments with significant trends: half increasing and half decreasing</td>
<td>Lins and Slack (1999)</td>
</tr>
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<td></td>
<td>California</td>
<td>Increasing concentration of streamflow in winter as a result of reduction in</td>
<td>Dettinger and Cayan (1995), Gleick and Chladek</td>
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<tr>
<td></td>
<td>Mississippi basin</td>
<td>Large and significant increases in flood magnitudes at many gauges</td>
<td>Olsen et al. (1999)</td>
</tr>
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<td></td>
<td>West-central Canada</td>
<td>Snowmelt peaks earlier, decreasing runoff in south of region, increase in</td>
<td>Westmacott and Bum (1997)</td>
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<td></td>
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<td></td>
<td>Colombia</td>
<td>Decrease since 1970s</td>
<td>Marengo (1995)</td>
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<tr>
<td></td>
<td>NW South America</td>
<td>Increase since 1970s</td>
<td>Marengo et al. (1998)</td>
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<td></td>
<td>Andes</td>
<td>Increase since 1960s</td>
<td>Genta et al. (1998)</td>
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<td></td>
<td></td>
<td>Increase north of 40°S, decrease to the south</td>
<td>Waylen et al. (2000)</td>
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<td><strong>Europe</strong></td>
<td></td>
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<tr>
<td></td>
<td>UK</td>
<td>No clear statistical trend</td>
<td>Robson et al. (1998)</td>
</tr>
<tr>
<td><strong>Africa</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sahelian region</td>
<td>Decrease since 1970s</td>
<td>Survolon (1990)</td>
</tr>
<tr>
<td><strong>Arabia</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Xiang region, China</td>
<td>Spring runoff increase since 1980 from glacier melt</td>
<td>Ye et al. (1999)</td>
</tr>
<tr>
<td><strong>Australia</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Australia</td>
<td>Decrease since mid-1970s</td>
<td>Thomas and Bates (1997)</td>
</tr>
</tbody>
</table>
2.3 River functions

2.3.1 River basins and catchments

Many factors, including physical, climatic, chemical and biological conditions, determine how a river functions. Understanding a river system involves understanding the complex interactions of these factors.

A river basin serves as the most appropriate unit for maintaining the health of its functioning and the conservation of freshwater systems. The reason is that: the quality of freshwater resources at any given location is a function of all upstream and upland activities, and sometimes downstream activities as well.

In addition, dynamic hydrological-ecological processes, such as flood events, occur over areas defined by catchments. Many of the threats to freshwater systems are the result of *land use practices* that occur within the catchment. Protection of natural communities or processes, therefore, must take into account these important catchment boundaries.

A river basin in the context of IRBM is comprised of one single catchment or of multiple “major” catchments, meaning those catchments defined by the largest rivers of a region. The world’s largest rivers are twelfth-order and greater.” Examples of major rivers are the Amazon, Congo, Mississippi, Nile and Yangtze.

River basins are open systems with sometimes ill-defined boundaries. Rivers may have a shared delta, watershed limits in flatland areas are either vague or man-made (and alterable), and watershed limits often do not correspond exactly with aquifer limits. Moreover, river basins interact continuously with the atmosphere (precipitation and evaporation, airborne pollution) and the receiving waters (seas and sometimes lakes). Furthermore, the uses made of river basins often excel river basin boundaries (e.g. inter-basin water transfers).

2.3.2 Stream corridors

Most stream corridors contain three main components (Fig. 2-4):

**The stream channel:** contains flowing water for at least a portion of the year.

**The floodplain:** the floodplain, the land adjacent to stream channel, receives floodwaters and concomitant sediment when the stream channel overflows. The nature and size of floodplain vary both along river systems and between river systems. Depending on the surrounding topography, the floodplain may include land on one or both sides of the channel, and the area may vary considerably along a river. and

**The transitional upland fringe:** the upland area on one or both sides of the floodplain that delineates the floodplain from the surrounding landscape.
2.3.3 Stream Channel

Flowing water and the sediment it carries form, maintain and modify the stream channel. Although the form of a stream channels can vary greatly, from meandering gentle streams to fast flowing rivers, it tends to take on a rounded u-shape. When scientists study a stream cross-section, they invariably examine two key attributes of the stream flow system - and channel size. Stream flow is the volume and velocity of water entering the channel.

Fig. 2-4: The Major Cross-Sectional Components of the Stream Corridor
(http://www.epa.gov/watertrain)

Precipitation takes after falling to the earth affect the quantity, quality and timing of the stream flow. The two basic flow pathways are storm flow and base flow. Storm flow is precipitation that reaches the channel very soon after precipitation via overland or underground routes. Base flow is precipitation that percolates to the ground water and moves slowly through the substrate before reaching the channel. Base flow provides stream flow during periods of little or no precipitation. The measure of stream flow used by those studying river systems is known as the discharge rate. Discharge rates depend both on the average velocity at which the water is moving downstream and the size of the channel through which the water is flowing.

Channel size is determined by stream flow and sediment load. Sediment load refers both to the amount of sediment the stream is transporting and depositing and to its characteristics. A stream balance equation formally describes the dynamic relationship between channel size and sediment load and stream flow see Fig.2-5. This equation states that the channel is in equilibrium when the sediment load is balanced with stream flow. If changes in either sediment load or stream flow occur, the balance will be lost temporarily. These changes will modify the channel over time, by either building up or scouring the riverbed, to bring the system back into equilibrium. The stream balance equation is useful for conceptualizing the potential impacts on a channel resulting from changes in runoff or sediment loads from the watershed.
Channel equilibrium (Fig. 2-5) involves the interplay of four basic factors:

- Sediment discharge (Q_s)
- Sediment particle size (D_{50})
- Stream-flow (Q_w)
- Stream slope (S)

Lane (1955) showed this relationship qualitatively as:

\[ Q_s \cdot D_{50} \propto Q_w \cdot S \]

Stream managers categorize streams based on the balance and timing of the storm flow and base flow components. There are three main categories:

- Ephemeral streams flow only during or immediately after periods of precipitation. They generally flow less than 30 days per year.
- Intermittent streams flow only during certain times of the year. Seasonal flow in an intermittent stream usually lasts longer than 30 days per year.
- Perennial streams flow continuously during both wet and dry times. Base flow is dependably generated from the movement of ground water into the channel.

Discharge Regime

Discharge is the term used to describe the volume of water moving down the channel per unit time. Discharge is calculated as:

\[ Q = AV \]

where Q = Discharge
A = Area through which the water is flowing and
V = Average velocity in the downstream direction.

Streamflow is one of the variables that determine the size and shape of the channel.

There are three types of characteristic discharge.
Channel-forming (or dominant) discharge. To envision the concept of channel-forming discharge, imagine placing a water hose discharging at constant rate in a freshly tilled garden. Eventually, a small channel will form and reach equilibrium geometry. At a larger scale, consider a newly constructed floodwater-retarding reservoir that slowly releases stored floodwater at a constant flow rate. This flow becomes the new channel forming discharge and will alter channel morphology until the channel reaches equilibrium. An estimate of channel-forming discharge for a particular stream reach can, with some qualifications, be related to depth, width, and shape of channel. Although channel forming discharges are strictly applicable only to channels in equilibrium, the concept can be used to select appropriate channel geometry for restoring a disturbed reach. However, there is no method for directly calculating channel forming discharge.

Effective discharge. The effective discharge is the calculated measure of channel forming discharge. Computation of effective discharge requires long-term water and sediment measurements, either for the stream in question or for one very similar. Since this type of data is often not available for stream restoration sites, modeled or computed data are sometimes substituted. Effective discharge can be computed for either stable or evolving channels.

Bankfull discharge. This discharge occurs when water just begins to leave the channel and spread onto the floodplain. Bankfull discharge is equivalent to channel-forming (conceptual) and effective (calculated) discharge for alluvial streams at equilibrium.

2.3.4 Structural Changes in the Stream Corridor

The physical structure of the channel and floodplain changes as a river travels from its headwaters to its outlet. Channel width and depth increase downstream as the drainage area and discharge increase. A simplified longitudinal model captures these observed changes by disaggregating the river into three zones (Fig. 2-6):

- **Headwaters zone**: generally has the steepest slope. As the water moves over these slopes, sediment erodes and is carried downstream.
- **Transfer zone**: receives sediment from upstream, the gradient decreases. The river widens as smaller streams merge and
- **Depositional zone**: the gradient flattens from a build-up of sediment over time. The river widens further and meanders toward its mouth.

These same three zones are also evident on a much smaller scale within the watersheds of contributing streams. The size and structure of watersheds vary significantly due to geologic, morphologic, vegetative, soil and climatic differences. Differences in topographic and geologic structure also influence watershed drainage patterns.
2.3.5 Stream Order Models

As water moves along pathways of least resistance in the watershed, it forms streams that join larger and yet larger streams. The resulting river is branched like a tree; the particular form of the branching depends on the watershed through which the water flows. A method of classifying the hierarchy of natural channels according to their position in the drainage system, referred to as stream order, permits comparison of the behaviour of a river with others similarly situated. It is useful for developing and testing generalizations and predictions about river processes. Several modifications exist of the original stream-order system developed by Horton in 1945. In the most commonly cited and used system (Strahler, 1957), small headwater streams are designated Order I. Streams formed by the confluence of two Order I streams are referred to as Order II, and so on, with larger numbers indicating larger rivers with multiple tributary streams (Fig.2-7). Stream order is used primarily by hydrologists to construct models of stream flow. Stream order correlates generally with gradient, drainage area, channel width, and discharge; but because of multiple intervening factors, the statistical variance of the correlations is large.
2.3.6 Longitudinal Changes in Stream Ecosystems

Beyond structural changes in the stream channel, there are observable changes in stream ecosystems from the headwaters to the mouth. The characteristics of biological communities vary in different reaches of a river system. Observation of abrupt changes in species associated with changes in stream size, channel width, gradient, stream flow and temperature supports the concept of stream zones, as described above. The best known longitudinal model for rivers, the River Continuum Concept (RCC), attempts to generalize and explain observed longitudinal changes in stream ecosystems (Fig.2-8). It proposes that rivers exhibit continuous longitudinal changes and identifies the relationships between the progressive changes in stream structure, such as channel size and stream flow, and the distribution of species (Table 2-2). According to the RCC, characteristics of particular reaches are associated not only with discrete factors such as water temperature, but with their positions along the length of the river. The model is especially useful at the basin and stream scale, because it accounts for observed longitudinal shifts in biotic communities.
The RCC as originally defined was most successful in describing rivers that emerge in forested mountains and descend into regulated channels on the floodplain. Since its initial development, the RCC has been expanded to include several alternative models. Rivers that regularly overtop their banks and inundate the floodplain have been characterized by a ‘Flood Pulse’ model that describes habitat characteristics and biotic communities along a temporal continuum. A temporal dimension is embedded in the RCC because the main features of a time-based river model (e.g., duration of inundation) vary longitudinally in a predictable fashion.

The River Continuum Concept applies only to perennial streams is a limitation. Another limitation is that disturbances and their impacts on the river continuum are not addressed by the model. Disturbances can disrupt the connections between the watershed and its streams and the river continuum as well.

Table 2-2: Commonly observed changes associated with river consortium concept (Source:http://www.pubs.asce.org)

<table>
<thead>
<tr>
<th>Simplified RCC</th>
<th>Upper reaches</th>
<th>Middle Reaches</th>
<th>Lower Reaches</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stream order</td>
<td>1-3</td>
<td>3-6</td>
<td>6 and above</td>
</tr>
<tr>
<td>Substrate</td>
<td>coarse</td>
<td>Sand, gravel</td>
<td>fine</td>
</tr>
<tr>
<td>Current</td>
<td>fast</td>
<td>slow</td>
<td></td>
</tr>
<tr>
<td>Oxygen</td>
<td>saturated</td>
<td></td>
<td>Periodic deficits</td>
</tr>
</tbody>
</table>
An alternative model adopted by some ecologists is referred to as “patch dynamics”. According to this model, stream habitat and species distribution exhibit patchiness. The patch dynamics concept reflects relatively short-term observations on a stream-reach scale at which the nature and distribution of biotic communities appear unpredictable. It is complementary with the RCC because most running waters that show local patch effects will exhibit predictable longitudinal patterns over larger scales and longer time periods (Brezonik, 1996).

2.3.7 Key Stream Processes and Other Important System Characteristics

The observed structure in a particular stream corridor is a result of hydrologic, geomorphic and physical and chemical processes operating within the river corridor as well as the influence of biological functions and overall system equilibrium. This section examines how these processes and characteristics influence the structure of the stream corridor.

### Geomorphic Process

Geomorphology is the study of the earth’s surface forms and the processes and mechanisms that create these forms (Mary and Susanna, 1999).

The hydrologic processes that characterize flowing water provide the mechanisms for the geomorphic processes discussed in this section. The three fundamental geomorphic processes associated with flowing water are erosion, sediment transport and sediment deposition.

As water flows along pathways in its watershed, it shapes the terrain through erosion, transport and deposition of sediments. Climate, topography, geology and land use influence the amount of sediment flowing through the watershed. Intense precipitation, steep slopes, easily erodible rock and soil, and land clearing all tend to increase sediment yields. In Minnesota, flowing water carries off more than 60 million tons of upland topsoil each year (Tester, 1995). Stream transported sediment is classified either as suspended load or bed load. Suspended load consists of small particles such as clays, silts,
and fine sands that are easily carried suspended in the flowing water. Bed load consists of large particles such as coarse sands, gravels and boulders that move by rolling, sliding, or hopping along the bed. River bed materials, referred to as the substrate, tend to vary downstream according to how easily the particles are transported (Fig. 2-9). Beds of headwater streams usually contain large particles such as gravel and boulders that are too heavy for the stream to move. Downstream, the size of particles decreases, as large rocks are broken and worn down, and smaller particles such as finer sands and silts are sorted out, carried off and eventually deposited in the river’s delta. Natural and artificial obstructions in a stream cause localized changes in the stream’s ability to transport particles.

**Braided Channels** - In streams having highly variable discharge and easily eroded banks, sediment gets deposited to form bars and islands that are exposed during periods of low discharge. In such a stream the water flows in a braided pattern around the islands and bars, dividing and reuniting as it flows downstream. Such a channel is termed a braided channel. During periods of high discharge, the entire stream channel may contain water with the islands covered to become submerged bars. During such high discharge, some of the islands could erode, but the sediment would be re-deposited as the discharge decreases, forming new islands or submerged bars. Islands may become resistant to erosion if they become inhabited by vegetation. (See Fig. 2-10a)

**Straight Channels** - Straight stream channels are rare. Where they do occur, the channel is usually controlled by a linear zone of weakness in the underlying rock, like a fault or joint system. Even in straight channel segments water flows in a sinuous fashion, with the deepest part of the channel changing from near one bank to near the other. Velocity is highest in the zone overlying the deepest part of the stream. In these areas, sediment is transported readily resulting in pools. Where the velocity of the stream is low, sediment is deposited to form bars. The bank closest to the zone of highest velocity is usually eroded and results in a cut bank. (See Fig. 2-10b)

**Meandering Channels** - Because of the velocity structure of a stream, and especially in streams flowing over low gradients with easily eroded banks, straight channels will eventually erode into meandering channels. Erosion will take place on the outer parts of the meander bends where the velocity of the stream is highest. Sediment deposition will occur along the inner meander bends where the velocity is low. Such deposition of sediment results in exposed bars, called point bars. Because meandering streams are continually eroding on the outer meander bends and depositing sediment along the inner meander bends, meandering stream channels tend to migrate back and forth across

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Fig. 2-9: Sediment Transport. (Mary and Susanna, 1999)
their flood plain. If erosion on the outside meander bends continues to take place, eventually a meander bend can become cut off from the rest of the stream. When this occurs, the cut-off meander bends, because it is still a depression, will collect water and form a type of lake called an oxbow lake. (See Fig. 2-10c)

![Image of channel plan forms](image)

(a) (b) (c)

Fig. 2-10: Types of channel plan forms (Daniel P. Loucks and Eelco van Beek, 2005)

The amount of sediment a river can transport depends on stream energy or power. Stream energy is a function of the velocity of its flow, the gradient of the channel and the channel depth. Other factors such as surface roughness also influence sediment transport. When stream energy is just sufficient to transport the sediment supplied to the river, the river is said to be in equilibrium, or graded. If an imbalance exists between the amount of sediment supplied to the river and stream’s power to transport the sediment, the channel characteristics will change over time to bring the river system into equilibrium. When sediment supplied exceeds stream carrying capacity, sediment deposition builds up (or aggrades) the stream bed, increasing its slope downstream and thereby increasing stream power. In contrast, when a river can carry more sediment than it receives, ‘excess’ stream energy scour (or degrades) the channel, decreasing downstream slope and stream energy. For better understanding of the relationship between flow rate, sediment particle size, erosion and transportation. (See Fig. 2-11 below)
Physical and Chemical Processes
The physical characteristics and chemistry of water change as water comes in contact with air, soil, rocks, bacteria, vegetation and biological communities. This section provides a brief description of the physical materials and chemical processes influencing stream water quality. As water moves along pathways in a watershed, eroded soil and plant materials enter the flowing water. Addition of these materials, in conjunction with chemical and biological processes operating within the river, influences the physical and chemical properties of the flowing water. External materials entering the river include eroded soils, salts carried by rain or leached from rock and soil, and leaves and woody material washed or dropped into the stream. Internal (or autochthonous) processes operating within the river include physical breakdown of rocks and plant materials, microbial decomposition of organic matter, cycling of carbon and dissolved nutrients in the presence of sunlight by plants and animals, and chemical transformations of inorganic ions under changing conditions of temperature, pH, and oxygen concentration.

The chemical constituents resulting from these external and internal processes may be suspended or dissolved in the stream water. Suspended particles are classified either as sediment or colloids, depending upon their size. Suspended particles measuring 0.1 mm or greater in diameter are considered coarse sediment and they will settle rapidly out of still water. Smaller suspended particles include silts, clays, and organic particles (sometimes called organic detritus) derived from plants and animal activity. Bacteria and suspended algae (phytoplankton) also are in this size range. Clay-sized particles (< 63 micro m) settle very slowly, even in still water, unless they become coagulated into larger particles. Colloidal particles are smaller than about 0.5 micro m in diameter. Although colloids
are too small to be seen with the naked eye, they provide surfaces for absorption of dissolved chemicals and affect water color and clarity (turbidity). Dissolved constituents include organic compounds, gases, and inorganic ions (salts) such as calcium, magnesium, and sodium. Some inorganic chemicals, such as phosphorus, are common in all natural stream waters and are beneficial and even necessary for life. For example, phosphorus is an essential nutrient for plant life. These solutes are considered pollutants only when their levels are elevated to the point where they threaten the health of the ecosystem. Elevated concentrations of trace constituents are usually linked to anthropogenic factors, such as industrial discharges or runoff carrying agricultural fertilizers.

Stream water chemistry can vary both daily and seasonally. Much of this variability results from changes in the proportions of storm flow and base flow, which often have very different chemical properties. Water chemistry also is affected by changes in the amount of flow. While periods of high flows decrease the concentration of some point source pollutants through dilution, they also may increase non-point source pollutants, such as those from atmospheric deposition, that accompany higher runoff.

Biological Community
The morpho-metric and physical properties of a stream determine the availability of suitable habitat for biota. The unidirectional flow of water is one of the most important factors controlling survival in rivers. River-adapted organisms must have strategies to protect themselves from being flushed downstream. Other factors that determine the suitability of habitat are flow regime, water quality, temperature, sunlight, oxygen, food, and protection from predators.

The organisms in an ecosystem are interconnected to form a food web. The food relationships commonly observed among stream biota are shown in Fig. 2-12. In rivers, the primary producers that compose the base of the food web include aquatic plants (macrophytes) and algae. Some types of algae, known as periphyton, attach to surfaces in the stream channel, whereas others, known as phytoplankton, are suspended in the water. Primary producers use energy from sunlight to turn dissolved inorganic nutrients (nitrogen, phosphorus, carbon) into organic matter through photosynthesis. Organisms that feed on this plant tissue convert it to animal tissue, waste and energy. Decomposition of organic materials occurs as other organisms break down dead plant and animal tissue and wastes.
The relationship between the rate of primary production and the rate of decomposition influences the availability of habitat for stream biota. If primary production exceeds decomposition, the stream reach is described as autotrophic. If decomposition exceeds primary production, as occurs in most streams, the stream reach is described as heterotrophic. Most of the organic matter for the food web in heterotrophic stream reaches comes from external sources, such as the leaves of riparian trees and soil organic matter.

Primary producers that anchor themselves to the bottom substrate, such as large aquatic plants and attached algae, are more abundant in stream reaches where sunlight is unobstructed by riparian shade or suspended sediment. These producers tend to thrive in mid-reaches with substrates composed of coarser materials, ranging from sands to gravel. Other primary producers, such as phytoplankton, remain suspended in water and prefer slow-moving flow conditions found near stream banks, behind obstructions, and in the backwaters of lowland rivers.

Organisms that feed directly on non-living coarse particulate organic matter (detritus) include bacteria, fungi, and some invertebrates known as shredders. These organisms proliferate in forested headwater streams, where detritus is plentiful and where the substrate allows for attachment. Other organisms, such as scrapers and grazers, feed directly on primary producers and thrive where the plants they feed on are most abundant. Both shredders and scrapers produce fine particulate organic material, bits of shredded and partly decomposed detritus and wastes. Invertebrates that feed on fine particulate organic material (collectors) flourish in lowland reaches where they collect food supplied...
by upstream activities. Fish and other vertebrate predators feed on collectors, shredders and other invertebrate predators.

Fish species have adapted to different stream habitats over time by modifying their forms, habits, and reproductive strategies. For example, the small agile bodies of fish in high-gradient upland streams allow them to accelerate quickly and move through the swift and rolling flow of these streams. In response to seasonal variability of water levels, from periods of flood to periods of low or no flow, some species mature rapidly and have short life spans. They usually require higher oxygen content and lower temperatures (<20°C) than downstream species. Low gradient floodplain rivers provide a greater variety of environments and therefore are populated by a wider variety of organisms. Fish in these rivers may be larger and are tolerant of wider ranges of temperature, higher temperatures, and lower oxygen concentrations.

For some fish, upland streams provide habitat for spawning and for young, while the lowland river is home to adults. In Floodplain Rivers where seasonal flood pulses provide a full range of flowing to still-water habitats, fish use shallow, seasonally flooded pools for reproduction and maturation.

### 2.3.8 Functions of the river system

Despite their open and sometimes ill-defined character, river basins are very important systems. They fulfill many important functions, such as water supply for households, industry and agriculture, navigation, fishing, recreation, and "living space". Economic and social development and even life itself cannot be sustained without sufficient water at the right time and place and of the right quality. Moreover, water has shaped and continues to shape the environment in which we live. It erodes mountain areas, transports sediment and creates delta areas. It can cause floods and is essential for nature.

Mankind uses water for a large range of activities: drinking and personal hygiene, fisheries, agriculture (irrigation and livestock supply), navigation, industrial production, cooling, hydropower generation, and recreational activities. It also serves as a metaphysic (religious) entity. Moreover, water is considered to be a most suitable medium to clean, disperse, transport, and dispose of wastes. Each of these user functions requires its own water quality criteria. Drinking water supplies exert the most sophisticated demands on water quality, while agricultural irrigation and industrial cooling generally require less in terms of water quality.

Although freshwater ecosystems occupy less than one per cent of the world’s surface, they make some of the largest contributions of all ecosystems to human welfare. People have long recognized the provisioning services of rivers for water, food and energy and the desire to maximize the benefits from rivers for irrigation, water supply and energy has led to a utilitarian approach to water resources management throughout the world. Joseph Stalin famously said that “water which is allowed to enter the sea is wasted”, and such views were still echoed in the 1980s even by the World Bank (Bocking, 1998). Today these views are rarely printed, but are still heard from some water developers in international fora. But recognition of other, equally important, services has grown. Regulating services of freshwater systems include water purification, flood mitigation and sediment deposition and cultural services vary from recreational opportunities to aesthetic and spiritual values.
Underlying these services are the supporting functions of freshwater ecosystems, playing a role in nutrient cycling, primary production and providing habitats and maintaining biodiversity (Table 2-3). Many provisioning services are provided by both free flowing and fragmented rivers. For large scale uses of freshwater, such as irrigation and water supply, construction of water infrastructure, such as dams, canals etc, is a necessity. However, the benefits gained by water infrastructure are often at an environmental cost, the extent of which is difficult to quantify and subsequently difficult to take into account.

In this section we examine the ecological importance of free-flowing rivers, as well as the specific contributions made by free-flowing rivers to human society. The analysis follows the framework for ecosystem services, Table 2-4, as set out by the Millennium Ecosystem Assessment (2005).

Table 2-3: Ecosystem services provided by rivers
(Source:http://assets.panda.org/downloads/freeflowingriversreport.pdf)

<table>
<thead>
<tr>
<th>Provisioning Services</th>
<th>Regulating Services</th>
<th>Cultural Services</th>
<th>Supporting Services</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food</td>
<td>Food</td>
<td>Spiritual &amp; religious</td>
<td>Soil formation</td>
</tr>
<tr>
<td>Fresh water</td>
<td>Fresh water</td>
<td>Recreation &amp; ecotour.</td>
<td>Nutrient cycling</td>
</tr>
<tr>
<td>Energy</td>
<td>Energy</td>
<td>Aesthetic</td>
<td>Primary Production</td>
</tr>
<tr>
<td>Fibre</td>
<td>Fibre</td>
<td>Educational</td>
<td>Habitat/ biodiversity</td>
</tr>
<tr>
<td>Bio-chemicals</td>
<td>Bio-chemicals</td>
<td>Sense of place</td>
<td></td>
</tr>
<tr>
<td>Genetic resources</td>
<td>Genetic resources</td>
<td>Cultural heritage</td>
<td></td>
</tr>
</tbody>
</table>

Table 2-4: Ecological functions of different river flow levels (Postel & Richter, 2003)

<table>
<thead>
<tr>
<th>Low (base) flows</th>
<th>Normal level:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Provide adequate habitat space for aquatic organisms</td>
</tr>
<tr>
<td></td>
<td>Maintain suitable water temperatures, dissolved oxygen, and water chemistry</td>
</tr>
<tr>
<td></td>
<td>Maintain water table levels in the floodplain and soil moisture for plants</td>
</tr>
<tr>
<td></td>
<td>Provide drinking water for terrestrial animals</td>
</tr>
<tr>
<td></td>
<td>Keep fish and amphibian eggs suspended</td>
</tr>
<tr>
<td></td>
<td>Enable fish to move to feeding and spawning areas</td>
</tr>
<tr>
<td></td>
<td>Support hyporheic organisms (those living in saturated sediments)</td>
</tr>
<tr>
<td></td>
<td>Drought level:</td>
</tr>
<tr>
<td></td>
<td>Enable recruitment of certain floodplain plants</td>
</tr>
<tr>
<td></td>
<td>Purge invasive introduced species from aquatic and riparian communities</td>
</tr>
<tr>
<td></td>
<td>Concentrate prey into limited areas to benefit predators</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>High pulse flows</th>
<th>Shape physical character of river channel, including pools and riffles</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Determine size of stream bed substrates (sand, gravel, and cobble)</td>
</tr>
<tr>
<td></td>
<td>Prevent riparian vegetation from encroaching into channel</td>
</tr>
<tr>
<td></td>
<td>Restore normal water quality conditions after prolonged low flows, flushing away waste products and pollutants</td>
</tr>
<tr>
<td></td>
<td>Aerate eggs in spawning gravels and prevent siltation</td>
</tr>
<tr>
<td></td>
<td>Maintain suitable salinity conditions in estuaries</td>
</tr>
<tr>
<td>Large floods</td>
<td>Provide migration and spawning cues for fish</td>
</tr>
<tr>
<td>Trigger new phase in life cycle (e.g., in insects)</td>
<td></td>
</tr>
<tr>
<td>Enable fish to spawn on floodplain, provide nursery area for juvenile fish</td>
<td></td>
</tr>
<tr>
<td>Provide new feeding opportunities for fish and waterfowl</td>
<td></td>
</tr>
<tr>
<td>Recharge floodplain water table</td>
<td></td>
</tr>
<tr>
<td>Maintain diversity in floodplain forest types through prolonged inundation (different plant species have different tolerances)</td>
<td></td>
</tr>
<tr>
<td>Control distribution and abundance of plants on floodplain</td>
<td></td>
</tr>
<tr>
<td>Deposit nutrients on floodplain</td>
<td></td>
</tr>
<tr>
<td>Maintain balance of species in aquatic and riparian communities</td>
<td></td>
</tr>
<tr>
<td>Create sites for recruitment of colonizing plants</td>
<td></td>
</tr>
<tr>
<td>Shape physical habitats of floodplain</td>
<td></td>
</tr>
<tr>
<td>Deposit gravel and cobbles in spawning areas</td>
<td></td>
</tr>
<tr>
<td>Flush organic materials (food) and woody debris (habitat structures) into channel</td>
<td></td>
</tr>
<tr>
<td>Purge invasive introduced species from aquatic and riparian communities</td>
<td></td>
</tr>
<tr>
<td>Disburse seeds and fruits of riparian plants</td>
<td></td>
</tr>
<tr>
<td>Drive lateral movement of river channel, forming new habitats (secondary channels and oxbow lakes)</td>
<td></td>
</tr>
<tr>
<td>Provide plant seedlings with prolonged access to soil moisture</td>
<td></td>
</tr>
</tbody>
</table>

Despite the important provisioning, regulating, supporting and cultural services provided by free-flowing rivers, in many places they are still seen as a threat, particularly in terms of flooding. Flooding from rivers has taken a large toll of human life over time, as well as caused large economic losses. Floods are often caused by a combination of several factors, frequently including heavy rainfall which causes rivers to overflow. Floods generally develop over a period of days, when there is too much rainwater for rivers to hold and water spreads over the adjoining floodplain. However, they can happen very quickly when a lot of heavy rain falls over a short period of time. These ‘flash floods’ occur with little or no warning and cause more loss of human life than any other type of flooding.

It is thus not surprising that throughout history people have sought to tame and control rivers by constructing dykes, diversions and dams.

Few cities on rivers have anything resembling natural river banks and walls line most rivers. As flood defences are developed, population pressures have resulted in increased inhabitation of former floodplains, increasing the risks of losses, both in terms of life and economic loss, in the case of extreme weather events. Whilst floods present a real threat, ‘taming the river’ by constructing reservoirs and dykes is not necessarily the best solution, and by providing a sense of security that may be partially false, can actually exacerbate the problems. In the case of multi-purpose reservoirs there is also a conflict of interest between electricity production and flood prevention. To optimize hydropower output, reservoirs need to be filled as much as possible, whilst for flood prevention reservoirs need to have a large capacity to capture extra water.
2.4 Human interventions and impacts

2.4.1 Man’s attitude towards nature and development

Human action has influenced to a very large extent the present state of the environment. The driving force that led to these actions is simply that humans needed to survive and feed, clothe and house themselves. About the way in which they interfered in their environment, however, it is important to realize what their attitude towards the environment was.

In genesis it is clearly stated that the world, the plants and the animals were created for man to benefit from it. The conviction in European tradition is very strong, both in classical (Celtic, Roman, Greek) and Christian traditions, that human beings have been put in a position of dominance over nature. Over time, although the culture has changed, this conviction has remained, until recently (the last few years), when the “green movement” started to convince us that man is as much part of nature as animals, plants and natural resources. However, the state of deterioration of the environment that we witness in many parts of the world is the consequence of the philosophy that man dominates over nature and has to fight nature to survive (Ponting, 1991). Not in all cultures is this conviction as clearly present. Buddhism, for example, considers man as part of nature, and so do several other eastern religions. Also several natural religions look upon man as part of nature.

In classical times (Roman, Greek and Celtic) one was convinced of the fact that in earlier times things had been better: the Gods were living on earth (the gold age) and that the society had been decaying through silver to the age of iron in which they lived. It is only after the Enlightenment and the Age of Reason in the 18th century and after the success of physical science and technology (which triggered the industrial revolution), that people started thinking of progress and economic growth as a necessity for survival and even as an economic law. The concept of market economy is very much related to economic growth. And although there are many countries in the world that have recently accepted the market economy as the principle for their future development (Eastern European countries, China, Vietnam, Mozambique, and many others) there is a fundamental flaw in it. The major problem is that it ignores the fact that resources are finite and that the consumption of finite resources is not sustainable. In economic growth scenarios, investments result in more production, production results in more money, more money results in more investments, more money, more production etc. Besides depreciation of money, this “Spiral of Money and Production” leads to exploitation of resources and unsustainable growth.

In classical economic thought, resources do not have a price. The only price they have is the price of extracting them and bringing them to the market. The crucial defect is that the earth’s resources are treated as capital. But since resources are finite, they have a price: the price of withholding them from future generations. This aspect is recognised in Environmental Economics and in more modern economic theories. This classical economic thinking has led to a situation where the best way to get rich is by undertaking an environment-unfriendly business and exploitation of resources: trade in industrial and nuclear waste, drugs-trade, arms-trade, trade in rare species, large scale fisheries, etc. Whenever governments try to limit these actions, they tend to be overtaken by criminal organizations.

Water development by us, humans, affects the hydrological cycle. Fortunately, the hydrological cycle is quite resilient, and can withstand a certain degree of disturbance by human interference. However,
there is a point where our interference will disturb the hydrological cycle to such an extent that the processes of water generation will be significantly altered. This may result in more frequent droughts and floods, decreased base flows, loss of soil nutrients and less biomass production from rainfall. We have to acknowledge that we are part and parcel of the hydrological cycle and depend on it. We therefore have to limit and minimise negative impacts of our water development efforts. Table 2-5 shows how man can influences the hydrological cycle in several ways.

Table 2-5: The influence of man on water quality and quantity
(UNESCO-IHE Institute for Water Education IRBM online Module, 2011)

<table>
<thead>
<tr>
<th>Human Interference on:</th>
<th>Water quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water quantity</td>
<td></td>
</tr>
<tr>
<td>flood protection</td>
<td>organic matter and nutrients</td>
</tr>
<tr>
<td>irrigation</td>
<td>Sediments</td>
</tr>
<tr>
<td>drainage</td>
<td>chemical pollution</td>
</tr>
<tr>
<td>groundwater withdrawal</td>
<td>thermal pollution</td>
</tr>
<tr>
<td>water supply</td>
<td>organic matter and nutrients</td>
</tr>
<tr>
<td>sanitation</td>
<td></td>
</tr>
<tr>
<td>flow regulation</td>
<td></td>
</tr>
<tr>
<td>power generation</td>
<td></td>
</tr>
<tr>
<td>navigation</td>
<td></td>
</tr>
</tbody>
</table>

In the following paragraphs, some of the human interferences will be discussed briefly:

Flood Protection. In low-lying and deltaic areas, floods occur regularly both from the sea and the river. The following types of dikes can be distinguished:
- sea dikes
- inland dikes
- river dikes
- submersible dikes
- compartmental dikes
- no dikes

The high economic value of the land permits the enormous annual amounts of money spent on the maintenance and construction of flood protection infrastructure. At present the sea dikes have been designed for a flood with a probability of exceedence of once in 10,000 years (UNESCO-IHE Institute for Water Education IRBM online Module, 2011). The river dikes along the Rhine delta, which protect low lying areas that run the risk of 4-6 m depth of long-duration flooding, have been designed for a design flood of once in 1250 years. For the Maas River, where the damage in case of an inundation is less, the flooding depth is in the order of 1 m and the flooding duration is short, a design flood of once in 500 years is used.

In general the level of protection against flooding is high in The Netherlands. However, if we could have started an extra, with the knowledge we have now, we would probably have done a few things differently. The complete protection against river flooding has led to a gradual increase in the bed level of the rivers. The rivers, which used to spill their sediment on the land, deposited their load in
the riverbed. The subsiding land, on the other hand, was not replenished with sediment. This meant that the dikes became gradually higher. In addition, the drainage of large areas of land aggravated the land subsidence so that it is now far below sea level. Controlled flooding would probably have been a better alternative. In fact this development has only been possible, because the rivers Rhine and Maas are relatively gentle rivers, with a slow morphological time scale. If the Dutch rivers had been more vehement, the present flood protection system would probably not have existed (UNESCO-IHE Institute for Water Education IRBM online Module, 2011).

On the coast, The Netherlands is in the situation that the no-dike alternative is completely unrealistic. The natural situation where land is deposited at approximately mean high water has for many years been disturbed by the interference of man. But in more or less undisturbed deltas, it would be wise to consider maintaining the mangrove-protected coastline. Until recently, in The Netherlands, a situation existed where people did not believe that flooding would ever occur. This was a dangerous situation, because the risk of floods is ever present. Since the floods in the Rhine and Maas of 1995, however, there is again a general concern for the flooding risk. Moreover, the political will to prevent flooding disaster in the future is high. The latest development is that international cooperation on the integrated management of international rivers is receiving renewed attention. Hopefully, the riparian countries will come to better cooperation in the control and prevention of floods, through improved physical planning, coordinated land use and the implementation of flood alleviating and compensating measures.

Irrigation and Drainage

Human settlement is closely related to irrigation. A society which consists of more than 100 people requires intensive agriculture to feed those people in the society that do not produce food but which have other important tasks, such as: religious services, protection (military services), administration, manufacturing, trade, transport, etc. To feed a part of the population that does not produce requires intensive agriculture and in many cases irrigation. The total area of cultivation in the world is about 1500 million ha. Of this total, about 250 million ha are irrigated. Normally water is diverted from a river and transported by gravity, or with the aid of pumping stations to the fields. In many cases, irrigation water is needed in the dry season, when the river flow is also low. Hence, irrigation works are often accompanied by the construction of reservoirs, in which case, high costs are involved. It should be kept in mind that few of the larger irrigation projects in the world, which involve the construction of reservoirs, are able to pay back the costs in crop production. The return of the costs involved in dam construction is generally paid from hydropower, or from the national budget.

In general, irrigation should be accompanied by subsurface drainage to avoid water logging and salinization. This is clearly illustrated by the fall of the Sumerian empire (4500-2500 BC) in present day Iraq and Iran, which was caused by desertification as a result of salinization. In these areas, as in large parts of Pakistan and India, the threat of salinization due to irrigation, is as strongly present as ever.

In addition, if no appropriate measures are taken, the drainage water from irrigated areas may cause the river from which the irrigation water has been drawn, to be polluted with salt, pesticides, herbicides and fertilizers, rendering the water useless for downstream consumption.

Flow Regulation and Reservoir Construction
The main purpose of reservoirs is to attenuate irregularities of flow through the creation of storage. The reason why man wants to smooth out irregularities can be manifold:

− to supply water for irrigation in the dry season or during dry spells
− to guarantee a constant supply of water for urban or industrial water consumption
− to have a reliable source of hydropower
− to reduce flooding hazard by smoothing out flood peaks
− to create a reservoir for recreation and fisheries

These reservoirs interrupt the downriver flow of materials, affect the residence time of the river water and interfere with the migration of fish.

The five purposes mentioned require different types of operation. In the case of a reservoir for irrigation, the reservoir is filled as early as possible, to ensure that the reservoir is full at the start of the dry season. During the dry season, as much water as possible is used, while enough water is conserved to cater for a possible drought. Normally, by the end of the dry season, the reservoir will be empty except for an amount saved for the eventuality of a prolonged drought.

The water supply reservoir does not differ much from the reservoir for irrigation, except that the risk one is willing to take of running dry is smaller. This will lead to a more prudent use of water by the end of the wet season, if the rains are late. The operation for hydropower is completely different. In the case of hydropower it is generally more beneficial to maintain the reservoir as full as possible, the whole year through, in order to maintain head. A small amount of water in a full reservoir generates as much power as a large amount of water with little head.

However, if the main purpose of the reservoir is flood control, the operation is quite different again. The reservoir should be kept as empty as possible the whole year round, to allow storage of floodwater in order to release it at a moderate rate. In reservoirs with a recreational purpose, a more or less constant water level should be maintained. For ecological purposes, a minimum amount of water is required in the reservoir for the animals to remain healthy. In some cases environmentalists require flood releases to simulate floods in downstream ecosystems.

Sometimes the sediment load of the river is so high that sedimentation control requires a special way of operating the reservoir to prevent loss of storage. These operational constraints are particularly strong in the Blue Nile (Roseris dam).

It may be clear from the above, that reservoirs that serve more than one purpose, so called multipurpose reservoirs, are not easy to operate. Many different water users will demand a different way of operating the reservoir. Hence, the water manager, also in the simple case of a single reservoir, has to take a decision in a situation of conflicting interests, taking into account multi-objectives and multi-constraints.

Multi-purpose reservoirs are normally operated based on rule curves that result in the zoning of the reservoir storage. Each zone has a certain operating rule. These operating rules are derived through systems analysis (optimization) or simulation.
2.4.2 Engineered River Systems

Many engineered river systems have to fulfill a series of functions, such as water supply, hydropower, navigation cooling, etc., which are often to some extent conflicting. Engineered river systems are defined as “river systems in various stages of development via the presence of water control and river training works”. This is a contrary to natural river systems, in which hydrological, hydraulic, morphological and ecological processes interfere and occur autonomous and are not being disturbed by mankind.

For centuries engineering activities in river basins have focused on the development of water systems, mainly from a sectoral point of view. Due to the multiple uses and the increasing number of functions river systems have to serve, the challenge river manager’s face nowadays is to optimize and integrate different operations and maintenance activities into sound and sustainable management plans. These plans should meet both the specific needs of various functions and simultaneously optimize the use of the river system. For this reason there has been a growing interest into operation and maintenance problems in engineered river systems. These issues do not only play a major role in the developed world, but increasingly in developing countries and countries in transition as well.

River System Management focuses on the operation and maintenance of both the main channel and floodplains, including different control works and river training structures. It balances between the planning and development of river systems on a basin or catchment scale, with a topic like water Resources Development on the one hand and the implementation of measures on a smaller (river stretch) scale.

Operation of Engineered River Systems

Operation of river systems should be geared at fulfilling certain criteria. These criteria are different for different functions. Hence, the first question that has to be addressed in the (short term) operation of river system is:

- What are the possible interventions (measures) which can be decided upon? In a river system with reservoirs or sluices this is an easy question:
- How can the control structures be operated in such a way that the consequences are optimized?

When considering an engineered river system in its totality, however, the situation is more complex. Table 2-6 lists some of the relevant criteria, together with operation measures, which can be applied to best serve these functions. This problem can be theoretically converted in a (stochastic) optimization problem, but in practice this approach has its limitations because of the data, which is needed to optimize the total system. This also shows the importance to know the state of system indicators. However, with the increase in the use of information systems in river management, this problem is getting less important.

Much attention has to be paid to the uncertainty. The main uncertainty is often the forecasting of the state variables, such as the discharge, the rainfall, or water demand of the users. Maximizing the expected (social) banalities is often used as an objective in optimization problems. Increasingly Decision Support Systems (DSS’s) are being used to support the operation of river system.
Maintenance of Engineered River System

In an engineered river system, the following elements have to be maintained:

- The main channel,
- The floodplains
- Different river training and control structures

Table 2-6: Function, criteria and possible operation measures (Douben et al., 2003)

<table>
<thead>
<tr>
<th>Function</th>
<th>Possible criteria</th>
<th>Possible measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydropower</td>
<td>Maximum firm energy</td>
<td>Reservoir operation</td>
</tr>
<tr>
<td></td>
<td>Maximum peak power production</td>
<td>Sluicing of reservoir</td>
</tr>
<tr>
<td></td>
<td>Reduction of reservoir sedimentation</td>
<td>Spillway operation</td>
</tr>
<tr>
<td>Water Supply and Irrigation</td>
<td>Minimum inflow</td>
<td>Storage and release of water in upstream reservoirs</td>
</tr>
<tr>
<td></td>
<td>Reduction of Sediment ingress</td>
<td>Temporal closure of intakes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Operation of gates of barrages</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Anti-sediment measures (e.g via sediment excluders)</td>
</tr>
<tr>
<td>Flood control</td>
<td>Maximum discharge/water level</td>
<td>Reservoir operation for flood control</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Emergency polders</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Operation of spillways (floodway’s, retention basins)</td>
</tr>
<tr>
<td>Navigation</td>
<td>Minimum discharge</td>
<td>Release policy from upstream reservoirs</td>
</tr>
<tr>
<td></td>
<td>Minimum keel clearance</td>
<td>Backing up by barrages</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dredging</td>
</tr>
<tr>
<td>Nature Restoration</td>
<td>Minimum inflow and inundation frequencies (pioneer)</td>
<td>Artificial release from upstream reservoirs</td>
</tr>
<tr>
<td></td>
<td>Vegetation development</td>
<td>Floodplain rejuvenation</td>
</tr>
</tbody>
</table>

As soon as a part of the river system does not fulfil its requirements, it should be maintained, preferably against minimal costs. Methods are available to determine cost-optimal maintenance decisions for parts of the river system that are subject to deterioration (such as sedimentation of the floodplains or reservoirs, hydraulic structures, river banks ect.). Inspection, repairs, renovations and replacement are possible maintenance actions (Douben, et al., 2003). Often two types of maintenance are distinguished: Corrective maintenance (after failure), and Preventive maintenance (mainly before failure).

Corrective maintenance can be best chosen if the cost arising from failure is low, and preventive maintenance is best when costs of failure are high. In Fig. 2-13 the decision diagram for the choice
between these two types of maintenance is given. Preventive maintenance can be further subdivided into time types of maintenance (regular intervals of use or time) and condition-based maintenance (carried out at times determined by inspecting or monitoring the condition).

![Decision diagram for corrective and preventive maintenance](Douben et al., 2003)

Maintaining (parts of) river systems against minimal cost depends on finding an optimum balance between (initial) costs now and future (uncertain) maintenance costs. This balance can also be applied on existing systems. In the cost function all kind of criteria can be applied.

### 2.4.3 Impacts of land-use practices

Terrestrial vegetation plays an important role in determining river flow. This is clear from the observed changes in run-off after deforestation. In the Hubbard Brook Experimental Forest (White Mountains, New Hampshire, USA) all the trees were fallen in one stream catchment. The overall export of dissolved inorganic substances increased 13 times (Fig.2-14), amongst others because of a reduction in transpiring surfaces (the leaves). This resulted in 40% more precipitation passing through the ground water and being discharged by the stream. This increased outflow also increased leaching of chemicals and weathering of rock and soil.

Fig. 2-15 gives a schematic summary of changes in sediment yield with changing land use in the area between Washington and Baltimore (USA). Until the end of the 18th century the area remained in its forested condition and sediment yields were low.
Fig. 2-14: The effects of deforestation on the concentration of some ions in streams; arrows indicate time of deforestation (Source: Begon et al., 1990).

When the area was converted to crop farms, sediment yields increased. This period was followed by some soil-conservation measures. During the period when the lands were converted to urban use, the sediment yields were extremely large. After the area became a city with paved streets and planted lawns, sediment yields became small again.

Fig. 2-15: Changes in sediment yield related to changes in land use in Maryland Piedmont (from Anonymous, 1993).
2.4.4 Discharge and transport of materials

Transport of Materials
Concurrent with the transport of water, dissolved and particulate matter is transported to the oceans. The distinction between dissolved and particulate matter is usually made on the basis of separation on a filter with a fixed pore size. The presence of a substance in water can be expressed as a concentration. For rivers, it is often important to know the amounts of transported materials. These are expressed as loads: concentration x discharge. Transported materials originate from: the river bed itself through erosion by the flowing water; run-off from the surrounding land; biological processes in and alongside a river. The composition (quality) of river water is basically determined by the geological nature of the catchment area and by land use.

The rivers from the various continents show quite some variation. Because of human influences, the original chemical composition may be largely masked nowadays. Sediment discharge varies with the climatic zones. Tropical areas (such as South-East Asia) in general have a large discharge because of high precipitation and the presence of high mountains (and deforestation!). North and South Europe also show considerable differences. The semi-arid southern part has a less well-developed vegetation cover and higher erosion; this results in a higher sediment discharge by rivers.

River water that enters a reservoir is released eventually, but much of the sediment is trapped permanently. The Colorado River serves as a good example. Since the closure of the Hoover Dam (1935) the rate of sediment delivered to the Gulf of California declined from ca 150 x 10^6 t.yr^-1 to about 10^5 t.yr^-1; the decline in discharge has been in response to an increasing diversion of water for irrigation and municipal water supplies. Another large river system whose sediment loads are strongly influenced by reservoirs is the Mississippi. The major sources of sediments used to be the western tributaries (Missouri River and Arkansas River). After World War II dams were constructed in the Missouri River for irrigation, hydropower and navigation control; locks and dams were constructed for navigation on the Arkansas River. Sediment discharges to the Gulf of Mexico by the Mississippi River are now less than one half of what they were before 1950. It is interesting to note the increase in sediment input from the eastern Ohio River Valley. This is attributed to the conversion of forests to cropland.

The possible effects of dam construction on the coastal environment are obvious from the following example. In the 1960s the Aswan High Dam in the River Nile was constructed. Annual water flow decreased to ca 10% of the previous discharge (Fig. 2-16) and there was a shift of peak flow from the autumn rainy season to winter months. As a result, physical, chemical and biological conditions in the south-eastern part of the Mediterranean Sea have changed. This has led to coastal erosion and retreat of the Nile Delta, shifts in navigation channels, lower agricultural production and decreased nutrient inputs in the coastal waters. As a result, phytoplankton densities have decreased leading to lower sardine and shrimp harvests (phytoplankton - zooplankton - sardines food chain).
2.4.5 Impacts on water quality

Due to the complexity of factors determining water quality, large variations are found between rivers or lakes on different continents or in different hydroclimatic zones. Similarly, the response to anthropogenic impacts is also highly variable. As a consequence, there is no universally applicable standard, which can define the baseline chemical or biological quality of waters. In spite of this, different countries and international organisations (WHO) have developed maximum allowable concentrations of water quality variables for different uses. The aspect of the ‘dynamics’ in water quality issues is presented in Fig. 2-17, which illustrates the sequence of water quality issues in the industrialised countries.

Fig. 2-16: Annual changes in water discharge from the River Nile and annual sardine and shrimp catches in the SE Mediterranean Sea.

Fig. 2-17: The sequence of water quality issues arising in industrialised countries
(after Meybeck and Helmer, 1989; in Chapman, 1996)
2.5 River Basins in Ethiopia

2.5.1 Introduction

Ethiopia covers a land area of 1.13 million sq.kms, of which 99.3 percent is a land area and the remaining 0.7 percent is covered with water bodies of lakes (MOWR 2002). It has an arable land area of 10.01 percent and permanent crops covered 0.65 percent while others covered 89.34 percent. The agricultural sector is the leading sector in the Ethiopian economy, 47.7 percent of the total GDP, as compared to 13.3 percent from industry and 39 percent from services (World Bank 2005). Though agriculture is the dominant sector, most of Ethiopia’s cultivated land is under rainfed agriculture. Due to lack of water storage and large spatial and temporal variations in rainfall, there is not enough water for most farmers to produce more than one crop per year and hence there are frequent crop failures due to dry spells and droughts which have resulted in a chronic food shortage currently facing the country.

Ethiopia has an extremely varied topography. The complex geological history that began millions of years ago and continues, accentuates the unevenness of the surface; a highland complex of mountains and bisected plateaux characterizes the landscape. Interspersed with the landscape are higher mountain ranges and cratered cones. According to some estimates about 50 percent of African mountains, about 371,432 sq.kms above 2,000 meters, are confined within Ethiopia (FAO, 1984). Altitude ranges from 126 meters below sea level in the Dalol Depression on the northern border, to the highest mountain, Ras Dashen in the Semien Mountains north of Lake Tana rising to 4,620 m.a.s.l. The plateau in the northern half of the country is bisected by the Ethiopian Rift Valley, which runs more than 600 km north–east of the Kenyan border to the Koka Dam on the Awash River south of Addis Ababa. The rift then descends to the northeast and its lateral escarpments begin to diverge from each other crossing the Afar Depression towards the Red Sea coast (Aynew et al. 2005).

2.5.2 Surface Water Resources

River Basins

Ethiopia has 12 river basins. The total mean annual flow from all the 12 river basins is estimated to be 122 BMC (Kloos and Legesse, 2010), Table 2-7. Fig. 2-18 below shows the map of Ethiopian River Basins.

At present, surface water and meteorological data are collected and processed on a regular basis through existing hydro-meteorological networks.

The idea of a river basin, despite its physical or natural attributes, is more than an engineering concept and encompasses the magnitude and dynamics of a resource that must be harnessed for the common good (Molle, 2006). It has often been advocated that the most logical unit for water resources planning and optimum utilization of available water resources is the river basin. Accordingly, it is desirable that all major river basins in Ethiopia have an integrated development master plan study, and their potential in terms of economic development be known.
Table 2-7: River basins, annual runoff and specific discharge

<table>
<thead>
<tr>
<th>River Basin</th>
<th>Area (Km²)</th>
<th>Annual Runoff BCM* (%)</th>
<th>Specific discharge (L/second/km²)</th>
<th>Potentially irrigable area in ha (%)</th>
<th>Irrigated area in 2002 in ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue Nile</td>
<td>199,812</td>
<td>52.60 (43.1)</td>
<td>7.8</td>
<td>760,000 (28)</td>
<td>30,000</td>
</tr>
<tr>
<td>Baro-Akobo</td>
<td>74,100</td>
<td>23.60 (19.3)</td>
<td>9.7</td>
<td>600,000 (22.1)</td>
<td>**</td>
</tr>
<tr>
<td>Omo-Gibe</td>
<td>78,200</td>
<td>17.9 (14.7)</td>
<td>6.7</td>
<td>248,000 (9.1)</td>
<td>**</td>
</tr>
<tr>
<td>Tekeze</td>
<td>89,000</td>
<td>7.63 (6.0)</td>
<td>3.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Genale-Dawa</td>
<td>171,050</td>
<td>5.8 (4.8)</td>
<td>1.2</td>
<td>300,000 (11)</td>
<td>8,850</td>
</tr>
<tr>
<td>Rift Valley</td>
<td>52,740</td>
<td>5.6 (4.6)</td>
<td>3.4</td>
<td>47,600 (1.8)</td>
<td>**</td>
</tr>
<tr>
<td>Awash</td>
<td>112,700</td>
<td>4.6 (3.8)</td>
<td>1.4</td>
<td>206,000 (7.6)</td>
<td>69,900</td>
</tr>
<tr>
<td>Wabe Shebele</td>
<td>200,214</td>
<td>3.15 (2.6)</td>
<td>0.5</td>
<td>355,000 (13.1)</td>
<td>**</td>
</tr>
<tr>
<td>Afar-Danakil</td>
<td>74,000</td>
<td>0.86 (0.7)</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mereb</td>
<td>5,700</td>
<td>0.26 (0.2)</td>
<td>3.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ogaden</td>
<td>77,100</td>
<td>0.00</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aysha</td>
<td>2,200</td>
<td>0.00</td>
<td>0.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Northern Rivers</td>
<td></td>
<td></td>
<td></td>
<td>200,000 (7.4)</td>
<td>**</td>
</tr>
<tr>
<td>Total</td>
<td>1,136,816</td>
<td>122.00 (100)</td>
<td></td>
<td>2,716,600 (100)</td>
<td>197,000</td>
</tr>
</tbody>
</table>

*Billion cubic meters

**No data available

Sources: Kloos and Legesse (2010).
Table 2-8: Hydropower (technical) potential of Ethiopia, 75% dependable surface water availability, and number of potential hydropower sites, by river basin.

<table>
<thead>
<tr>
<th>River Basin</th>
<th>Technical potential (GWh/yr)</th>
<th>75% dependable surface water (BCM)</th>
<th>Potential hydro power sites</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue Nile</td>
<td>78,820</td>
<td>51.48</td>
<td>132</td>
</tr>
<tr>
<td>Baro-Akobo</td>
<td>18,880</td>
<td>8.51</td>
<td>39</td>
</tr>
<tr>
<td>Omo-Gibe</td>
<td>36,560</td>
<td>14.46</td>
<td>23</td>
</tr>
<tr>
<td>Tekeze</td>
<td>5,930</td>
<td>5.73</td>
<td>15</td>
</tr>
<tr>
<td>Genale-Dawa</td>
<td>9,270</td>
<td>4.58</td>
<td>23</td>
</tr>
<tr>
<td>Rift Valley</td>
<td>800</td>
<td>4.36</td>
<td>6</td>
</tr>
<tr>
<td>Awash</td>
<td>4,470</td>
<td>4.1</td>
<td>43</td>
</tr>
<tr>
<td>Wabe Shebele</td>
<td>5,440</td>
<td>2.34</td>
<td>18</td>
</tr>
<tr>
<td>Aysha</td>
<td>*</td>
<td>0.57</td>
<td>*</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>160,170</strong></td>
<td><strong>96.13</strong></td>
<td><strong>299</strong></td>
</tr>
</tbody>
</table>

* No data available

Except two internal basins (Rift valley and Afar-Danakil), all basins are drained by rivers that flow across international boundaries or into lakes shared by Ethiopia with Kenya (Omo River into Lake Turkana) and Djibouti (Awash River into lake Abe). The four major rivers originating in the western highlands (Blue Nile, Baro-Akobo, Tekeze, and Omo Gibe) account for about 83% of the total runoff from all catchments but their basins cover only 38% of the total area of the country. The Blue Nile River Basin generates nearly half of all surface water (52.6 billion m$^3$), followed by the Baro-Akobo and Omo-Gibe Basins, largely reflecting the spatial distribution of rainfall. The main river basins in the central and eastern parts of the country (Awash, Wabe Shebele, and Genale-Dawa) occupy about 43% of the countries area, but their combined runoff constitute only about 11% of the total runoff generated within the country.

River flow throughout Ethiopia is highly seasonal, with far-reaching implications for water accessibility, the economy, dams, ecosystems, and flooding. The dry/wet season ratios of the flow volume of the Blue Nile, Tekeze, Awash, Wabe Shebele and Genale Rivers vary from about 1:20 to 1:15, with peaks extending from June to October or November, after the end of the main rains. Even the Omo and other rivers originating in the most humid part of the south western highlands, although having relatively larger dry season flows and longer flood periods, are characterized by significant seasonal fluctuations. Inter annual flows also fluctuate significantly with rainfall.

Despite the continuous food and water insecurity, less than 5% of the potential irrigable land and 1% of the hydropower potential have been developed. Nevertheless, increasing utilization of streams, springs, and lakes in drought-prone areas for irrigation and domestic purposes and climatic change are already contributing to local water insecurity. Many springs dried up within the last few decades and in Harage Highlands, lakes Haramaya and Adele disappeared in 2006 due to a combination of environmental degradation, siltation, and over pumping (Alemayehu, et al., 2007).

* Lakes, Reservoirs and Wetlands
Ethiopia has 11 fresh and 9 saline lakes, 4 crater lakes and over 12 major swamps or wetlands. Majority of the lakes are found in the Rift Valley Basin. Table 2-9 provides information for 19 main natural lakes and reservoirs (MCE 2001). The total surface area of these natural and artificial lakes in Ethiopia is about 7,500 sq.kms. The majority of Ethiopian lakes are rich in fish. Most of the lakes except Ziway, Tana, Langano, Abbaya and Chamo have no surface water outlets, i.e., they are endhoric. Lakes Shala and Abiyata have high concentrations of chemicals and Abijata is currently exploited for production of soda ash. With the exception of Lake Tana, the largest Ethiopian lakes are located in the Rift Valley.

Lake Tana in the north-western highlands, the largest lake in Ethiopia, is about 3000 to 3500 sq.kms with an estimated storage volume of 28 km3. The major tributaries, including the Gilgel-Abbay, Ribb, Gumara, and the Megech contributes more than 93% of the inflow into the lake (Kebede, et al., 2006). The weir constructed from 1995 to 1997 regulates the water level and outflow of Lake Tana to increase generation of electricity through the Tis Abbay II hydropower plant on the Blue Nile. Although the use of Lake Tana was not, unlike other lakes, regulated by environmental laws until recently, the level of exploitation of its water resources, particularly for irrigation, was insignificant in the past. But Lake Tana and its tributaries have been selected for irrigation development and hydropower production. A notable development is the Tana-Beles growth pole, which is expected to stimulate integrated water resources development programs as part of the Nile Basin Initiative.

Of the 10 largest Rift Valley Lakes, Shala, Abiyata, Abe and Beseka are salt lakes, Turkana, Langano, Awasa, and Chamo have brackish water (between 1 and 2g/l salt) and only lakes Ziway and Abaya have freshwater. Rising water level in lakes Abaya, Chamo, and Awassa have been associated with increasing silt load deposited by their tributaries in the lake beds, a result of watershed degradation. Lake Beseka expanded more than 10-fold between the 1950s and 2005, largely due to a combination of increased groundwater inflow related to geo-tectonic activity and drainage water from nearby Abadir irrigation farm. Increasing soda ash extraction from Lake Abiyata and ongoing large-scale irrigation development around Lake Ziway catchment are significantly reducing their volumes. Lake Abe’s water level also declined, by two thirds since the 1930s, due to large scale irrigation development in the Awash Valley.

Four large Reservoirs have been created by Koka, Finicha, Melka Wakena and Gilgel Gibe I dams and at least five additional reservoirs (Tekeze in Tekeze Basin, Tendaho and Kessem in the Awash, Koga near Lake Tana, and Gibe III in the Omo Basin are expected to be filled by 2012. The new Millennium Dam for the development of hydroelectric power is under construction on Blue Nile River near to the border of Sudan in Benishangule Region. The dam is planned to create an artificial reservoir which has a capacity of 63 BMC (about 2 times of Lake Tana). After the completion of the dam it is planned to produce 5250MW power.
Wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. Various researchers and investigators have attempted to document the wetlands of Ethiopia but no comprehensive inventory has been made. Although little is known about the impact of agricultural and urban development on Ethiopia’s wetlands (Abebe, 2003), an estimated 35% of the largest wetland area of Ethiopia, in Illubabor Region had been developed to agriculture by 1999 (Hailu, 2003), and pent-up demand for wetland cultivation in that region is threatening their sustainability (Mulugeta, 2004). Only one wetland area, in the Omo River Delta in Lake Turkana, has increased in recent years (by more than 500sq.kms), due to silt inflow from the Omo River and decreasing lake levels, but its future is threatened by dam construction. Although some policies specifically address wetlands, no national wetlands policy exists and none of the country’s wetlands are covered by a conservation and management plan.

**2.5.3 Groundwater Resources System**

The study and mapping of ground water resources is the responsibility of the Ethiopian geological surveys. Reliable assessment of the ground water resources potential of the country is not yet available. However, little reliable information exists on the volume, location and quality of...
groundwater resources, and estimation of the groundwater potential of Ethiopia is complicated by the complexity of its geology. As compared to surface water resources, Ethiopia has lower groundwater potential. However, by many countries’ standard the total exploitable groundwater potential is high. Based on the scanty knowledge available on groundwater resources, the potential is estimated to be about 2.6-13.5 BMC (Billion Metric Cube) annually rechargeable resource (Dingamo, 2008). Groundwater is paramount importance in areas affected by recurrent droughts or with limited or polluted surface water, in urban areas, and as a supplementary source of irrigation water. However, yield levels of many shallow water wells are low (less than 5 lit/sec), groundwater tables have been declining in recent years as a result of drought, and aquifers in the lowlands are generally too deep for economic exploitation for irrigation purposes. More than two thirds of the estimated utilizable groundwater potential is in the Blue Nile Basin and around 90% is in the western half of the country (Dingamo, 2008).
2.6. Exercises/Tutorials and Project

2.6.1 Exercises/Tutorials

Explain the effect of climate change for confined and unconfined aquifers?

Explain how the ground recharge of flood aquifers has been improved in semi-arid areas?

Conceptually runoff can be determined by dividing stream flow measurements (m$^3$/s) from catchment area. Explain why this concept doesn’t hold for all catchments?

Explain how the following climatic conditions affect stream flow?
Cold and cool temperate climates
Mild temperate climates
Arid and semi-arid regions
Humid tropical regions

How the downstream activities affect the river functions?

Visit http://www.waterandnature.org/eatlas and explore the different river basins. Select a number of basins, for instance in your region. What are the differences between the basins in natural conditions, population pressure and biodiversity?

Based on a visual analysis of the maps and your own experience what are (potentially) conflicting situations between development and environment?

When we speak of using catchments within the context of Integrated River Basin Management (IRBM), what do we mean?

Briefly discusses the Structural Changes in the Stream Corridor from its Headwaters to Outlet. Explain why stream order classification is important?

Did people look upon the environment as something separate from them or did they consider themselves as being an integral part of the environment? Explain their cultural and religious attitude on environment.

What are the main causes of floods?

Define the following: (a) stream long profile, (b) stream gradient, (c) stream discharge, (d) suspended load, (e) bed load (f) drainage basin, (g) drainage divide

What happens to a stream's discharge as one moves down stream? Explain why this occurs.

List and give a brief description of the various types of stream deposits.

What conditions are necessary for stream to be meandering stream and a braided stream?
How do streams erode?

How do dams affect wetlands, riparian habitats and other sensitive areas?

2.6.2 Project

Students work in small groups (maximum of four students in one group) studying selected river basins. Their analysis will result in a group report describing the hydrology, climatology, socioeconomic development and ecosystem of the selected basin, and identifying relevant existing and planned activities and issues at the basin scale. Each group will present and discuss their results.

Reference


− WWF Global Fresh Water Programme. Free-flowing rivers: Economic luxury or ecological necessity?
3. River Basin Planning and Management

By: Dr Mekonnen Ayana

3.1 Water Resources Planning in River Basins

3.1.1 The Need for Planning

Water resource systems are indispensably important for human survival and economic development. However, with increasing pressure on freshwater resources, many still lack access to adequate water supply for basic needs. Typical causes of such failures include (Cap-Net, 2005):

- Water resources are increasingly under pressure due to population growth, economic activity and intensifying competition for the water among users;
- Water extraction have increased at a faster than population growth and many peoples are living in water shortage areas;
- Pollution is further exacerbating water scarcity by reducing water suitability for uses;
- Deficiency in the management of water, a focus on developing new sources rather than better managing existing ones, and top-down sector approaches to water management result in uncoordinated development and management of the resource.
- More and more development means greater impacts on the environment.
- Current concerns about climate variability and climate change demand improved management of water resources to cope with more intense floods and droughts.

The water comes from all parts of the basin (from settlement areas, farms and the natural environment). It is also used in all parts and establishes connection between all parts. Water is consumptively used through irrigation and drinking as well as non-consumptively used through hydropower production, recreation, navigation and etc. which take place in the river basin. Most of the return flows from irrigation and wastewater are again directed back to the river system (Molle, 2009). Deterioration of water resources systems reflect failures in planning, management and decision-making at levels broader than water.

Consequently, river basin planning should ensure the consideration of the different interrelations within water systems the interrelations between water systems and land, and the interrelations between complete river basins and their socio-economic environment. In general terms, water resources planning and management involves influencing and improving the interaction of three interdependent subsystems. These are:

- the natural river subsystem in which the physical, chemical and biological processes take place
- the socio-economic subsystem, which includes the human activities related to the use of the natural river system
- the administrative and institutional subsystem of administration, legislation and regulation, where the decision and planning and management processes take place.
Figure 3-1 illustrates the interaction between these subsystems, all three of which should be included in any analysis performed for water resource systems planning and management. Inadequate attention to one can destroy the value of any work done to improve the performance of the others.

![Interaction between subsystems](image)

**Fig. 3-1: Interaction between subsystems (Loucks and Eelco van Beek, 2005)**

Planning represents an important element of river basin management (Figure 3-2). It provides a timeframe and a set of actions for the operational management. A plan helps to:

- evaluate the initial condition of the river basin, to establish the objectives and the ways to achieve them;
- to establish priorities and to focus the operational management on certain issues;
- organize efficiently all the stakeholders that have an active role in the operational management;
- coordinate actions and information exchanges with other management systems in the neighbour areas.

![Elements of the integrated river basin management](image)

**Fig. 3-2: Elements of the integrated river basin management (Teodosiu et al., 2003)**
Water resources management principles

The four Dublin principles that laid foundation for the need for sustainable development and management of water resources are:

− Fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment.
− Water development and management should be based on a participatory approach, involving users, planners and policymakers at all levels.
− Women play a central part in the provision, management and safeguarding of water.
− Water has an economic value in all its competing uses and should be recognized as an economic good as well as a social good.

3.1.2 Planning and Management Aspects

Planning and management involve: 1) technical aspects, 2) economic and financial aspects, and 3) Institutional aspects

Technical aspects

Technical aspects of planning include hydrological and socioeconomic assessments. These identify and characterize interactions among the resources in the basin or region, including the land, the rainfall, the runoff, the stream and river flows and the groundwater. Existing watershed land use and land cover, and future changes in this use and cover, result in part from existing and future changes in regional population and economy. Planning involves predicting changes in land use/cover and economic activities at watershed and river basin levels. These will influence the amount of runoff, and the concentrations of sediment and other quality constituents (organic wastes, nutrients, pesticides, etc.) it contains as a result of any given pattern of rainfall over the land area. These predictions will help planners estimate the quantities and qualities of flows and their constituents throughout a watershed or basin, associated with any land use and water management policy. This in turn provides the basis for predicting the type and health of terrestrial and aquatic ecosystems in the basin. All of this may affect the economic development of the region, which in part determines the future demands for changes in land use and land cover.

Economic and financial aspects

The fourth Dublin principle states that water has an economic value in all its competing uses and should be recognized as an economic good. It addresses the issues of gaining the maximum benefits as much as possible from a limited resource as well as the need to generate funds to recover the costs of the investments and that of operation and maintenance of the system.

Usually maximization of benefits from resources use is based on an economic market approach. Many of the past failures in water resources management are attributable to the fact that water has been and still is viewed as a free social good. The experiences show that prices of water for irrigation and drinking water in many countries are below the full cost of the infrastructure and personnel needed to provide that water, which comprises the investment, operation and maintenance (O&M) costs, the opportunity cost, economic and environmental externalities.
Institutional aspects

The precondition for successful implementation of plans is to have an enabling institutional environment. There must be national, provincial and local policies, legislation and institutions that make it possible for the right decisions to be taken and implemented correctly. The government plays a crucial role with this regard. The reasons for governmental involvement are manifold:

- Water is considered as a resource beyond property rights: basically it cannot be ‘owned’ by private individuals. Water rights can be given to individuals or companies, but only the rights for use and not to own it.
- Water is a resource that often requires large investment to develop. Because many water resources development projects are very expensive and have many societal beneficiaries.
- Water is a medium that connects natural systems and societal groups and hence can easily transfer external effects. The use of water by one person often has negative effects on others (externalities). The common example is the discharge of waste into a river that may have negative effects on downstream users.

3.1.3 Types and Approaches of Planning and Management

Strategic and operational planning are the two planning types that are commonly applicable to river basin. Strategic plan tends to covers complete river basins and all relevant policy sectors. Whereas operational plans have to go more into detail and usually cover only one policy sector or part of a sector. Plans and policies that are relevant to integrated river basin management can differ in their policy and geographical scope (Table 3-1).

Table 3-1: Types of plan and policies relevant to RBM (cf. online course material – UNESCO-IHE, 2011)

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Type of plan</th>
</tr>
</thead>
</table>
| Strategic versus operational character | Setting aims and goals  
 Setting short or medium-term targets, strategies and/or specific guidelines for operational management (operational plans and strategies)  
 Setting prioritizing and/or specifying, scheduling and financing operational activities (programmes) |
| Policy scope                      | Only surface or groundwater, quantity or quality  
 Only some users (e.g. hydropower)  
 All water, all uses  
 Water and land |
| Geographical scope                | Whole basin  
 Sub-basin(s)  
 Part(s) of (sub) basins(s)  
 Administrative area  
 National/international |
| Character                         | Purely informative, politically binding or legally binding |
| Validity                          | Short, medium, long-term |
| Time horizon                      | Short, medium, long-term |
The types of plans needed to be adapted depend on the need for the different functions that plans can perform. For example, in case there is an urgent problem such as pollution danger for drinking water sources that need urgent solution, it may not be important to adapt integrated strategic planning that provides a complete integrated description of the basin and sets long-term goals. The resources could much better be used for making and implementing an operational plan that sets concrete targets, proposes operational measures, and creates the necessary support.

Generally, the number of plans to be adapted should be kept low, especially in countries and basins with a low management capacity. If too much planning is going on at the same time, too few resources may be available for each planning exercise, co-ordination between the plans can become problematic and transparency for the citizen is reduced. Moreover, resources that are spent on planning cannot be spent on operational management.

**3.1.4 Planning Process**

The planning process also called planning cycle is a logical sequence of phases that is driven and supported by continuous management support and consultation events shown in the centre of Figure 3-3. The main component parts of the planning cycle include:

- Plan initiation
- Work plan and stakeholders participation
- Building of strategic vision
- Situation analysis
- Water management strategies
- Plan preparation and approval
- Implementation and
- Monitoring and evaluation
These components are briefly discussed in the following sections.

**Phase 1: Initiating the planning process**

The triggers to start a planning process may be external or internal or a combination of both. Internationally, governments have agreed at the global summit on sustainable development to put in place plans for sustainable management and development of water resources. This is being followed up with support from the international community and donors. This kind of driver for plan is considered as external. At country level, many governments are aware of the problems that their own water sector is facing from issues such as pollution, scarcity, emergencies, competition for use and have identified action as a priority. Many have also taken steps of developing a water policy or water vision or have contributed to the development of such visions in their region – internal drive.

Whatever the drivers for water resources planning exercise the key activities at the beginning include:

- Obtaining government commitment,
- Raising awareness on sustainable management of water resources, and
- Establishing a management team

1. Obtaining government commitment

For a plan to be accepted and implemented it has to be owned by the government and be housed within the government structure from the outset. The development of commitment may be required beyond a single ministry if the expected changes are going to be far reaching. Indicators of government commitment include: financial allocation to the planning process, leadership of the planning team, number of ministries and agencies involved in the decision to develop a plan.

2. Raising awareness on water resources management
The raising of awareness will continue throughout the planning process. However, at this point it is targeted at key government officials who must be aware of the potential for impact and success before they will commit to the planning exercise.

3. Establishing a planning team
Planning requires a team to organise and mobilize relevant stakeholders to facilitate a regular stakeholder consultation with a particular emphasis on broad participation. The structure of a management team for the planning and the raising of awareness about water resources management are both linked to achievement and maintenance of government commitment. Key organisations for managing the water resources planning process include for instance: the National Government, a Process Steering Committee and a Management Team (Table 3-2).

Phase 2: Developing the work plan
In the planning cycle (Figure 3.3), work plan is placed in the middle of the cycle to indicate that work plan and its components are essential for all stages in the process. This stage of the planning cycle addresses preparing for the work of producing the water resources management plan and therefore the expected outputs from this stage would be:

- A programme of action with detailed work plan and means of funding is in place.
- Political will and support for the planning process is built.
- A framework for broad stakeholder participation is in place.
- Capacity building activities to support the planning process are identified.

Table 3-2: Suggested roles and responsibilities (GWP, 2005)

<table>
<thead>
<tr>
<th>Organizations</th>
<th>Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>NATIONAL GOVERNMENT</td>
<td>Lead role, ‘Owner’ of the process</td>
</tr>
<tr>
<td></td>
<td>Mobilize funding</td>
</tr>
<tr>
<td></td>
<td>Set macro-economic policy environment</td>
</tr>
<tr>
<td>STEERING COMMITTEE</td>
<td>Guide the process (group with wide representation)</td>
</tr>
<tr>
<td></td>
<td>Mobilize support across sectors and interest groups</td>
</tr>
<tr>
<td></td>
<td>Guarantee quality output</td>
</tr>
<tr>
<td></td>
<td>Monitor implementation progress</td>
</tr>
<tr>
<td>MANAGEMENT TEAM</td>
<td>Manage day-to-day processes for strategy development, implementation</td>
</tr>
<tr>
<td>Group of qualified</td>
<td>and capacity building</td>
</tr>
<tr>
<td>professionals</td>
<td>Organize and coordinate the overall strategy process</td>
</tr>
<tr>
<td></td>
<td>Planning specific activities and meetings</td>
</tr>
<tr>
<td></td>
<td>Procuring expertise and resources</td>
</tr>
<tr>
<td></td>
<td>Support working groups and other committees</td>
</tr>
<tr>
<td></td>
<td>Act as a focal point for communication.</td>
</tr>
</tbody>
</table>

Generally speaking, the start up of the planning process include: mobilising the team, development of the work plan, drawing in relevant stakeholders, and ensuring political commitment.
The work plan has to be prepared by the team and/or any consultant hired for that purpose, and will form one of the principal outputs of the first stage. Typical areas to be covered by the work plan are: briefing on tasks required, work plan and methodology to be applied, management and expert responsibilities, key project delivery points, key meetings / seminars / communication mechanisms.

**Stakeholders participation.**

Stakeholder participation is the core principle of modern water resources management. Water concerns everyone’s business and for the success of water sector reforms it is important to know what the views and interests of the concerned stakeholders are.

Stakeholder participation is the process through which the views of all interested parties (stakeholders) are integrated into project decision-making. Here stakeholder refers to individuals or groups having an interest in the project. They can be divided into four categories: government agencies, directly affected parties, indirectly affected parties, and other parties including NGOs. Stakeholder participation refers to the involvement of such individuals or groups in decision-making or trying to influence decisions.

It is generally accepted that planning initiatives begin with problem awareness and progress through various information-gathering stages to a point of decision or action. Problem awareness may come from agency representatives, from interested professionals such as consulting engineers or planners, or from regulatory directives, but may most frequently come from the community. They are the community members who are most directly affected by water resources quality and quantity in the basin. The benefits of stakeholder involvement are among others:

- It leads to informed decision-making as stakeholders often possess a diverse information which can benefit the project;
- Stakeholders are the one that are most affected by lack of water resources or poor management of water resources;
- Consensus at early stages of the project can reduce the likelihood of conflicts which can harm the implementation and success of the project;
- Stakeholder involvement contributes to the transparency of public and private actions;

The involvement of stakeholders can build trust between the government and civil society. Hence, careful participation of stakeholder in the entire process of planning and management is essential. For this purpose, stakeholder analysis essentially involves four steps:

- Identify the key stakeholders from the large array of groups and individuals that could potentially affect or be affected by changes in water management.
- Assess stakeholder interests and the potential impact of the plan on these interests.
- Assess the influence and importance of the identified stakeholders.
- Outline a stakeholder participation strategy (a plan to involve the stakeholders in different stages of the plan preparation).

**Political commitment**

Some of the reasons for strong political support are to (cf. GWP, 2005):
− ensure that priority water resource problems and issues can be addressed from multi-agency dimension;
− ensure political support to enable coordinating system work
− ensure that the water resources vision and objectives incorporate political goals consistent with other national goals;
− ensure that sustainable approaches to water management are included in national developments, plans and policy statements from other sectors;
− make decisions on recommended policy, legal and institutional changes;
− ensure that the plan is adopted and followed through;
− commit government funds and mobilize donor assistance.

Phase 3: Establishing the strategic vision
Vision is the guiding principle and direction to future actions. It captures shared dreams, aspirations and hopes about the state, use and management of water resources in the basin. The output from this phase of the planning process is a statement of a water vision or water policy which embraces the principles of sustainable management and development of water resources. A vision must be bounded, i.e. it has to be oriented to a given time period. The vision starts with the development of common view of the future and may include defined common goals and objectives, and may be translated into policies and legislation.

A vision can be developed with the combination of ideas emanating from the following questions: why water management needs to be improved; where you want water management to be at the end of the planning period, say, 15-20 years; how management and services are to be improved; when specific goals will be reached.

Phase 4: Situation analysis
To identify the actions required to reach the vision, it is essential to examine the current conditions and needs of the stakeholder at this stage. The purpose of this step is to describe the existing situation and examine the key factors of influence as well as to use the information to predict future conditions. Situational analysis is used to identify the existing issues and problems in the basin as well as potential future issues.

Consultation with stakeholders and various government entities is vital for understanding of competing needs and goals. During these discussions, possible solutions to the problems may also be brainstormed. This phase identifies the strengths and weaknesses in the water resource management and points out the ways to improve the situation and realize the vision. Awareness of the problems and the motivation to seek solutions are created during the analysis.

The output from the situation analysis is a report elaborating the outstanding issues, the problems and some of the solutions. The report should adequately reflect the concerns and impacts of the present water management systems on users, development, the environment and society as a whole. The sharing of the report with politicians and other senior members of government helps to maintain political commitment. A summary of areas to be covered during situation analysis is given in Box 2. The situation analysis report should present the issues and problems and prioritise those requiring most urgent attention. Criteria for this should be developed. Example of such criteria could be (Cap-
Net, 2005): is it a barrier to solve other problems; does it have an impact on a large number of people; is it a major equity issue; will it improve development and reduce poverty; will it significantly improve efficiency; will it positively impact on environment; will it improve water resource availability.

The through stakeholders participation priority issues in terms of significant and urgent water resources problems to be dealt with are identified and grouped into a problem-tree with cause and effect.

**Box 3-2: Scope for water resource situation analysis (cf. Cap-Net, 2005)**

**Institutional and legal analysis:** assess the mandates of institutions, laws and policies for conflict, conformity, overlap and consistency with sustainable management of water resources.

**Hydrological and hydro-geological assessment:** examine the extent of the surface and groundwater resources available, taking account of seasonality and long-term trends in supply.

**Demand assessment:** examine the competing uses of water with the physical resource base and assesses demand for water (at various prices), thus helping also to determine the financial resources available from tariff revenues for water resource management in different development scenarios.

**Environmental impact assessments (EIA):** collect data on the social and environmental implications of development programmes and projects. EIA is an important tool for cross-sectional integration involving project developers, water managers, decision-makers and the public. It can be seen as a special form of water resources assessment.

**Social assessment:** examine how social and institutional structures affect water use and management, degree of equitable access to water such as by gender and how specific projects might affect the social structure.

**Risk or vulnerability assessment:** analyse the likelihood of extreme events, such as flood assessment; the environmental implications of development programmes and projects; management, or how a specific project might affect social structures; and droughts, and the vulnerability of society to them.

**Demand management assessment:** assess the potential for water savings through water conservation and demand management.

**Phase 5: Water management strategies and options**

The output from this stage is selected strategies that help achieve the prioritized goals and objectives set to solve the identified problems. For each goal the most appropriate strategy needs to be selected and assessed for feasibility as well as its conformity to the overall goal of sustainable management.

Now the question arises how to decide what measures to put in place to solve problems identified and prioritized in phase 4. What should be changed in the way water is being managed and what are the implications of the proposed changes? The basin management strategy sets out the long-term goals and aspirations for water resources management, and how these goals are to be realized.

There are five main elements in developing a basin strategy. These are (GWP, 2009): 1) identifying the issues, 2) setting priorities, 3) identifying management options, 4) analysing costs and benefits; and 5) assessing risks.

**1. Identifying the issues**
The first step in developing a strategic plan is to get a clear idea of the water and land resource management issues and ongoing activities in a basin. Issues can be identified through impact assessment. The objective is to gain an overview of the issues, how critical they are, who they affect and the chances of being able to achieve results in the short term.

2. Setting priorities
Once the issues have been identified the next step is to set priorities. Often it is better to tackle the more feasible development and resource management problems first, rather than to attempt to resolve more complex problems or address all problems simultaneously. Importantly, local priorities must be integrated with regional and national priorities for water management, linking them to overall integrated water resource management strategies and plans.

3. Identification of management options
Once priorities for basin management have been agreed, the next step is to determine what management action is necessary to address these priorities. In this step, identifying and targeting action needs to take place at several levels:
- at the local level, for specific farms, properties or neighbourhoods, municipalities and industries, tourism areas, or fragile ecosystems, such as site management plans;
- at the sub-basin level, where there are cross-cutting issues which require a broader scale of management, such as storm water management plans, pollution control;
- at the whole basin level, where government and other institutions need to take action, on for example cost-sharing, tax incentives, laws to abate pollution, poverty reduction, building the capacity of water user groups.

4. Analysing costs and benefits
Once water management options have been identified, the next steps are:
to select the most cost-efficient set of options regarding selected priorities, that is the set of actions that will address the priorities (objectives) at the lowest cost;
- to assess the costs and benefits of the selected set of options (and how these costs will be divided between different sectors).
- To do this, economic analysis tools, such as cost-effectiveness analysis and cost–benefit analysis, can be used.

5. Assessing risks
One of the key issues in developing long-term basin management strategic plans is to assess risks, such as those posed by floods, droughts or other natural disasters, and to devise measures to alleviate these risks (Box 3). Box 3. Strategies for risk management

**Box 3-3 Strategies for risk management**

**Hard strategies** – infrastructure and technology:
- traditional water storage systems;
- flood proofing;
- storage management;
- early warning systems;
– integrated water systems and supply security;
– water reuse and desalination

**Soft strategies** – institutions, technologies and management systems:
– demand management;
– efficient technologies;
– establishing a culture of conservation;
– managing water scarcity through trade;
– integrated flood management;
– land use planning;
– education and communications.

**Phase 6: Plan preparation and approval**
On the basis of the vision and the results of situational analysis and strategies plan can be prepared at this stage. The plan shows details of what has to be done, by whom, when and using what resources. The production of a feasible, acceptable and relevant plan is the expected result of this step in the planning cycle. Several drafts may be required to achieve feasible and realistic activities as well as to get the agreement of the stakeholders to the plan. Action plans are varied in scope, but they all share one feature: they consist of a series of actions (projects) in a logical implementation sequence. Action plan objectives should be clear, measurable, realistic and easy to communicate.

There are a range of issues that a basin plan could address. These issues will differ from country to country depending on what the state of water and water management is in a particular country and should be driven by strategy and long terms objectives. The basin action plan sets out the goals, objectives and programmes for managing water resources for a specific period. The agreed plan will specify responsibilities for action, how costs will be shared, lines of accountability and channels for exchanging and distributing information. According to GWP (2009), the main components of river basin management action plan are:

– Description of the state of basin natural resources, trends, and how changes are happening and will be monitored.
– Inventories of land use, ecosystems, current water availability and demands, pollution sources.
– Assessments of aquatic and terrestrial ecosystem needs, vulnerability to floods, droughts or extreme meteorological events, implications of changing land use.
– Analyses of stakeholders, stakeholder needs and mechanisms for participation.
– Analyses of priority issues.
– Basin and sub-basin goals, both short- and long-term.
– Water allocation and water quality objectives.
– Benefit shares.
– Water-related development scenarios, assessments of future water demand, risk assessments.
– Strategy, measures and action plans for the achievement of goals, including sub-basin management plans and implementation guidelines.
– Financing arrangements for water use and management, including details of cost-sharing programmes for projects and other actions.
– Responsibilities and schedules for implementation.
Details of the monitoring programme.
- Appendices describing particular basin management issues, areas and management techniques, and specific studies such as areas of environmental significance.

Approval by the government is essential for resources mobilization and implementation of the plan. After completion of the plan, it needs to be accepted by all stakeholders including government. That is why political and stakeholder participation from the onset of the process of developing water resources management plan is so important. If the participation process was good, then approval should not be problematic.

Agreeing on the conditions of what the process to develop the plan and what the content of the plan should be in the beginning enhances the change that the plan will be approved by stakeholders and Government. If all the stakeholders (including Government) have been involved in the development of the plan from the very beginning, approval should be a mere formality.

**Phase 7: Implementation**
Implementation implies a societal consensus that the plan is acceptable as a means of reaching water resources management goals for a river basin. According to Heathcote (1998) implementation means getting individuals and organizations to: 1) agree on a desired plan for action, 2) agree on indicators of progress towards the shared goal, 3) allocate task among the various water users in the basin, 4) allocate the cost of water management among the various water users in the basin, 5) agree on periodic review of water management activities in the basin.

This sequence of tasks means that individuals and organizations must agree on equitable sharing of water resources and the responsibility for water management. In effect, it means balancing private interests against public interests. This balancing act requires agreement among players who may have very different values and different visions of ideal basin condition. The most difficult part of implementation lies in reaching agreement among the various players. It requires political will, encouraged by well-developed public consensus, to ensure that the plan is put into action.

**Phase 8: Evaluation**
To achieve long term sustainability, the plan should be seen as revolving with features of evaluation and reformulation at periodic intervals to reflect adjustments to changing situation. Completion of the plan is a major achievement, however very often plans may not be implemented totally or partially for the following main reasons:

- Lack of political commitment to the process due to external constraints or a lack of engagement of key decision makers in initiating the process.
- Unrealistic planning of resource requirements that the government may not be able to fund.
- Plans rejected by one or more influential groups due to inadequate consultation or unrealistic expectations of compromise where economic benefits or power relations may be affected, adequate consultation is vital.
- Lack of adequate knowledge greatly affects stakeholders’ ability to contribute or perform as well as the quality of the plan and its implementation. It is essential to consider the capacity building needs during the planning process and revise and refine it as the work moves along.
3.2 Operational Management

3.2.1 What is operational management?

Operation management is by far the most important element in integrated river basin management (Figure 3.2). It has a direct impact on the river basin because the decisions taken in the river basin management plan are transformed into actions (Teodosiu et al., 2003). In other words, operational management is concerned about putting into action the plans and programs that planners believe will be effective in improving the state of the river basins ecosystem. It takes place in an organizational and institutional setting. Operational management can affect river basins in different ways. It may interfere directly in the river basin by means of river regulation, constructing and operating water supply infrastructure, reforestation projects, etc (Table 3-3). It may also address the behaviour of the different users or managers by explicitly forbidding or allowing certain activities (regulation), by offering economic (dis)incentives and by providing information. Different resources are necessary to apply these instruments, such as money, personnel, legal resources, appropriate policy directives and data.

3.2.2 Instruments of operational management

Instruments are required to enforce the implementation of the agreed plan. The instruments can be adjusted and applied according to the nature of the problem to be solved. For example, for the pollution control in the river basin economic measures can be applied, with regard to the principle of “polluter pays” or technical solutions to reduce pollution (provide adequate treatment for wastewater).

Table 3-3 gives an overview of the different types of instruments for operational river basin management. Any effective river basin management system requires a mix of these instruments.

<table>
<thead>
<tr>
<th>Type of actions</th>
<th>characteristics</th>
<th>Instruments</th>
</tr>
</thead>
</table>
| Direct actions        | Direct interference by the managers in the river basin | § Structural flood protection  
§ River regulations  
§ Water supply and sanitation infrastructure  
§ reforestation     |
| Legal actions         | Influencing other managers or users by primitive or prohibitive measures | § rules and regulations  
§ standard setting  
§ water right and permits  
§ compliance monitoring  
§ sanctioning     |
| Economic instruments  | Influencing other managers or users by means of financial incentives or disincentives (market mechanisms) | § charges (taxes, levies, fees etc.)  
§ Subsidies (financial contributions etc.)  
§ Tradable water use and pollution  |
3.2.3 Operational Infrastructure

Implementation of water resources management plan is unthinkable without the required infrastructure (example: water supply, flood protections, conservation etc). Yet, infrastructure is also very expensive, and someone has to bear the cost, also in case of subsidies. Moreover, infrastructure often reduces the ‘resilience’ (adaptability) of river basins and can offer an alternative. In water supply, they include water re-use, water saving, water pricing, educational activities and locating water-intensive activities in water rich areas (demand management). In flood protection, non-structural measures include land use planning (e.g. not building up flood-prone areas) and insurance.

3.2.4 Water Quality Management

The quality of surface and groundwater resources can significantly affect water use in many regions. In regions where water pollutants from human activities have seriously degraded water quality, the main issue in water quality management is to control pollution sources.

The wide range of water pollutants can be classified into two major pollutant categories. These are: **Point sources**: these include domestic sewage and industrial wastes because they are collected and discharged into receiving surface and groundwater from a single point. Sanitary sewage from homes, commercial establishments, and public institutions is referred to as domestic sewage. **Non-point sources**: if the pollutants are discharged to water bodies from multiple points, then the pollutant sources are non-point sources. The major non-point sources can be classified as agricultural return flows and urban runoffs.

Reduction or elimination of point sources of pollution can be implemented by proper treatment processes before discharging to receiving waters, but treatment of non-point effluents usually is not economically feasible. Pollution from non-point sources need to be controlled directly at their sources through regulatory mechanisms (Table 3-4).

| **Table 3-4: Regulatory approach to pollution control** |
|-----------|-----------------------------------------------|
| **Approach** | **Description** |
| Public participation |  |
| Non-binding plans |  |
| Voluntary agreements |  |
| Funding desirable activities |  |
| Obligations (fees) |  |
| Capacity building |  |
| planning |  |
| Legislation |  |
| Extension services |  |
| Product policy                                                                 | Explicit forbidding or allowing the use of specific products  
| Quality standards for products                                                 |                                                                 |
| Process standard                                                              | Prescribing specific processes  
| Standards concerning the environmental performance of production processes     |                                                                 |
| Uniform emission standards                                                    | Emission standards applying to all emissions in a certain area |
| Water quality approach                                                        | Emission standards, usually set in a permit, that reflect the quality of receiving water in relation to the prevalent quality standards |

There is no universally best approach. It depends on factors such as the urgency of pollution problems, the substance concerned, the pollution source, the capacity of the managers, etc. In practice the different approaches are often combined.

### 3.2.5 Water charges and cost recovery

Water charges are economic instruments used in water management. Water tariffs are among the most important economic instruments and are set to change users for recurrent use of water service. Other instruments are water fees, which are charged when water permits are issued. Users can also be charged for abstraction of water by multiple users and discharge of effluent into water bodies. Water charges are an effective and efficient means to finance resource development activities, minimize wastage, and control pollution. Generally speaking, charging for water is applying an economic instrument to achieve the following multiple objectives (Cap-Net, 2008):

- To support disadvantaged groups;
- Influence behaviour towards conservation and efficient water usage;
- Provide incentives for demand management;
- Ensure cost recovery; and
- Signal consumer willingness to pay for additional investments in water services.

Water can be charged in two ways: based on the actual usage or on a lump-sum basis. The charges that are based on actual water use certainly help reduce the water use and wastage to a certain extent. The extent of the impact of price depends on the price elasticity of water demand.

Elasticity of demand is a measure of responsiveness of consumers' purchases to variation in price. It is defined as the percentage by which the quantity used changes in response to a 1% change in price. The price elasticity of demand for water is a measure of willingness of a consumer to reduce the use of water in response to the rise in price or use more water if price falls. If the quantity demanded does not change much with price, then the demand is said to be inelastic and it is elastic when there are large changes in demand with price.
Price elasticity of water demand is generally low in the case of the drinking water use and high for irrigation water. When charges are on a lump-sum basis, wastage is high and recovery of full cost of providing services is difficult.

Charges that reflect the full economic and environmental costs of water and pollution are economically efficient since they confront the water users/polluter with the real costs and promote an integral assessment of the costs and benefits. Moreover, they solve the financial problems of the providers of the water service concerned. Yet, there are some potential complications. First, water should not become too expensive for the poor to meet their basic needs. Second, high charges can make irrigated agriculture unprofitable, resulting in a drop in production. This will cause an often welcome drop in water use, but the effects on the rural communities can be quite substantial, especially if there is no alternative source of income. Related to this point, very high charges and especially rapid increases may decrease the willingness to pay and may result in massive political oppositions.

3.2.6 Water right

Water right is defined as the “right to take and use water subject to the terms and conditions of the grant”. There are two basic categories of water rights. The first is a “basic water right” that people have as a consequence of primary legislation, which is permanent and not subject to any administrative process. The second is a “water-use right” conferred through an administrative process of water allocation, such as licensing (cf. Bird et al., 2009).

Figure 3-4 distinguishes between basic water rights, such as those defined in primary legislation for basic human needs, water-use rights that are decided through a defined administrative process and reserved amount of the water resource that is to be retained in the river or aquifer for environmental or other sustainability related downstream purposes. The figure depicts the importance of including economic, social and environmental issues while allocating water resources.

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**Fig. 3-4: Categories of water rights (After Bird et al., 2009)**
Basic water rights generally amount to a very small percentage of overall water resources, whereas water resources allocated for municipal, industrial, or irrigation uses are generally far larger. Environmental reserve is sometimes quoted as a simple percentage of minimum flow, but in practice needs more specific definition because it comprises a complex pattern of seasonally managed flows tailored to the environmental objectives in each location.

Use rights do not always follow automatically from ownership rights. In case of government ownership, water use rights are generally granted by a government body by means of permits, concessions, etc. Private ownership, however, does not necessarily mean that the private owner can use the water as he pleases. His ownership may be limited by the government and permit may be needed for specific uses. If the water is seen as the property of the whole community or as incapable of being owned by anyone, water use is often regulated by the government. However, in many places local communities of users have their own institutions to manage water use (‘community property management’).

In the case of water use rights major issues are whether these rights are granted for a specific period or in perpetuity and under which conditions they can be revised. A relatively high degree of flexibility - combined with existing rights and if necessary compensation - seems essential for effective IRBM in a changing world.

3.2.7 Water allocation

Water is a shared resource among various sectors such as water supply and sanitation, irrigation, industrial sectors, and hydropower generation. Water allocation is the process in which an available water resource is distributed to legitimate claimants. The resulting authorization for use is granted, transferred, reviewed, and adapted as a “water use right.” Priorities for allocating water can be defined in law or through strategy development or planning processes. Water allocation is the process of assigning water from a given source to a given user or number of users for abstracting it and applying it to a given use (cf. Bird et al., 2009).

Societies invested capital in infrastructure to maintain allocation of water. Water has traditionally been provided to meet demand with substantial involvement of governments. Allocation by governments, usually referred to as public allocation, has usually not addressed economic efficiency, but has been necessary because of several features that distinguish water from other scarce resources. Water has several characteristics that make the role of the public sector in its development and management more essential than for other goods that can be handled efficiently in a market framework. For example, some water services are public goods, that is, their provision to one individual does not eliminate other individuals from using it (cf. Dinar et al., 1997). There are other characteristics of water, such as its physical nature, which make it hard to transport and allocate. It is a common pool resource, allowing several users to benefit from its consumption. For these reasons, public (government) allocation of water is still the main mechanism in many countries.

Since countries and circumstances vary widely, water allocation within any country can be regarded as a unique system for sharing the available water across the known sources of demand. The structure
of any particular system of water allocation is of course influenced by the existing institutional and legal frameworks as well as the water resources infrastructure.

With increased population, improved life style, and dwindling supplies (both in terms of quantity and quality), the competition for scarce water resources is increasing. It is thus crucial that the existing water resources be allocated more efficiently. It is therefore necessary to make economic decisions compatible with social objectives, i.e. efficiency and equity considerations. Many forms of water allocation schemes attempt to combine both efficiency and equity principles.

**Principle of economic efficiency**
Resource allocation is economically efficient when the marginal benefit from the use of the resource is equal across sectors (i.e. uses) in order to maximize social welfare. In other words, the benefit from using one additional unit of the resource in one sector should be the same as it is in any other sector. If not, society would benefit by allocating more water to the sector where the benefits, or returns, will be highest.

**Principle of equity**
Resource allocation may also be based on equity. Equity objectives are particularly concerned with fairness of allocation across economically disparate groups, and may or may not be consistent with efficiency objectives. In the case of drinking water, for example, an equitable allocation of water resources suggests that all households, regardless of their ability to purchase water, still have a basic right to water services. Meeting this objective may entail providing government subsidies or free service, or perhaps adopting a differential pricing structure based on income.
3.3 Economics and Finance

3.3.1 General

Economics refers mainly to the situations in which a decision must be made regarding the allocation of scarce resources among alternative uses. Economic analysis give due attention to the efficiency of the allocation and to the distribution of assets and incomes behind and around the allocation process.

Finance, on the other hand, refers to specific actions taken by organizations or firms, which can be private or public, in order to maximize short or long-term returns to their assets and investments. With increasing scarcity of water, economic and financial instruments are increasingly used for water resources management.

Water resources development projects create value on one hand and on the other side they encounter costs. The value side of the analysis is based on the fact that individuals have preferences for goods and services. The value of a good to a person is what that person is willing to pay for that good. Thus, the value of a good or service is tied to willingness to pay. The marginal willingness to pay is what each person is willing to pay for an additional unit of a good or service.

The costs associated with different economic activities can be classified as fixed and variable. Fixed costs are not affected by the range of operation or activity level. General management and administrative salaries and taxes on facilities are some examples of fixed costs. Variable costs are those associated with the quantity of output or other measures of activity level. An incremental cost or incremental revenue is the additional cost or revenue that results from increasing the output of a system by one unit.

3.3.2 The time value of money and discount rates

One of the most important concerns of economic analysis is that the value of money changes with time. Two factors operate on the value of money over time: interest (a fee paid by the borrower or user of money for the privilege of that use), and inflation (the phenomenon by which prices for goods and services are not constant over time but fluctuate in response to a variety of social and economic conditions. Often, higher interest rates are paid for riskier investments. Two types of interest rates can be distinguished: simple and compound interest rates.

Simple interest is interest paid as a percentage of the original loan. Compound interest is the more commonly used form. Here the interest is paid on the original loan amount (the principal) plus any accumulated interest charges. For example, a loan of $1000 at 10% interest over five years would require the following simple and compound interest payments:

<table>
<thead>
<tr>
<th>Year</th>
<th>Simple interest</th>
<th>Compound interest</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10% of $1000 = $100</td>
<td>10% of $1000 = $100</td>
</tr>
<tr>
<td>2</td>
<td>10% of $1100 = $110</td>
<td>10% of $1200 = $121</td>
</tr>
<tr>
<td>3</td>
<td>10% of $1200 = $121</td>
<td>10% of $1331.10 = $133.10</td>
</tr>
<tr>
<td>4</td>
<td>10% of $1331.10 = $133.10</td>
<td>10% of $1464.10 = $146.41</td>
</tr>
<tr>
<td>5</td>
<td>10% of $1464.10 = $146.41</td>
<td>10% of $1610.51 = $161.051</td>
</tr>
</tbody>
</table>
In the case of compound interest, the total interest charges paid on the loan would be $610.51, as compared with $500 using simple interest. This concept can be expressed by an exponential relationship of the form:

\[ F = P(1+i)^n \]  

(3.1)

Where:
- \( F \) = future value, the future amount payable on the loaned amount, \( P \)
- \( P \) = present value, the principal of the loan, the amount borrowed
- \( i \) = the interest rate expressed in %
- \( n \) = number of compounding intervals (if compounded once a year, this would be number of years)

This simple relationship is the foundation of all time-value-of-money calculations. It can be used to calculate the amount payable on a loan after \( n \) years at \( i\% \) interest.

Common units are important for comparison of projects and their consequences. The most convenient unit in the present era is a money unit. But the value of money changes with time and therefore, even though the consequences are expressed in monetary units, amounts at different times cannot be compared or combined. To make them comparable, all monetary values are converted to equivalent amounts at some definite time. This conversion is made by using discount factors.

The major obstacles in comparison of alternatives are the differences in kind and in time. The two basic principles: equivalence of kind and equivalence of time are employed to facilitate the comparison. To explain this, we begin with the simplest case. Assume that some principal amount \( P \) units (say ETB) are invested at an annual interest rate of \( i \) percent. After one year, the amount will grow to become \( P(1+i) \). After one more year, it will be \( P(1+i)^2 \). In this way, after \( n \) years, the final amount will be \( P(1+i)^n \).

Depending upon the payment of principal and compounding interest, many discount factors are used in economic analysis. A summary of these is given in Table 3-5.

Table 3-5: Summary of discounting factors

<table>
<thead>
<tr>
<th>Types of discount factors</th>
<th>Description</th>
<th>Formula</th>
<th>Interest factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-payment factor</td>
<td>Compound-amount factor</td>
<td>An amount ( P ) invested at the beginning of first year grows to ( F ) after end of ( n ) years</td>
<td>[ F = P(1+i)^n ]</td>
</tr>
<tr>
<td></td>
<td>Present worth factor</td>
<td>It gives the present value of a future amount ( F ) that might be available after ( n ) years (inverse of above).</td>
<td>[ P = F \bigg/ (1+i)^n ]</td>
</tr>
<tr>
<td></td>
<td>Series-compound</td>
<td>The amount ( F ) that will be obtained at the end of ( n )</td>
<td></td>
</tr>
</tbody>
</table>
### Uniform annual series factors

<table>
<thead>
<tr>
<th>Amount factor</th>
<th>Description</th>
<th>Formula</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uniform annual series factors</td>
<td>Amount factor years if a series of uniform payments A is made (e.g. monthly payments into a bank account: how much money will have accumulated after n years?)</td>
<td>$F = A \left[ \frac{(1+i)^n - 1}{i} \right]$</td>
<td>$F/A, i%, n$</td>
</tr>
<tr>
<td>Sinking-fund factor</td>
<td>The inverse of the above equation (i.e., the individual payment amount required to accumulate a total of F dollars at the end of the period of investment). The term in bracket is sometimes called ‘sinking fund’ factor.</td>
<td>$A = F \left[ \frac{i}{(1+i)^n - 1} \right]$</td>
<td>$A/F, i%, n$</td>
</tr>
<tr>
<td>Series-present worth factor</td>
<td>The present value (the value in today’s dollars) of a series of uniform payments. This calculation may be of interest if the investor wishes to withdraw a certain amount in each of several years and wants to know how much money must be invested now to support these withdrawals.</td>
<td>$P = A \left[ \frac{(1+i)^n - 1}{i(1+i)^n} \right]$</td>
<td>$P/A, i%, n$</td>
</tr>
<tr>
<td>Capital recovery factor</td>
<td>The inverse of the above equation may be calculated to determine the value of a series of uniform payments required to repay a loan of present value P.</td>
<td>$A = P \left[ \frac{i(1+i)^n}{(1+i)^n - 1} \right]$</td>
<td>$A/P, i%, n$</td>
</tr>
</tbody>
</table>

### 3.3.3 Project economics and evaluation

Project economics involves the identification and quantification of all kinds of costs and benefits associated with a project and economic analysis of the proposed plans. Project evaluation involves testing the project for all types of feasibilities and assessment of implications of changes in inputs. These studies are important before adopting a project plan or policy because water resources projects directly affect the development of a state, or region and the living standard of the people therein.

**Benefit-cost analysis.**

The benefit-cost ratio method has been widely used in the economic analysis of water resources projects. This method is based on the calculation of the ratio of benefits to costs. Calculation of this ratio is relatively simple. More controversial is the problem of what to include in, and exclude from the analysis. One of the basic formulations for the benefit–cost ratio method is as follows:
\[ \frac{B}{C} \text{ factor} = \frac{B}{I + C} \]  
(3.7)

where:

- \( B \) = the net equivalent benefits.
- \( C \) = the net equivalent annual costs, usually classified as operation and maintenance costs.
- \( I \) = the initial investment.

For any project to remain under consideration, its benefit–cost ratio should exceed one. Therefore,

\[ \frac{B}{I + C} > 1 \]

Then,

\[ B - (I + C) > 0 \]

Therefore, the benefit–cost criterion will eliminate all those projects for which equivalent amounts are less than zero. Another formulation for this method, which reflects the net gain expected per dollar invested, is as follows:

\[ B/C \text{ factor} = \frac{B - C}{I} \]

Eq. (3.8)

In order to consider the salvage value associated with an investment, the following relation can also be used in applying the benefit–cost method:

\[ B/C \text{ factor} = \frac{B - C}{I - S} \]

Eq. (3.9)

Where \( S \) is the salvage value of the investment

If present value or present worth is the desired measure, the ratio can be calculated as the present value of all benefits to present value of all costs.

\[ B/C \text{ factor} = \frac{\sum_{t=0}^{n} B_t}{\sum_{t=0}^{n} C_t} \]

Eq. (3.10)

Where \( B_t \) and \( C_t \) are the monetary values of benefits and costs incurred at time \( t \) respectively.

Depending on the type of project and the goals and objectives of decision makers, it may sometimes be important to maximize or minimize components of the benefit-cost analysis. Table 3-6 provides examples of common targets in cost-benefit analysis and decision rules.
### Table 3-6: Some common targets and decision of cost-benefit analysis

<table>
<thead>
<tr>
<th>Targets</th>
<th>Decisions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximize total benefit</td>
<td>Choose the alternative that has the highest present worth of total benefit, for instance, to emphasize the positive impact a project would have on a community</td>
</tr>
<tr>
<td>Maximize net benefits</td>
<td>Choose the alternative that has the highest net benefits (net benefit = total benefits – total costs), to draw attention to the net (incremental) benefit to the community</td>
</tr>
<tr>
<td>Maximize total costs</td>
<td>Choose the lowest-cost alternative that still demonstrates a B/C ratio &gt; 1.0, perhaps because total available funds are limited</td>
</tr>
<tr>
<td>Minimize capital (investment) costs</td>
<td>Choose the alternative that has the lowest initial cost, but which still demonstrate a B/C ration &gt; 1.0, perhaps because a fixed sum is available for project construction</td>
</tr>
<tr>
<td>Minimize operating and maintenance costs</td>
<td>Choose the alternative that has the lowest operation and maintenance costs, but which still demonstrate a B/C ration &gt; 1.0, perhaps to minimize the annual financial load of a project</td>
</tr>
<tr>
<td>Maximize rate of return</td>
<td>For some projects like major irrigation projects, which have significant expected revenues, cost recovery or even cost surpluses may be possible. In these cases, decision makers may opt for the alternative that shows the highest rate of return</td>
</tr>
</tbody>
</table>

In theory, analysis of benefit-cost ratios is straightforward: project is considered economically viable if benefit outweighs costs. In practice, however, this analysis is often more complicated by several factors. There is the problem of deciding what to include as ‘benefit’ and as ‘costs’.

#### 3.3.4 Economic analysis and multiple alternatives

The principal objective of economic analysis is to find out whether a capital investment and the costs associated with the project within the project lifetime can be recovered by revenues. In addition, it is important to find out whether the investment is sufficiently attractive considering the risks involved and potential alternative uses. The five methods explained briefly in this section are 1) present worth, 2) future worth, 3) annual worth, and 4) internal rate of return. When comparing alternatives, the selection of one alternative might exclude the others; these alternatives are mutually exclusive. Different projects usually have different useful lives, which should be reflected in the economic analysis.

**Present worth method**

In this method, the alternative that has the largest present worth ($PW$) of the discounted sum of benefits minus costs over its life is selected:

$$PW = \sum_{t=1}^{n} \left( B_t - C_t \right) \left( P / F, i\%, t \right)$$

Eq. (3.11)

Where:

- $C_t$ = the monetary value of cost of each alternative in year $t$.
- $B_t$ = the monetary value of benefit of each alternative in year $t$. 

95
\[ n\] = the study period in years or the planning horizon.

\[ i\] = the interest rate.

By using this method to evaluate investment alternatives, the one with the greatest positive equivalent worth or least negative equivalent worth is selected. This technique is also called the net present worth or the net present value because this method reduces a stream of costs and benefits to a single number. The net worth (benefit-cost) for each year is computed and discounted to the present. A sum of these gives the net present value (NPV):

\[
NPV = \frac{B_0 - C_0}{(1+i)^0} + \frac{B_1 - C_1}{(1+i)^1} + \frac{B_2 - C_2}{(1+i)^2} + \ldots + \frac{B_n - C_n}{(1+i)^n}
\]

Eq. (3.12)

The steps involved in this method are enumerated below:

- Calculate the present worth of each alternative using appropriate discounting factor.
- Choose all the alternatives having a positive present worth. Reject the rest. If no sets of mutually exclusive alternatives remain, stop. Otherwise, step 3 or 4, as appropriate, is adopted to choose the best alternative.
- In a set of mutually exclusive alternatives, choose the one that has the greatest present worth.
- If in a set of mutually exclusive alternatives, some have benefits that cannot be quantified but are approximately equal, choose the alternative having the least cost.

The following rules are followed while calculating the present worth of a project:

- Compute all present worth to the same time base, irrespective of the initial time of different alternatives.
- Compute all present worth by using the same discount rate, even if the alternatives are being financed from different sources.
- Base all present worth on the same period of analysis, irrespective of differences in economic life.

**Future worth method**

This measures what today’s money would be worth at a specified time in the future assuming a certain discount rate. In this method, all benefits and costs of different alternatives are converted into their future worth figures. Then, the alternative with the greatest future worth or the least negative future worth is selected. When using this method, the following items should be considered:

- The same discount rate should be used for all alternatives.
- The same time base should be used for estimating the future worth of alternatives.
- The same study period should be used for all alternatives.

**Annual worth method**

In this method, the costs and benefits of all alternatives are converted to uniform annual figures, and then the alternative with the greatest annual worth or the least negative worth, in the case of cost alternatives, is selected. When using this method, projects with different economic lives can be
compared irrespective project life. It should be noted that when applying this method, the same
discount rate should be used for all alternatives, just as for the present worth and future worth
methods.

**Internal rate of revenue (IRR) method**
The IRR method is one of the most widely used methods for economic analysis. In this method, the
IRR is defined as the discount rate that will set the net present value or the net future value of the cash
flow profile equal to zero. This rate, which is found by trial and error, is the rate-of-return that equates
the initial cost and the sum of discounted future net benefits. At this rate, the benefit-cost ratio is close
to one. This rate represents the average rate of interest at which a project pays back the investment
over its life time. Therefore, it is a criterion for comparing alternative investment opportunities.
In this method, the projects that have IRR less than the minimum attractive rate of return (MARR)
will be rejected. The present worth and annual worth methods are usually used to find the IRR.
Mathematically, IRR is some discount rate \( r \) such that the initial cost \( C_0 \) is equal to the present worth
of benefits:

\[
C_0 = \frac{B_1 - C_1}{(1+i)^1} + \frac{B_2 - C_2}{(1+i)^2} + \ldots + \frac{B_n - C_n}{(1+i)^n}
\]

Eq. (3.13)

Alternatively, it is the discount rate \( i \) which would make NPV of the project equal to zero.
The following steps are involved in comparing alternatives by this method:

- Calculate the rate of return for each alternative.
- Choose all alternatives having a rate of return exceeding the minimum acceptable value,
  known as minimum attractive rate of return (MARR). Reject the rest. If sets of mutually
  exclusive alternatives are involved, proceed to steps 3, 4 and 5.
- Rank the alternatives in the set of mutually exclusive alternatives in order of increasing cost.
  Calculate the rate of return on the incremental cost and incremental benefits of the next
  alternative above the least costly alternative.
- Choose the more costly alternative if IRR exceeds the minimum acceptable discount rate.
  Otherwise choose the less costly alternative.
- Continue the analysis by considering the alternatives in order of rank.

Example:
Suppose you have invested $1000 in a project. Based on the contract, you will receive benefits of
$500 and $1500, 3 and 5 years later, respectively. How much is the IRR of the investment?

Solution: Using the present worth method, it can be written that:

\[
-1000 + 500 \left( \frac{P}{F, i\%, 3} \right) + 1500 \left( \frac{P}{F, i\%, 5} \right) = 0
\]

\[
-1000 \left( \frac{1}{(1+i)^1} \right) + 500 \left( \frac{1}{(1+i)^3} \right) + 1500 \left( \frac{1}{(1+i)^5} \right) = 0
\]
By trial and error \( i = 16.9\% \)

So, if MARR is less than 16.9% the investment will not be rejected

### 3.3.5 Cost and value of water

Provision of water incurs a certain amount of cost. From the use of water, one can derive a value which can be affected by the reliability of supply and the quality of water. The ideal for the sustainable use of water is that the values and the costs should balance each other.

Figure 3-5 provides the general principles of costs of water. There are three important concepts illustrated in this figure: the full supply cost, the full economic cost, and the full cost. The details of these costs are described in Table 3-7.

![Figure 3-5: General principles for cost of water (After Rogers et al., 1998)](image)

<table>
<thead>
<tr>
<th>Components</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full supply cost</td>
<td>The full supply cost includes the costs associated with the supply of water to a consumer without consideration neither the externalities imposed upon others nor the alternate uses of the water. Full supply costs are composed of operational and maintenance costs.</td>
</tr>
<tr>
<td>Full economic cost</td>
<td>The full economic cost of water is the sum of the full supply cost as described in the above, the opportunity cost associated with the alternate use of the same water resource, and the economic externalities imposed upon others due to the consumption of water by a specific actor.</td>
</tr>
<tr>
<td>Opportunity cost</td>
<td>The opportunity cost arises because by consuming water, another user of water is being deprived of water. If that other user has a higher value for the water, then there are some opportunity costs experienced by society due to this misallocation of resources. The opportunity cost of water is zero only</td>
</tr>
</tbody>
</table>
when there is no alternative use – that is no shortage of water.

<table>
<thead>
<tr>
<th>Economic externalities</th>
<th>The issue of water may result in pervasive externalities. The most common externalities are those associated with the impact of an upstream diversion of water or with the release of pollution on downstream users.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full cost</td>
<td>The full cost of consumption of water is the full economic cost, given above, plus the environmental externalities.</td>
</tr>
<tr>
<td>Environmental externalities</td>
<td>Environmental externalities are those associated with public health and ecosystem maintenance. Hence, if pollution causes increased production or consumption costs to downstream users, it is an economic externality, but if it causes public health or ecosystem impacts, then we define it as an environmental externality.</td>
</tr>
</tbody>
</table>

Full cost recovery should be the goal for all water uses unless there are compelling reasons for not doing so. While, in principle, the full cost needs to be estimated and made known for purposes of rational allocation and management decisions, it need not necessarily be charged to the users.

The value of water depends both upon the user and to the use to which it is put. Figure 3-6 shows schematically the components of the value in use of water, which is the sum of the economic and intrinsic values. As shown in the figure, the components of economic value are: value to users of water, net benefits from return flows, net benefits from indirect use, and adjustments for societal objectives.

![Fig. 3-6: General principles for the value in use (Rogers et al., 1998)](image)

For economic equilibrium, the value of water, which we estimate from the value in use should just equal the full cost of water. At that point, the classical economic model indicates that social welfare is maximized. In practical cases, however, the Value in Use is typically expected to be higher than the estimated full cost. This is often because of difficulties in estimating the environmental externalities in the full cost calculations. The descriptions of values indicated in Figure 3-6 are given in Table 3-8.
Table 3-8: Description of the components of full value given in Figure 3-6

<table>
<thead>
<tr>
<th>Components</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value to users of water</td>
<td>For industrial and agricultural uses, the value to users is at least as large as the marginal value of product (i.e. the additional value to the consumer (or society) of an additional unit of water). For domestic use, the willingness to pay for water represents a lower bound on its value.</td>
</tr>
<tr>
<td>Net benefit from return flow</td>
<td>Return flows from water diverted for urban, industrial, and agricultural uses constitute a vital element of many hydrological systems, thus the effects of these flows must be taken into account while estimating the value and cost of water.</td>
</tr>
<tr>
<td>Net benefit from indirect use</td>
<td>The typical example of these benefits occurs with irrigation schemes that provide water for domestic use (drinking and personal hygiene) and livestock purposes, which can result in improved health and/or higher incomes for the rural poor.</td>
</tr>
<tr>
<td>Adjustment for societal objectives</td>
<td>For water use in the household and agricultural sectors, there may be an adjustment made for societal objectives such as: poverty alleviation, employment and food security (particularly in rural areas, where food-grain prices tend to be high in the absence of the additional food output gained from irrigated agriculture, and where it may be difficult to supply imported food-grains).</td>
</tr>
</tbody>
</table>

3.3.6 Finance

River basin management requires adequate, reliable and sustained financing. Before setting up a basin management system, the funds required for its operation must be quantified and sources of funds identified. The two conventional cost categories are recurrent and capital costs. Recurrent costs are the regular expenses involved in operating all parts of the water infrastructures, including wages & salaries, fuel, electricity, chemicals, spare parts and minor capital items necessary to maintain and repair systems. The most sustainable source of funding these costs is user charges including cross-subsidies between user categories. Funding can also be made through government annual budget. Capital costs are relatively large investment, including:

- water infrastructure (dams, urban water distribution networks, etc.)
- resource development (e.g. protection of catchments and drilling groundwater wells)
- major maintenance and repairs
- modernization (e.g. the upgrading of a water treatment plant, irrigation projects) and
- rehabilitation of old or broken installations, etc.

Different kinds of financial instruments are increasingly used to generate financial revenues for the operation and development of the sector (Box 4).

Box 3-4: Instruments for financing water projects (Cap-Net, 2008)

i. Charges for the use of water and water service
   water abstraction charge
water tariffs for households, industries, farmers an
sewerage & effluent charge
water pollution charges and taxes
license fees & charges for use of specific services
flood protection levies

ii. National government grant
Payments from national, state or municipal budgets
Financial intermediaries and development banks
iii. External grants (official development assistance)
iv. Philanthropic and not-for-profit agencies & partnerships
v. Commercial loans, bonds and private equity
   Loans
   Commercial bank loans and microfinance
   Bonds
   Private equity
   External guarantees and risk sharing

Water institutions are highly specific, and their financial structure must be tailor-made for each case. There is no universally valid blueprints strategy for water financing. However, some general principles provided by Cap-Net (2008) are as follows:

**Using public finance for public goods**: Certain water management activities possess clear “public good” features and have strong externalities (e.g. research & information, flood control, forestation, catchment protection, policy formation and protection of wetland biodiversity).

**Recover costs from users for directly productive services**: Introduce charges for the use of water services where these are affordable and where the services are used in a commercial or leisure context. For household water and sanitation, tariffs need to be designed with affordability in mind. If subsidies are used, they should be targeted to those most in need.

**Appropriate delegation of financial powers to local bodies**: This is in line with the widespread delegation of service responsibilities to sub-sovereign agencies.

**Increased self-financing of service providers**: Potentially self-financing projects and institutions should be encouraged to improve their finances and attract a wider spread of funds.

**Co-financing should be sought for transnational projects and those with international benefits**: The case for this is greater where upstream activities, or downstream environmental standards, impose additional costs on the country concerned.

**The cost of multipurpose schemes can be shared**: where water resource management creates other products and services (e.g. hydropower, flood protection, irrigation and recreation).
Some externalities of water can be captured in monetary form and the proceeds applied to WRM: According to the Polluter Pays Principle, the release of untreated effluent into watercourses should be taxed.

Partnerships (between governments, external agencies, NGOs, private operators, not-for-profit foundations, community & civil society organisations, etc.) are a good way to tap new sources of finance.

Tapping finance from commercial sources is a logical progression for water agencies or service providers that have achieved a sufficient degree of autonomy, capacity and creditworthiness.
3.4 Examples, Case studies and Tutorials

3.4.1 Examples- Time value of money and project analysis

*Examples 1:*
Consider two projects A and B that are to operate in the same area. Project A is able produce $5000 in the year 2011 and project B will produce 5200 after one year. Assuming interest rate, I, of 5% which project do you think is financially sound?

Solution:
$5000 is the present value (PV) and $5500 is future value (FV)

\[
FV \left( \frac{1}{(1+i)^n} \right) = 5200 \left( \frac{1}{(1+0.05)^1} \right) = 4952
\]

The PV of 2012:

Hence, project A is financially worth

*Example 2:*
Consider a project that has an initial investment cost of $50,000 and that returns $18,000 per year for the next four years. If the firm’s minimum attractive rate of return (MARR) is 12%, can this be a good investment?

\[
PW = -50,000 + 18,000 \left( P/A, 12\%, 4 \right) = -50,000 + 18,000 \left( \frac{(1 + 0.12)^4 - 1}{0.12(1 + 0.12)^4} \right) = 4672
\]

This is a good investment as it has 4672 dollars after returning the investment costs.

*Example 3:*
The possible costs and benefits of two water resources development projects that are proposed to supply the water demand of an industrial complex are given in the following table.

<table>
<thead>
<tr>
<th></th>
<th>Project A</th>
<th>Project B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction costs</td>
<td>$40,000</td>
<td>$25,000</td>
</tr>
<tr>
<td>Operation and maintenance costs</td>
<td>$160</td>
<td>$100</td>
</tr>
<tr>
<td>Annual benefits</td>
<td>$4,000</td>
<td>$4,000</td>
</tr>
<tr>
<td>Economic life (years)</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>

Assuming MARR = 5%, which project do you think is the best alternative?

Solution
By using the present worth method, it can be written that

\[
PW_A = -40,000 -160 \left( \frac{P}{A}, 5\%, 20 \right) + 4,000 \left( \frac{P}{A}, 5\%, 20 \right)
\]
\[-40,000 - 160 \left( \frac{1 + 0.05}{0.05(1 + 0.05)^{20}} - 1 \right) + 4,000 \left( \frac{1 + 0.05}{0.05(1 + 0.05)^{20}} - 1 \right) \]
\[-40,000 - 1,994 + 49,845 = 7,855 \]

Factor in bracket are calculated according to formula in Table 3.5

The present worth of alternative A = $7,855

Present worth of alternative B:
\[PW_A = -25,000 - 100 \left( \frac{P_A}{5\%, 20} \right) + 4,000 \left( \frac{P_A}{5\%, 20} \right)\]
\[-25,000 - 100 \left( \frac{(1 + 0.05)^{20} - 1}{0.05(1 + 0.05)^{20}} \right) + 4,000 \left( \frac{(1 + 0.05)^{20} - 1}{0.05(1 + 0.05)^{20}} \right)\]
\[-25,000 - 1,246 + 49,845 = 23,603 \]

Future worth of alternative A:
\[PW_A = -40,000 \left( \frac{F_A}{P, 5\%, 20} \right) - 160 \left( \frac{F_A}{P, 5\%, 20} \right) + 4,000 \left( \frac{F_A}{P, 5\%, 20} \right)\]
\[-40,000(1 + 0.05)^{20} - 160 \left( \frac{(1 + 0.05)^{20} - 1}{0.05} \right) + 4,000 \left( \frac{(1 + 0.05)^{20} - 1}{0.05} \right)\]
\[-40,000(2,65333) - 160(33.0660) + 4,000(30.0660) = 20,840 \]

Future worth of alternative B:
\[PW_A = -25,000 \left( \frac{F_A}{P, 5\%, 20} \right) - 100 \left( \frac{F_A}{P, 5\%, 20} \right) + 4,000 \left( \frac{F_A}{P, 5\%, 20} \right)\]
\[-25,000(2,65333) - 100(33.0660) + 4,000(30.0660) = 62,625 \]

In both present and future worth scenarios project B is found to be worth.

**Example: 4**

Consider that three flood control projects have been proposed for a given river. Each of the projects has a useful life of 25 years and the interest rate is 5% per year. The benefits and costs of the projects are as listed in the following table:

<table>
<thead>
<tr>
<th>Cost benefit (in millions of $)</th>
<th>Project A</th>
<th>Project B</th>
<th>Project C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital investment</td>
<td>10</td>
<td>10.5</td>
<td>11</td>
</tr>
<tr>
<td>Annual O&amp;M costs</td>
<td>0.7</td>
<td>0.65</td>
<td>0.63</td>
</tr>
<tr>
<td>Annual expected reduction in flood damage</td>
<td>1.5</td>
<td>1.55</td>
<td>1.6</td>
</tr>
</tbody>
</table>

Compare the alternatives using the benefit–cost ratio method.
For all the projects the benefit-cost ratio are greater than one. This indicates that all projects are acceptable.

For comparison of the projects:

1. **Project B vs. project A**: Project B has is more attractive than A both in terms of low costs and higher benefit.

2. Project B vs. project C:

   \[
   C - B : \left(\frac{\Delta B}{\Delta C}\right) = \frac{22,550,311 - 21,845,684}{19,879,185 - 19,661,064} = 3.23
   \]

   The estimated ratio is greater than one; therefore, project C is recommended.

**Summary questions**

- Why is river basin management important?
- Who initiates the river basin planning and management?
- What makes river basin planning different from other planning exercises?
- What is meant by vision?
- Identify the important elements of planning process and describe them.
- Why is situational analysis required?
- Compare and contrast the different planning approach?
- What is the importance of stakeholder involvement in planning and management of river basin?
- What are the instruments of operational management?
- Discuss the different regulations used to control water quality.
- What is meant by water right and how is it issued?
- Discuss the governing principles for water allocation.
- Distinguish between economic and financial analysis.
- Explain the four methods of economic analysis which are used to choose among multiple alternative projects.
- Distinguish between different values of water.
- What are the mechanisms of financing river basin projects?
3.4.2 Case study

_Tama River Basin in Japan (cf. UNESCO-IHP, 2009)_

1. Description of the River
The Tama River flows from its source in Mount Kasatori in Yamanashi Prefecture down to Tokyo Bay at the river mouth at Haneda. Its total length is 138 km with the river basin area spanning 1,240 sq. kilometers. The Tama River, which has about 20 million visitors annually, has several major features in the areas of flood control, water usage, and environmental preservation. In terms of flood control, as shown by the Komae Flood of 1974, the Tama River is set at a relatively steep slope compared with other rivers in the capital region, making it especially susceptible to flooding. In terms of river use, it faces issues such as water intake in the upstream areas and the inflow of treated sewage water in the midstream areas. In terms of environmental preservation, authorities implemented the Tama River Environment Management Plan in 1980, the first of its kind in Japan, based on direct dialogue with local residents.

2. Dialogue with residents
The dialogue aimed at river management and environmental conservation. The Tama river basin was rapidly urbanized from the 1960s. The use of riparian zones by communities as well as environmental conservation soon became major issues. At the beginning of the 1970s, while Tama River’s riparian zones were being progressively developed and utilized, civil societies became concerned of the decreasing areas of natural land, and civil movements started to appear opposing the development of ecologically diverse riparian zones into sports areas. Furthermore, public activities to protect the river also began to appear.

This context led to the development of the Tama River Environmental Management Plan in 1980, which was a result of direct dialogue between the administrative agency and the residents of the basin, and discussed the state of Tama River’s riparian zones as a precious open space in an urban setting.

The plan is based on 3 principles:
- provide a place for interaction between the Tama River and its residents;
- maintain the Tama River’s unique characteristics; and,
- utilize the Tama River’s unique characteristics.

It provided provisions for the conservation of the natural environment and the sustainable utilization of Tama River, as shown below. They clearly stated their commitment to ecological conservation some twenty years before biodiversity was internationally recognized.

**Five zones** were identified: a human development zone, a facility utilization zone, an environmental improvement zone, an environmental utilization zone, and an environmental conservation zone.

**Eight functional spaces** were attributed: an evacuation space, a local facility recreational space, a wide-area facility recreational space, a sports/health management space, a natural recreational space, an educational space, an information space, and an ecological maintenance space.
In 1986, the Minister for Construction, the governor of Tokyo Metropolitan Government, the governor of Kanagawa prefecture, and heads of related municipalities assembled for the Tama River Summit and announced a Tama River Summit Declaration, which called for “passing on the Tama River to the next generation where everyone can get acquainted with water and greens”. They recognized that the environment was an issue that concerned and spanned generations two years ahead of the Earth Summit in Rio de Janeiro, where ‘sustainable development’ was first recognized internationally.

In response to this declaration, the Ministry of Construction, the Tokyo Metropolitan Government, Kanagawa Prefecture, Yamanashi Prefecture, and related municipalities in the basin established the Tama River Basin Council in 1987 in order to promote measures to improve the Tama River environment and to enhance the interaction of people with water and the environment. Furthermore, in 1998, residents, academic experts, basin municipalities, river managers, and other concerned stakeholders established a Tama River Basin Roundtable in order to promote continuous exchange of information and opinions on Tama River improvement and the basin environment so as to build a collaborative framework with a deeper relationship of trust, and to facilitate loose-knit consensus-building towards a ‘good river/good city’ management approach.

The Tama River was transformed into a place where everyone who enjoys the river can participate in various activities such as children who began to play in the water again. As a result, the number of people using the river had increased from 6 million to 20 million in one year.

3. The fundamental spirit of direct dialogue
‘3 principles, 7 rules’ were laid out as the fundamental spirit for dialogue between the residents and the administrative agencies. As it was supposed that consensus would not be achieved from the outset, all parties agreed on the importance of discussing the issues on an equal footing while aiming for consensus. The word ‘loose-knit consensus’ was borne from the civil groups.

The 3 principles were:
− Speak freely.
− Discuss thoroughly.
− Build consensus.

The 7 rules were:
− Opinions of participants do not represent the official opinion of their organizations.
− Do not target specific individual or organization.
− Discuss under the spirit of fair play.
− Respect demonstrative data during discussion.
− Identify the problems and aim towards agreement.
− Any problems under dispute will be treated from an objective standpoint.
− When preparing a programme, distinguish them into long-term and short-term programs, and try to make realistic recommendations.
4. Consensus-building process
In 2001, the Tama River Improvement Plan – a plan for river improvement for the next twenty to thirty years – was developed through collaboration with various stakeholders including residents, municipalities, academic experts and so forth. The key points and innovations utilized for the consensus-building process are given below:

(i) Grass roots discussion
Discussions in rooms tend to fall into idealism, which can often lead to conflicts. It was attempted, as much as possible, to bring the discussion to the actual sites. A paper was prepared summarizing the discussion points. It ensured that the discussion stayed on the subject and led to a conclusion.

(ii) Joint secretariat with civil groups
The round table was jointly organized by administrators and civil groups with all topics discussed thoroughly.

(iii) Proactive participation of municipalities and civil groups
The issue of the river environment raises fundamental conflicts of interest between municipalities, regional communities and civil groups. In the case of Tama River, this problem was addressed by organizing ‘River Inspection Tours’ led by the municipalities. Municipalities and other civil groups walked together along the river and listened attentively to the different opinions being expressed. The communication promoted in the activities led to better understanding among the residents and civil groups.

(iv) Consensus building for the plan is a step-by-step process
The draft plan was presented in a phased manner, as follows: preliminary draft plan summary ⇒ preliminary draft plan ⇒ first draft plan ⇒ draft plan. The first phase of the preliminary draft plan summary included the presentation of thorough discussions and several drafts. Consensus at this point was crucial to ensure that the process moved forward.
3.4.3 Tutorials and assignments

Activity 1: River basin situation analysis for planning management
Take a river basin of your choice, i.e. the one which you are more familiar. Characterize the river basin in terms of its hydrological, ecological, demographic and socioeconomic factors. Analyse the situation of the river basin in terms of:
- Water demand and availability
- Water uses
- Problems and challenges (water quality and quantity, conflict, upstream-downstream issues, environmental concerns, flood, drought, poverty, etc.)
- What types of development projects (hydropower, irrigation, water supply, etc.) exist in the river basin?
- Whether there is any intervention underway to curb one or more of the existing problems
- Identify the stakeholders affected?

Table A: Threat analysis matrix

<table>
<thead>
<tr>
<th>Key problems and pressures</th>
<th>Scale of pressure (quantify and/or describe significance)</th>
<th>Underlying causes for pressures</th>
<th>Possible solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>etc.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Activity 2: Planning for improvement of one or more of the problems of the river basin described during the first activity

Propose intervention measures that you think will curb one or more of the problems described while you are dealing with first activity.

Give due emphasis to the following issues:
- Outline how you proceed with this intervention planning
- What are needs derived the realization of the project?
- What are the negative social, economic and environmental effects of the considered scheme?
- Which groups of people are affected; which group should involve in the planning process for change? (use Table B for analysis)
- What alternatives can you identify that would meet development needs specified under 2 and at the same time minimize the negative effects?
- Which of the alternatives do you see as the preferred development alternative and why?

Table B: Stakeholder analysis matrix

<p>| List stakeholders per category in relation to your Threats Analysis | Describe the &quot;stake&quot; | Importance in relation to key | Describe potential role |</p>
<table>
<thead>
<tr>
<th>Matrix</th>
<th>problems</th>
<th>in the project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Who make use or benefit from the Natural Resources (NR). Distinguish between commercial and subsistence &amp; indicate who is threatening them. 1. 2. 3. etc.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Who are responsible for NR management? 1. 2. 3. etc.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Who has specific interest in the problem? 1. 2. 3. etc.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Who has most knowledge or are most capable of dealing with the problems? 1. 2. 3. etc.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**References**

- UNESCO-IHE. 2009. IWRM guidelines at river basin level.
4. Tools and methods for IRBM

By: Dr Semu Moges

4.1 Monitoring and Water Resource Information System

4.1.1 Monitoring, Acquisition and processing of Water Resource Data

I. Types of Water Resource Data (Spatial and temporal)

There are several ways to classify water resources data. The most common way is to classify the data into three categories: time-oriented data (Time Series Data), space-oriented data (Spatial data), and relation oriented data.

Time-Oriented Data

The time-oriented or time-series data consist of hydro-meteorological, water quantity, and water quality data that are periodically measured at a station. The time interval between observations can be constant or varying. The examples of such types of data are rainfall, river stage, and sediment concentration. Some surface water data are equally spaced in time.

These data can be further classified as meteorological data, hydrological data, and water quality data. The time-series data include all the measurements which have an observation time associated with them and most water resources data have this property. The variable could be an instantaneous value, e.g., water level in a river; an accumulated value, e.g., daily rainfall; an averaged value, e.g., mean daily discharge; or a statistic over a specified time period, e.g., annual maximum flow. The distinction between instantaneous and accumulative values is important when the data are further processed.

Depending on the frequency of observations, the time-series data can also be classified as:

- Equidistant time-series are measurements which are made at regular intervals of time (hourly, daily); the values may be instantaneous, accumulated or averaged.
- Cyclic time-series are the measurements which are made at irregular intervals of time but the irregular time sequence is repeated regularly, for example, the observation of river stage daily at 08:30 and 17:30 hrs.
- Non-equidistant time-series are the measurements which are made when some specified event takes place. For example, in a tipping bucket raingauge, each tip of the bucket is recorded after a certain depth of rain has fallen.

The two most important data for hydrological analysis are precipitation and stream flow. The measurement and processing of these two will be discussed in greater detail. The time-series of evaporation data forms another important input in hydrological studies. The temperature of air, soil and water bodies is important as many processes depend on it. Other important meteorological variables include humidity, wind speed and direction, and sunshine duration.

Space-Oriented Data

The space-oriented data comprise of catchment data (physical and morphological characteristics), river data (cross-sections, profile, bed characteristics), and lake or reservoir data (elevation-area-
storage capacity). Such data are stored in the form of paper maps and manually analyzed. The recent trend is to use a Geographical Information System (GIS) to input, store and analyze such data. Different types of information, such as topographical and land use of an area, are stored in a GIS in different layers of a map which can be overlaid and analyzed.

**Relation-Oriented Data**

The relation-oriented data consist of mathematical relationships between two or more variables. The variables themselves may form a time-series but their relationship is of interest here. The relationship may be expressed in mathematical, tabular, or graphical form and is derived using the data. Typical examples are river rating curves or a spillway rating table.

A mathematical relationship between two or more variables is established for a variety of purposes, such as data validation, filling-in of data gaps, etc. The relationships between stages at two adjacent gauging stations and between the average rainfall in a catchment and the resulting outflow are some typical examples. In some instances, relationships may be established between water quality parameters and discharge to determine pollutant loads. The parameters of the relationship along with the ranges of independent variables, error statistics and the period of applicability are required while establishing a relationship.

2. **Techniques for monitoring (observation of) water resource data**

There are many ways in which the data that are used for water resources studies can be collected. The major techniques are described below.

**Gauging Equipment**

This is the most common way to observe hydro-meteorological variables, such as precipitation, streamflow, etc. A gauging site is established and is equipped with the devices that can measure the variable(s) of interest. An observer visits the site to manually note the value of the variable and record or transmit it to the place of use. Using a modem means of communication, it is possible to get the desired data from the stations geographically spread over an area at a central place. An automated hydrologic station can measure a number of hydro-meteorological variables and store/transmit the data. The equipment may be programmed to transmit the data after selected time interval or it can be interrogated at any time to get the data. The design of networks, equipment, and methods of observation of some important variables are described in detail in later sections.

**Remote Sensing**

In this technique, the data about an object are obtained without coming in physical contact with the object. Weather radars are being increasingly used for measurement of precipitation.
Chemical Tracers
In this approach, some chemicals, known as tracers, are added to the process whose data are to be obtained. The procedure to measure river discharge using tracers has been described in Section 2.6.3. Tracers can also be used to determine the flow path of water or a pollutant. The nuclear or isotope techniques are employed to trace the movement of water molecule in any part of the hydrological cycle and derive information about hydrological processes. Nuclear techniques are helpful to assess the rate of sediment deposition in a water body, identify the rainfall recharge and recharge areas of aquifers, study of seawater intrusion in coastal regions, measure seepage and leakage from surface water bodies, analyse surface water and ground water interaction, etc. The stable isotopes, such as Oxygen-18, Deuterium, Carbon-13 (for C-14 dating), and N-15, are commonly used.

3. Sources of water resource data
The sources of water resources data can be obvious or usual as well as unusual. The usual data sources include water resources/irrigation departments, River basin / regional water authorities, experimental and research organizations, universities (for research and experimental basins, farms, etc.), public health authorities, and the like. The unusual sources include non-governmental organizations, airport authorities (mainly meteorological data), municipal bodies, etc. In any detailed study, it is advisable to search and contact unusual data sources too. This could be a painful effort but may turn out to be worth the trouble. A field visit is always helpful in getting supplementary information. For example, high-water marks along rivers are useful in delineating flood-prone areas and can also be used to crosscheck peak discharges.

The collection of hydrologic data involves locating the data sources, followed by inspection and evaluation of these data to establish their suitability and sufficiency for the study. In view of wide differences in the practice of data storage and dissemination, the efforts required for data collection tremendously vary from country to country. In some cases, it may just mean browsing the Internet and downloading the requisite data. In others, it may mean physically visiting the concerned offices and manually copying the data from the available records.

Many times, one data-observing organization is unaware of the data collection efforts of others; even governmental agencies often know little about the data collected by other governmental and non-governmental institutions. This poses additional problems during data collection and processing. Some of the data that are used in water resources analysis may fall under the category of secret data and special procedures and precautions are to be followed to obtain, handle, analyze the data and disseminate the results.

4. Design of hydro-meteorological networks
The information on temporal and spatial characteristics of water resources is obtained by a network of observational stations. The main purpose in planning a hydro-meteorological network is to find out the hydrological characteristics of an area and gather data for planning, design and management. Setting up a station requires investment for equipment, logistics, and for operation and maintenance. Scientific planning is, therefore, necessary for network design so that the desired results could be achieved with minimum cost.

The requirement of water resources data depends on their end use. Therefore, it is difficult to formulate general rules on network design. Based on spatial features, there are two types of networks:
a) areal networks, such as those for precipitation, and ground water levels, and b) linear networks such as those for streamflow and river sediment. Areal networks are established to get spatial characteristic of the variables over an area while the linear networks are set-up for rivers, canals, etc. On the basis of purpose, the networks can be classified in three categories: basic (to get the fundamental characteristics of the variables of interest), specific (to gather data for some specific purpose, e.g., a reservoir project), and temporary (which are in operation for a short period of time).

While designing hydrologic networks, the items to be decided are:

- the variables to be measured and the frequencies and duration of observations;
- the location of gauging stations;
- the instruments to be installed and methods of observation; and
- data observation and transmission system.

The basic network is designed to provide a level of hydrological information at any location within its region of applicability that would preclude any gross mistake in water resources decision making (WMO, 1994).

Table 4-1: Recommended minimum densities of stations (area in km²) [WMO, 2008]

<table>
<thead>
<tr>
<th>Physiographic unit</th>
<th>Precipitation</th>
<th>Evaporation</th>
<th>Streamflow</th>
<th>Sediments</th>
<th>Water quality</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Non-recording</td>
<td>Recording</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coastal</td>
<td>900</td>
<td>9000</td>
<td>50000</td>
<td>2750</td>
<td>18300</td>
</tr>
<tr>
<td>Mountains</td>
<td>250</td>
<td>2500</td>
<td>50000</td>
<td>1000</td>
<td>6700</td>
</tr>
<tr>
<td>Interior plains</td>
<td>575</td>
<td>5750</td>
<td>5000</td>
<td>1875</td>
<td>12500</td>
</tr>
<tr>
<td>Hilly/undulating</td>
<td>575</td>
<td>5750</td>
<td>5000</td>
<td>1875</td>
<td>12500</td>
</tr>
<tr>
<td>Small islands</td>
<td>25</td>
<td>250</td>
<td>50000</td>
<td>300</td>
<td>2000</td>
</tr>
<tr>
<td>Urban areas</td>
<td>–</td>
<td>10-20</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Polar/arid</td>
<td>10000</td>
<td>100000</td>
<td>100000</td>
<td>20000</td>
<td>20000</td>
</tr>
</tbody>
</table>

4.1.2 Water Resource Information System

Data transformation

WMO (1994) has given the classification of data transmission systems:

- Manual with the observer at a station sending data to the central office.
- Manual/semi-automatic system where the central office manually interrogates the automatic field stations through telephone, radio, etc. and receives the data.
- Pre-program and time system where automatic equipment initiates the transmission of observations.
- Automatic event indicator and the station automatically transmitting the specified change of variable to a central location
- Automatic system with station transmitting and central office recording data continuously.
The possible choices of transmission links are:

- Dedicated land lines are used when distances are short and commercial lines are not readily available.
- Commercial telephone lines are used wherever feasible. Two-way communication and data transmission is possible. With improvements in information technology, very good voice quality and high band rates of data transmission are possible.
- High frequency radio links are used when land lines are not available or topography is difficult. The installation cost can be high.

A significant development of last few decades has been the use of satellites for data transmission. A satellite-based system consists of Data Collection Platforms (DCP) that are installed at hydro-meteorological stations. DCPs are (rechargeable) battery-operated devices that collect, encode, and communicate the data of the station to a central location through a satellite link. This system is very useful for remote and difficult to access locations.

The choice of a particular transmission system depends on:

a) The frequency of data observation and the urgency of data,
b) The additional benefits of having forecasts based on telemetered data,
c) Robustness and reliability of the system, particularly in inclement weather, and
d) Availability of finance, infrastructure and manpower to efficiently run the system.

With growth in information technology, the trend is towards automatic observation, transmission and storage of data, particularly in developing countries. Multiparameter data loggers can measure, store, and transmit data observed by several observation sub-systems. These days, the data loggers are small, rugged, and have small power requirement. These may be battery or solar-power operated. The automatic transmission of data is usually in coded form. WMO has evolved codes related to hydro-meteorological data. They have also launched an elaborate system for data observation and transmission through the World Weather Watch (WWW) programme (www.wmo.ch/web/www).

Data storage and retrieval

The vast amounts of data which are observed by incurring huge efforts and resources should be stored in such a way that they are easily obtainable and safe from weather and other harmful agents. Also, it is much more useful if the basic data is processed into various useful forms and kept ready to be used by the end users. This can save a lot of money and effort of the user agencies and they would be encouraged to use the data to solve different water resources problems. Archival of data is important in any field. When done in a proper manner, it enables the end users to exploit its potential of data in an efficient way and thus eliminate the tedious task of manually handling voluminous data.

Every day, vast quantities of water resources data are collected all over the world. In this computer era, the archival of data may be accomplished in a very efficient and economic way. The basic and other processed information may be stored on computer media and the same may then be quickly made available to intended users. Hard copies in the form of data year-books may also be brought out for use by practicing engineers, planners and managers. These water year-books can also be made available to the users on computer. Besides the processed data, it is advisable to store the raw data as
well because it may be needed for research purposes and it might be realized at a later date that the data validation procedures had missed some aspects.

A typical setup for water resources data management is depicted in Fig. 4-1. The main components are:

a) Data entry module to input data from various sources in the database,
b) User interface for data editing, display, and management, and
c) Applications that can retrieve data or write to the data base.

Due to large volumes of water resources data, it is necessary that the data are stored such that minimum space is needed. It is estimated that the storage of graphical data on micro films requires only about 1/300th of the storage space needed for the original data. Till recently, the digital data were archived on magnetic tapes. However, the life of these tapes is limited and these are to be stored in controlled environment. The current trend is archive the data on CD-ROMs each of which can hold 600MB of data and do not require stringent environmental conditions for storage. The problem is considerably less severe now since high capacity hard disks are available and the cost of hardware has dropped drastically. Of course, the volume of data that are being generated each day is also progressively increasing.

![Fig. 4-1: Management and use of hydrological database](image)

In order to reduce the requirement of storage space, some type of data compression is applied. WMO (1994) has described such procedures. A number of data compression algorithms have been developed recently. For example, daily rainfall is measured to an accuracy of 0.1mm. Rather than storing it as a real number which requires 4 bytes, the values can be multiplied by 10 and stored as an integer requiring only 2 bytes. The daily data of one month when rainfall was zero need not be stored as 30 zeros. An efficient way is to use notation ‘30’0’. The database files are not normal ASCII files that require larger space; these are special types of files. The suitability of a particular compression technique will depend on the characteristics of the data.

An efficient data retrieval system is also necessary so that the requisite data are quickly fetched from the database. A good retrieval system should provide the user a combination of options to select the
data using criteria, such as by variable, basin, station, time period or range of values. The user should also have a control on the format of the output, i.e. tabular, plot or ASCII data files that can be directly input to another software. If graphs are displayed on the monitor, the user should have an option to print them or store on hard disk for later use. Adequate security measures should also be built in the retrieval system so that only authorized users have access to the database. Among the authorized users also, there should be various categories. Most users are given read-only access and they cannot do any modification to the database. A limited group of users are given all privileges, i.e., they can read, modify and delete data from the database. It is useful to have a log of all users who have accessed the database and the operations that they have performed so that the source can be identified in case of any mishap.

Data dissemination
The basic objective of creating databases and storing data in an efficient manner is to encourage the use of data for planning, design, management, and research purposes. Therefore, there should be no hurdle in accessing the data by genuine users. Dissemination of information goes a long way to achieve this objective. The first and foremost step in the dissemination process is an up-to-date catalog of database. WMO (1994) has outlined a data catalog format and summary reports. The catalogue of data held in various databases should be updated periodically.

Many organizations routinely publish basin-wise data-year books. A typical water year book consists of description of the basin, its topography, soils, land use etc., major rivers, and salient features of various water resources projects. Maps are included to illustrate all these features. The data section contains typically precipitation, streamflow, evaporation, and ground water data. Periodically, special reports may be published giving long-term statistics of stations or highlighting special or unusual events, such as floods or droughts.

Of late, many organizations have started dispensing with paper publishing due to high costs and handling problems. With the bulk of data now available in digital form in a WRIS, the hard-copy publication is not considered as an efficient means of data dissemination. A water-year book can be conveniently published on a computer media, such as CD-ROMs which are cheaper to produce and easier to handle. A browser may also be supplied to handle data search, display and print facility. This trend is likely to accelerate further. An important thing to remember is that the format and content of publications should depend on the need of users. The contents should be so designed that the need of most data users are answered and the efforts to handle data requests are reduced. The contents may also depend on the frequency of publication. The price of publication should be fixed such that it is not a burden on the organization and is affordable to the users.

Finally, in this age of computers and Internet, it is appropriate that many international organizations have established databases that can be accessed through Internet. The Global Runoff Data Centre (GRDC) at the Federal Institute of Hydrology, Germany, has a large archive of surface water data. The center was established under the auspices of WMO and mechanisms have been evolved to supply data to a user. INFOHYDRO of WMO is metadata base that does not actually contain any data but facilitates quick dissemination of information about institutions and agencies dealing with hydrology and catalogs of data. A similar service for climate data is INFLOCLIMA.

Emerging techniques in water resources data
Due to emergence of state of the art techniques of data collection the quality and quantity of water resources data acquisition have been enhanced tremendously. The emergence of digital data loggers, radar systems are typical data collection methods. Remotely sensed water resources data is also becoming key sources of spatial and spatio-temporal water resources data sources. It is possible to estimate rainfall, evapotranspiration based on remotely sensed data.
4.2 Statistical Methods

4.2.1 Statistical Data Summary and Description

Statistical data presentation (mean, Std, CV, Cs, Ck, etc...)
There are four principal moments for characterizing probability distributions:
− the central tendency or the value around which all other values are clustered,
− the spread of the sample values around mean,
− the asymmetry or skewness of the frequency distribution, and
− the flatness of the frequency distribution.

These characteristics are expressed in terms of the parameters of distributions; the parameters can themselves be expressed in terms of moments. These parameters are estimated from the observed sample data, and are then used as estimates of the parameters of the population distribution.

Measures of Central Tendency
In statistics various measures of location are described. The important measures are the following:

Arithmetic Mean: If $x_1, x_2 \ldots x_n$ represent a sequence of observations, the mean of this sequence is the ratio of the sum of values and the number of values:

$$\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i$$

Where $\bar{x}$ represents the sample mean; population mean is generally represented by $\mu$.

Mode: It is the value in the sample (or population) which occurs most frequently. It is the peak value of the PDF. Note that a sample or population may have more than one peak.

Median: It is the middle value of the ranked values for a sample (or population). The median divides the distribution in two equal parts.

Measure of Dispersion or Variation
Some of the important measures of dispersion or variation include:

Variance: It represents the dispersion of data about the mean and is expressed as:

$$s^2 = \frac{1}{n} \sum_{i=1}^{n} (x_i - \bar{x})^2$$

Standard deviation: The unbiased estimate of population standard deviation ($s$) from the sample is given as the square root of the variance, i.e.,

$$s = \left[ \frac{1}{n} \sum_{i=1}^{n} (x_i - \bar{x})^2 \right]^{1/2}$$
For \( n < 30 \), the unbiased estimate of \( s \) is found by replacing \( n \) by \( n-1 \) in this equation.

**The coefficient of variation, \( C_v \),** is a dimensionless dispersion parameter and is equal to the ratio of the standard deviation and the mean:

\[
C_v = \frac{s}{\bar{x}}
\]

The variance has the square of the units of the original data. The standard deviation has the same dimensions as of the data. The coefficient of variation is a dimensionless quantity.

**Measures of Symmetry**

If the data are exactly symmetrically displaced about the mean then the measure of symmetry should be zero. If the data to the right of the mean (larger) are more spread out from the mean than those on the left then, by convention, the asymmetry is positive and vice-versa for negative asymmetry.

The third moment of the sample data about the mean is given by:

\[
M_3 = \frac{1}{n} \sum_{i=1}^{n} (x_i - \bar{x})^3
\]

This moment is zero if the data are symmetrical. Otherwise it is positive or negative.

**Coefficient of Skewness:** It is a non-dimensional measure of the asymmetry of the distribution of the data. An unbiased estimate of the coefficient is given by:

\[
C_s = \frac{n\sum_{i=1}^{n} (x_i - \bar{x})^3}{(n-1)(n-2)s^3}
\]

Symmetrical frequency distributions have very small or negligible sample skewness coefficient \( C_s \), while asymmetrical frequency distributions have either positive or negative coefficients. Often a small value of \( C_s \) indicates that the frequency distribution of the sample may be approximated by the normal distribution since \( C_s = 0 \) for this function. The symmetrical and skewed distributions are shown in Fig. 4-2.

**Fig. 4-2:** Symmetrical and skewed distributions
Note that because the third central moment has dimensions equal to the cube of the data, it is not of direct use while comparing different data sets. The coefficient of skewness does not have this disadvantage and is, therefore, preferred.

Measures of Peakedness or Flatness
The kurtosis coefficient measures the peakedness or the flatness of the frequency distribution near its centre. An unbiased estimate of this coefficient is given by:

\[
C_k = \frac{n^2 \sum_{i=1}^{n} (x_i - \bar{x})^4}{(n-1)(n-2)(n-3)s^4}
\]

The kurtosis for a normal distribution is 3.

4.2.2 Regression Analysis

Linear regression analysis
It is an approach which is widely used to describe linear cause and effect relations between two variables. The objective is to predict a dependent variable based on an independent variable. The linear regression equation is:

\[
y_i = a + bx_i + \epsilon_i \quad i = 1, 2, \ldots, n
\]

Where, \(y_i\) is the \(i^{th}\) value of the dependent or regressed variable, \(x_i\) is the \(i^{th}\) value of the independent or regressor variable. The regression line crosses the y-axis at a point \(a\) (the intercept), and has a slope \(b\), and \(\epsilon_i\) is the random error term for the \(i^{th}\) data point. The variables involved in regression should be chosen carefully and there should be a logical reason behind this choice. A scatter plot of \(y\) vs. \(x\) should be made to ascertain the dependence structure. Sometimes, a transformation of \(x\), such as a power or log transformation, improves the regression relation.

Multi-linear regression analysis
The association of three or more variables can be investigated by multiple linear regression and correlation analysis. If all the variables (dependent and independent) are in linear form, the regression is referred to as the multiple linear regressions. Often a nonlinear association between the variables is handled by transforming the variables to linear form and applying multiple regressions as it is easier to treat linear equations. The general form of the multiple linear regression equation is:

\[
y_i = b_1 x_{i1} + b_2 x_{i2} + \ldots + b_p x_{ip}
\]

When set of \(n\) observations is available on the dependent and each of the \(p\) independent variables, there shall be \(n\) equations for \(p\) unknowns.
where $y_i$ is the $i^{th}$ observation of the dependent variable, and $x_{i,1}, x_{i,2}, \ldots, x_{i,p}$ are independent variables.

If a regression equation with $p$ parameters is fitted to a set of $n$ data points of variables, the number of degrees of freedom will be $n-p$. If the number of parameters is equal to the sample size the regression equation will pass through all the points as there is no degree of freedom. It cannot be used for prediction as the errors of parameters are inversely proportional to the number of degrees of freedom.

In designing the multiple linear and nonlinear regression relations, the selection of dependent and independent variables is very important. The dependent variable is defined by the problem itself. The independent variables are selected due to the following two reasons:

- They have been observed in the past concurrently with the dependent variable so that the regression equation may be established. In future, they may be used to predict the dependent variable.
- An analysis of physical phenomenon indicates a cause-and-effect relation between dependent and independent variables. These criteria are necessarily subjective. The variables that are known to have no effect on the dependent variable are neglected.

**Correlation analysis**

Correlation is a mathematical measure of the strength of relationship between two variables or within the same series. The measure of the relationship is a dimensionless coefficient, called correlation coefficient. However, note that correlation is not an evidence of a causal relationship between two variables. If one variable drives the other, they may be correlated, as rainfall and runoff. The variables may also be correlated if they share the same cause. Examples include dependent variables, such as river discharge, concentration or transport rates of sediment, and concentration or transport rates of substances that are transported in association with suspended sediment (Hirsch et al. 1993).

**Cross-Correlation**

The correlation between two time-series or cross-correlation $r_{x,y}$ is given by:

$$r_{x,y} = \frac{s_{x,y}}{s_{x}s_{y}}$$

Where $S_{x,y}$ is the sample covariance between $X$ and $Y$ and $s_x$ and $s_y$ are the sample standard deviations of $X$ and $Y$, respectively. As with autocorrelation, $r_{x,y}$ also range from -1 to 1; $r_{x,y} = +1$ or $-1$ implies a perfect linear relationship between $X$ and $Y$ and $r_{x,y} = 0$ implies linear independence, although there may be other types (say, non-linear) of dependence. If observations in a time-series are correlated, this must be kept in mind while drawing any inferences about the data or when modeling the process that has produced the time-series.
A high correlation between two variables need not necessarily be due to a cause-and-effect relation between them. If there is a correlation between some variables that do not have a cause and effect relation, this is termed as spurious correlation. The monthly flows of two adjacent streams may be highly correlated but this could be because the influencing external causes are the same. A high correlation in this case does not mean that a change in flow of one stream will force the other stream’s flow to change. It is to be noted that independent variables are uncorrelated but uncorrelated variables are not necessarily independent. The dependence in correlated variables is a stochastic dependence and not always physical or cause-and-effect dependence. Any apparent correlation between variables that are in fact uncorrelated is termed as spurious correlation.

Serial or Auto-Correlation

The autocorrelation or serial correlation of a series is defined as linear correlation between a time series and the same series at a later interval of time. Assume that in a time-series, observations are equally spaced in time and that the statistical properties of the process do not change with time. The autocorrelation of a time series (having n observations) at lag k ($r_k$) is given by:

$$r_k = \frac{\left(\sum_{i=1}^{n} x_i x_{i+k} - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} x_{i+k}\right) / (n-k)}{\left(\sum_{i=1}^{n} x_i^2 - (\sum_{i=1}^{n} x_i)^2 / (n-k)\right)^{1/2} \left[\sum_{i=1}^{n} x_{i+k}^2 - (\sum_{i=1}^{n} x_{i+k})^2 / (n-k)\right]^{1/2}}$$

Here the lag is the amount of offset when comparing the values of the series. The autocorrelation of lag 1 is determined by computing the correlation between elements 1, 2, ..., (n-1) of a series and the elements 2, 3, 4, ..., n of the same series. From the equation, it is clear that $r_0$ is unity. Note also that as k increases, the number of pairs of observations used in estimating $r_k$ decreases since all of the summations contain n – k terms. Therefore, serial correlation should only be estimated for k sufficiently smaller than n; usually correlation at lags exceeding 20 are not much useful.

A purely random process will have $r_k = 0$ for all k, indicating that all of the observations in the sample are independent of each other. The elements of a sample of data possessing serial correlation are not random elements. The plot of autocorrelations at various lags is known as a correlogram. A typical correlogram begins at a value of +1.0 at 0 lag, and then decays at higher lags. At lags of near coincidence of the elements, the correlogram shows a rise; it falls otherwise. Correlograms help reveal the characteristics of a time-series and disclose intervals of time or distance at which the time series has a repetitive nature.

The correlogram of annual flows of Sabarmati River at Dharoi of series up to a lag of 20 is plotted in Fig. 4-3. It can be seen from the correlogram that there is very poor auto-correlation in the series. The autocorrelation at lag 1 is 0.0064 and at lag 2, it is-0.0295.
4.2.3 Frequency Analysis

Application of frequency analysis in water resource systems

Frequency analysis is performed to determine the frequency of the likely occurrence of hydrologic events. This information is required to solve a variety of water-resource problems, for example, design of reservoirs, floodways, bridges, culverts, levees, urban drainage systems, irrigation systems, stream-control works, water-supply systems, and hydroelectric power plants, floodplain zoning, setting of flood-insurance premiums, etc.

Although the frequency analysis of virtually every component of the hydrologic cycle is required, the emphasis here will be on frequency analyses of streamflow extremes and rainfall only.

The hydrologic data to be analyzed for frequency analysis must be treated in light of the objectives of the analysis, length and completeness of record, randomness of data, and homogeneity. The length of record should be more than 25 years for the derived distribution to be acceptable. The hydrologic data must have been controlled by a uniform set of hydrologic and operational factors. For example, the factors causing a winter rain flood are quite different from those during a spring snowmelt flood or a local cloudburst flood. These two types of floods should not be combined into a single record. Sometimes a hydrologic record may have gaps. Missing data may sometimes be estimated using regional analysis or by correlation with other hydrologic data in the region.

Hydrologic data are generally presented in chronological order constituting the complete duration series (CDS). For frequency analysis, CDS is seldom used because the hydrologic design of a project is normally dictated by only a few critical events. Therefore, hydrologic data can be selected in two ways: (1) partial duration series (PDS) and (2) annual duration series (ADS). PDS is comprised of the data exceeding a specified base level. In ADS, one value (usually the highest) is selected from each year. The two series are comparable if the record is longer than 10 years and either can be used.

Methods of frequency analysis

Point frequency analysis

The frequency distributions presented earlier can be fitted to the data. Two commonly used methods of fitting are: (1) the graphical method and (2) frequency factors.
Graphical method
This method involves fitting of an assumed probability distribution to observed data. The sample data are arranged in either ascending or descending order of magnitude and each data point is assigned a rank. If these are arranged in descending order of magnitude, then the highest value will be assigned the rank of 1, the second highest the rank of 2, and so on; the lowest value will have the rank of N, where N is the number of data points in the sample. This arrangement gives an estimate of the exceedance probability, that is, the probability of a value being equal to or greater than the ranked value. If the values are arranged in ascending order, then an estimate of the non-exceedance probability, that is, the probability of a value being less than or equal to the ranked value, is obtained. These data points are plotted on probability paper, with their positions determined from a plotting-position formula.

Many plotting-position formulas are available; some commonly used ones are given in Table 4-2. Adamowski (1981) has shown that all of these formulas are special cases of

$$P_m = \frac{m - a}{N + b}$$

Where a and b are constants, Pm is the exceedance probability of the mth observation, and m is the mth value of N ordered observations, such as P1 < P2 < ... < PN. A commonly used plotting-position formula in hydrology is

$$P_m = \frac{m}{N + 1}$$

Clearly, the return period of the mth data point, Tm, is

$$T_m = (N + 1)/m$$

The observed values and their exceedance probabilities are plotted on the probability paper corresponding to the assumed probability distribution. On the ordinate of the graph paper are observed values and on the abscissa the probabilities or return periods. The objective of using the probability paper is to linearize the distribution so that plotted data can be represented by a straight line. A best-fit straight line is then drawn through the plotted points. The line is assumed to give the probabilities of all values beyond the observed range.
Table 4-2: Some commonly used plotting-position formulas

<table>
<thead>
<tr>
<th>Method</th>
<th>Formula</th>
<th>Values for m = 1 and N = 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hazen (1914)</td>
<td>( \frac{(m - 0.5)}{N} )</td>
<td>( P_m ) 20.0</td>
</tr>
<tr>
<td>California (1923)</td>
<td>( m/N )</td>
<td>0.10</td>
</tr>
<tr>
<td>Weibull (1939)</td>
<td>( m/(N + 1) )</td>
<td>0.091</td>
</tr>
<tr>
<td>Beard (1943)</td>
<td>( m - 0.31)/(N + 0.38)</td>
<td>0.066</td>
</tr>
<tr>
<td>Chegodayev (1955)</td>
<td>( m - 0.3)/(N + 0.4)</td>
<td>0.067</td>
</tr>
<tr>
<td>Blom (1958)</td>
<td>( m - 0.375)/(N + 0.25)</td>
<td>0.0609</td>
</tr>
<tr>
<td>Gringorten (1963)</td>
<td>( m - 0.44)/(N + 0.12)</td>
<td>0.055</td>
</tr>
<tr>
<td>Cumane (1978)</td>
<td>( m - 0.4)/(N + 0.2)</td>
<td>0.58</td>
</tr>
<tr>
<td>Adamowski (1981)</td>
<td>( m - 0.25)/(N + 0.5)</td>
<td>0.071</td>
</tr>
</tbody>
</table>

The observed values and their exceedance probabilities are plotted on the probability paper corresponding to the assumed probability distribution. On the ordinate of the graph paper are observed values and on the abscissa the probabilities or return periods. The objective of using the probability paper is to linearize the distribution so that plotted data can be represented by a straight line. A best-fit straight line is then drawn through the plotted points. The line is assumed to give the probabilities of all values beyond the observed range.

Frequency analysis factor

Chow (1951) proposed the use of a frequency factor in hydrologic frequency analysis. If a hydrologic variable \( X \) is plotted chronologically in time, then a particular value \( x \) is found to be composed of two parts: namely, the mean, \( \bar{x} \), and the departure from the mean \( \Delta x \):

\[
x = \bar{x} + \Delta x
\]

The variable \( \Delta x \) can be expressed as the product of the standard deviation \( S \) and the frequency factor \( K \). Therefore,

\[
x = \bar{x} + S K
\]

where \( K \) depends on the return period \( T \) and the PDF of \( X \); \( K \) literally means the number of standard deviations above and below the mean to achieve the desired quantile. For a distribution, a relation between \( K \) and \( T \) can be derived. For two-parameter distributions, \( K \) varies with \( T \). For skewed distributions, it varies with the coefficient of skewness (C~) and is very sensitive to the length of record. The frequency factor for some commonly used distributions is given here.

**Normal distribution:** Recall the definition of the standard normal variate, \( Z = (X - \mu)/\sigma \), where \( \mu \) the population mean, and \( \sigma \) is population standard deviation of the variable \( X \). Its observed values are expressed as

\[
z = (x - \bar{x})/S \quad \text{or}
\]
Thus, for the normal distribution, \( K \) is the standard normal variant, which can be obtained from the tables of standard normal distribution.

**Log-normal distribution**: If a variable follows log-normal distribution, its logarithms will follow normal distribution and then the formula for normal distribution can be applied.

**Gumbel distribution**: If the reduced variate is \( Y \), the frequency factor for this distribution is

\[
K = \frac{(y - 0.577)}{1.283}
\]

where

\[
y = \frac{1.283(x - \bar{x})}{S} + 0.577
\]

**Log-Pearson Type 3 Distribution**: For the Log-Pearson Type 3 Distribution, \( K \) is a function of both the return period and \( C_s \). Values of \( K \) for log-transformed data are given by the Water Resources Council (1967). To fit this distribution, transform the data, \( x_i \) (annual floods), to their logarithmic values, \( y_i \). Compute the mean, standard deviation \( S_y \), and \( C_s \) for the log values. Get the value of \( K \) for the desired \( T \) from the tabulated values. If \( C_s \) falls between -1 and +1, an approximate value of \( K \) is obtained from

\[
K = \frac{2}{C_s} \left[ \left( \frac{z - \frac{C_s}{6}}{ \frac{C_s}{6} + 1} \right)^3 - 1 \right]
\]

Compute \( y \) from

\[
y = \bar{y} + K S_y
\]

Then compute \( x = \exp(y) \) for the desired \( T \) value.

**Confidence limits**

A value of the variant estimated from a probability distribution for a given time period is usually in error due to the limited sample size. Therefore, a statement indicating the limits about the estimated value within which the true value is contained with a specific probability is needed. This statement is made by constructing confidence limits, which are also called the confidence intervals, confidence bands, error limits, or control curves. The confidence interval indicates the limits about the estimated value and the probability with which the true value will lie between those limits. This statement accounts for the sampling errors only.

Let the confidence probability be \( \alpha \). The confidence interval of the variant \( x \) corresponding to a return period \( T \) is bounded by values \( x_l \) and \( x_2 \) (Nemec, 1973) as

\[
x_{1,2} = x \pm G(\alpha) S_e
\]
where \( G(\alpha) \) is a function of the confidence probability \( \alpha \) and can be determined by using the table of normal variants. As an example,

<table>
<thead>
<tr>
<th>( \alpha ) (%)</th>
<th>50</th>
<th>68</th>
<th>80</th>
<th>90</th>
<th>95</th>
<th>99</th>
</tr>
</thead>
<tbody>
<tr>
<td>( G(\alpha) )</td>
<td>0.674</td>
<td>1.00</td>
<td>1.282</td>
<td>1.645</td>
<td>1.96</td>
<td>2.58</td>
</tr>
</tbody>
</table>

\( S_e \) is the probable error expressed as

\[
S_e = (1 + 1.3K + 1.1K^2)^{0.5} \frac{S_{\sqrt{N}}}{\sqrt{N}}
\]

in which \( K \) is the frequency factor of the distribution under consideration, \( SN \) is the standard deviation of the sample, and \( N \) is the sample size. By using this method, confidence limits can be placed above and below the fitted distribution curve. If the Gumbel distribution is considered, then for a given sample and \( T \), 80% confidence limits are about twice as big as 50% ones and 95% confidence limits are about thrice as big as 50% limits.

**Regional frequency analysis**

For many watersheds, streamflow data are either insufficient or non-existent at the sites of interest. The methods of frequency analysis using data from a single site will have then limited predictive value because of large sampling errors. To overcome the data deficiency, a regional frequency analysis is performed. By defining a region that is hydrologically similar in terms of the variable to be studied, data from several gauging sites within this homogeneous region are pooled together into a single regional frequency analysis. Examples of regional frequency analysis are estimation of design flood from rainfall-runoff relationship, prediction of flood peaks from the relation between observed values and drainage-basin characteristics, and estimation of rainfall depths and frequencies in ungauged areas from characteristics at well-gauged sites in the same area.

The first step in a regional analysis is to define the region itself. The definition of a region depends on the quantities to be estimated. Many methods are available to define a region that is homogeneous. For mean annual precipitation, large physiographic regions can be used, whereas for peak flow, the regions may be confined to drainage basins of certain sizes. Regional boundaries can be defined in terms of similarity of flood-frequency curves or flow curves. Homogeneity tests are used to check if flood-frequency curves in a region can be considered homogeneous.

### 4.2.4 Time Series Analysis

**Application of time series methods in water resource systems**

A time series is a set of observations generated sequentially in time. If the set is continuous, the series is said to be continuous; if it is discrete, the time series is said to be discrete. Here only discrete time series where observations are made at some fixed interval \( h \) will be considered. The observations in a discrete series made at equidistant time intervals \( x_0 + h, x_0 + 2h, \ldots x_0 + Nh \) may be denoted by \( z(t_1), Z(t_2), \ldots z(tt), \ldots Z(tN) \). For many purposes, the value of \( t_0 \) and \( h \) are unimportant; these are needed if the observation times are to be defined exactly. Of course, the information content of a time-series is affected by the choice of \( h \), particularly if the series has rapid changes. If \( to \) is adopted as the origin and \( h \) as the unit of time, \( zt \) can be regard as the observation at time \( t \).
A discrete time series may arise in two ways:
- By sampling a continuous time series; for example, the continuous river flow at a station may be sampled at hourly intervals.
- By accumulating a variable over a period of time; for example, rainfall may be accumulated over a period of a day.

A hydrologic time series can be divided in two basic groups: 1) Univariate (single) time series, e.g., monthly streamflow at a point, and 2) multivariate (multiple) series of different kinds at one point. The examples of the second type are series of flow and water quality variables at a station.

If a time-series, e.g., daily precipitation, is composed of nonzero and zero values, it is known as intermittent series. A time series whose values have been observed at regular intervals, such as each day or each hour, is termed as regularly spaced time series.

Time series analysis is useful for many applications, such as forecasting, detecting trends in records, filling-in missing data, and generation of synthetic data. The analysis of a time-series is a subject in itself and only a brief introduction of it is given in the following.

**Stationary Vs. Non Stochastic processes**
A special class of stochastic processes, called stationary process, is based on the assumption that the process is in a particular state of statistical equilibrium. A stochastic process is said to be strictly stationary if its properties are unaffected by a change of time origin; that is, if the joint probability distribution associated with m observations \( z_t, z_{t+1}, \ldots, z_{t+n} \), made at any set of times \( h, t_2, \ldots, t_m \), is the same as that associated with m observations \( Z_{t_1+k}, \ldots, Z_{t_m+k} \), made at time \( t_1 + k, t_2 + k, \ldots, t_m + k \). Thus, for a discrete process to be strictly stationary, the joint distribution of any set of observations must be unaffected by shifting all the times of observation forward or backward by any integer amount \( k \). The statistical properties of a non-stationary time-series are time dependent.

Assuming that the stationarity assumption holds true, the joint probability distribution \( P(z_t, z_{t+k}) \) is the same for all times \( t_1, t_2 \), which are a constant interval apart. Therefore, the nature of the joint distribution can be inferred by plotting a scatter diagram using pairs of values \( (z_t, Z_{t+k}) \), of the time series, separated by constant interval or lag \( k \). The covariance between \( z_t \) and \( Z_{t+k} \) is called the autocovariance at lag \( k \) and is calculated by:

\[
\gamma_k = \text{cov}(z_t, z_{t+k}) = E[(z_t - \mu)(z_{t+k} - \mu)]
\]

For a stationary process, the variance at time \( (t + k) \) is the same as at time \( t \). The estimate of the \( k \) the lag autocovariance \( \hat{\gamma}_k \) is

\[
\hat{\gamma}_k = \frac{1}{N} \sum_{i=1}^{N-k} (z_i - \bar{z})(z_{i+k} - \bar{z}), \quad k = 0, 1, 2, \ldots, K
\]

The estimate of lag \( k \) autocorrelation is obtained by
which implies that $r_0 = 1$.

A common cause of autocorrelation or dependence in many hydrologic time series is the storage effect. In case of river flow series, for example, this storage might be at the catchment surface, in unsaturated zone, or in groundwater zone.

**Time series models**

Mathematical model representing a time series or stochastic process is called a time series model. The model has a certain structure and a set of parameters. The important categories of time-series models are as follows.

**Autoregressive (AR) Models**: AR models are extremely useful to represent certain practical series. Let the values of a process at equally spaced times $t, t-1, t-2, \ldots$ be $Y_t, Y_{t-1}, Y_{t-2}, \ldots$ and let $z_t = z_{t-1}, z_{t-2}, \ldots$ be the deviations from the mean $\mu_t$; for example, $\mu = Y_t - \mu_t$. In an AR model, the current value of the process is expressed as a finite, linear aggregate of previous values of the process and a shock at. Thus

$$z_t = \phi_1 z_{t-1} + \phi_2 z_{t-2} + \ldots + \phi_p z_{t-p} + a_t$$

is called an autoregressive process of order $p$ and is denoted by AR($p$). Introducing a backward shift operator $B$, defined by $Bz_t = z_{t-1}$ and the equation can be written as:

$$(1 - \phi_1 B - \phi_2 B^2 - \ldots - \phi_p B^p) z_t = a_t$$

or

$$\phi(B) z_t = a_t$$

Here $\mu = 1 - \phi_1 B - \phi_2 B^2 - \ldots - \phi_p B^p$ is termed as an autoregressive operator of order $p$. The AR models have been extensively used in water resources because, this form has an intuitive type of time dependence and the AR models are simple to use.

**Moving Average (MA) Models**: Another kind of model of great practical importance in the representation of observed time series is the finite moving average process. Here $z_t$ is linearly dependent on a finite number $q$ of previous $a$'s. Thus,

$$z_t = a_t - \theta_1 a_{t-1} - \theta_2 a_{t-2} - \ldots - \theta_q a_{t-q}$$

is called a moving average (MA) process of order $q$ and is denoted by MA($q$). Similar to the autoregressive operator, a moving average operator of order $q$ can be written as

$$\theta(B) = 1 - \theta_1 B - \theta_2 B^2 - \ldots - \theta_q B^q$$
and the MA(q) process can be written as

\[ z_t = \theta(B) a_t \]

Autoregressive-moving Average Models: Greater flexibility in firing time series models is achieved by including both autoregressive and moving average terms in the model. This leads to the mixed autoregressive-moving average ARMA (p, q) model:

\[ z_t = \phi_1 z_{t-1} + \ldots + \phi_p z_{t-p} + \alpha_t - \theta_1 \alpha_{t-1} - \ldots - \theta_q \alpha_{t-q} \]

or

\[ z_t = \phi_1 z_{t-1} - \ldots - \phi_p z_{t-p} = \alpha_t - \theta_1 \alpha_{t-1} - \ldots - \theta_q \alpha_{t-q} \]

or

\[ \phi(B) z_t = \theta(B) a_t \]

Which employs \( p+q+2 \) unknown parameters \( \phi_1, \ldots, \phi_p, \theta_1, \ldots, \theta_q, \alpha_t \), that are estimated from the data. The simplest member of ARMA (p,q) family is the ARMA(1,1) model which can be written as

\[ z_t - \phi_1 z_{t-1} = \alpha_t - \theta_1 \alpha_{t-1} \]

The combination of AR and MA models makes it possible to simulate many hydrologic processes by using a small number of parameters. For example, the flow in a stream results due to a number of causes such as precipitation and groundwater effluence. This mixed behaviour can be conveniently modelled by ARMA models. In practice, an adequate representation of actually occurring stationary time series can be frequently obtained with autoregressive, moving average, or mixed model, in which \( p \) and \( q \) are not greater than 2 and often less than 2. Note that ARMA (p,0) model is the same as AR(p) and ARMA(0,q) model is same as MA(q). In the above eq., \( z_t \) and \( a_t \) may represent time dependent discharge (output) and rainfall (input).

The ARMA models are suitable for stationary hydrologic series. In case of non-stationary series, the periodic or seasonal fluctuation can be removed by taking the differences and the ARMA model can be applied to the resultant series. The resultant model is termed as Autoregressive Integrated Moving Average (ARIMA) model. Consider a time series that is homogeneous except in level, i.e., the various segments of the series look identical except, the difference in level about which it changes. Such a series can be adequately represented by a model of the form:

\[ \phi(B) \nabla z_t = \theta(B) a_t \]

where \( \nabla \) is the \textit{backward difference operator} defined as

\[ \nabla z_t = z_t - z_{t-1} = (1 - B) z_{t-1} \]

Thus, ARIMA (p, d, q) is an ARMA model that is fitted to the data after taking the d the difference of the series:

\[ \phi(B) \nabla^d z_t = \theta(B) a_t \]
where \( V_d \) indicates that the series is differenced \( d \) times. The notation \( V_n = 1 - B^n \) indicates differencing with lag of \( n \). The first order differencing [in the same eq.] is helpful in removing the trend of a series or non-stationarity in the mean. Two consecutive differencing operations are necessary to remove non-stationarity in the mean and slope. However, it may not always be possible to remove non-stationarity by differencing alone; other transformations may also be needed.

Thomas Feiring Model
Hydrological processes are affected by seasons within a year. The mean, variance, lag-1 autocorrelation and skewness coefficient of the river flows tend to vary from season to season. When dealing with river flow data that are sampled in durations less than a year, (e.g. daily, weekly or monthly) one has to account for the effect of seasonality (unpublished lecture note). There are two ways to capture the seasonality of hydrological processes in time series modeling. One is a deseasonalizing approach and the other is develop seasonal time series models.

Deseasonalize
Explicitly remove the seasonal variation from the data and fit it to stationary time series models (e.g. AR1) and add the seasonal component to the generated flow.

Seasonal Thomas Feiring Model
Develop a time series mode (TF) in which the model parameters are allowed to vary from season to season. Thomas Fiering model is essentially a stationary AR(1) process which incorporates the seasonal nature of the hydrological processes which is obtained by replacing the constant parameters of non-zero mean AR1 model by seasonal parameters. A correction is applied for taking into account the unequal variance of the flows in successive months. The model represents a linear regression of two variables (flows of month \( j \) (x) and month \( j+1 \) (y)). Accordingly, the following is the Thomas-Fiering model expressed for ensemble time series as well as sample data series.

\[
x_{i,j+1} - \mu_{j+1} = \rho_{1,j} \frac{\sigma_{j+1}}{\sigma_j} (x_{i,j} - \mu_j) + \sigma_{j+1} \sqrt{1 - \rho_{1,j}^2} \xi_{i,j+1}
\]

Replacing population parameters by sample estimates
\[
x_{i,j+1} - \bar{x}_{j+1} = r_{1,j} \frac{s_{j+1}}{s_j} (x_{i,j} - \bar{x}_j) + s_{j+1} \sqrt{1 - r_{1,j}^2} \xi_{i,j+1}
\]

\[
\hat{\mu}_j = \bar{x}_j = \frac{1}{n} \sum_{i=1}^{n} x_{i,j}
\]

\[
\hat{\sigma}_j^2 = s_j^2 = \frac{1}{n} \sum_{i=1}^{n} (x_{i,j} - \bar{x}_j)^2
\]
Remarks on Thomas Fireing (T-F) Model

T-F model requires the estimation of 36 parameters (i.e. Non-parsimonious in the use of parameters). The modeling of deseasonalised flows by a stationary time series model will be the alternative T-F model is essentially a seasonal AR(1) model. For short duration data (weekly, decade), the TF model would require the estimation of far too many parameters. Sometimes negative values of flow are generated.

\[
\hat{\rho}_{1,j} = \tau_{1,j} = \frac{\sum_{i=1}^{n} [(x_{i,j} - \bar{x}_j)(x_{i,j+1} - \bar{x}_{j+1})]}{n \delta_{j} \delta_{j+1}}
\]
4.3 Decision Support Systems

4.3.1 Optimization

1. Description of optimization and application in WR

In many engineering problems, there are a number of possible solutions. It is, therefore, required to evaluate each alternative solution and then choose the best from the point of view of interest, say economic or convenience. Optimization is the science of choosing the best amongst a number of possible alternatives. The driving force in the optimization models is the objective function (or functions in multi-objective optimization). The term optimal solution essentially refers to the best from the solution of the mathematical model under all assumptions and constraints, whether explicitly stated or implicitly included in the formulation. Clearly, the optimal solution indicated by the model may be far from the actual system's optimal solution. Dantzig and Thapa (1997) defined mathematical programming (or optimization theory) as "that branch of mathematics dealing with techniques for maximizing or minimizing an objective function subject to linear, non-linear, and integer constraints on the variables". The word programming should not be related to computers; here it means 'scheduling', the setting of an agenda, or creating a plan of activities (ReVelle et al., 1997).

2. Formulation of optimization equations

Any "optimal" solution derived is clearly dependent on the assumptions and criteria and their associated uncertainties. Some of these uncertainties might be derived from the selection of model structure, parameters, scope, or focus. Others might be related to data, the optimization techniques used to solve the mathematical models and the inability to account for many non-quantitative and non-tangible considerations in the model.

An optimization problem can be stated as:

Maximize (or Minimize)  \[ f(X) \]

subject to  
\[ g_j(X) \leq 0, \quad j = 1,2,\ldots,m \] 
\[ h_j(X) = 0, \quad j = m+1, m+2,\ldots,p \]

Where \( X \) is a vector of \( n \)-variables which are known as decision variables, \( g(X) \) are the equality constraints, and \( h(X) \) are the equality constraints. To solve an optimization problem, the value of decision variables is systematically changed. The range over which a decision variable can be changed is known as its feasible range. The decision-maker evaluates the available alternatives on the basis of some prescribed criterion function. This criterion function, denoted by \( f(X) \), is known as the objective function. Its choice depends on the problem. While formulating the optimization problem, one should carefully decide the objective function and it should properly reflect the preference of the decision-maker. In the beginning of analysis, objectives are often unclear or loosely stated. Considerable efforts may be needed to clarify them. Typically, the objective function may represent benefits which are maximized or it may represent costs which are to be minimized.
The availability of resources is usually limited and is expressed with the help of constraints. Here, \( g \) and \( h \) are the inequality and equality constraints. These constraints restrict the range over which the decision variables can change and thus affect the optimum solution. The number of decision variables and the number of constraints depend on the problem. If the number of constraints is zero then the problem is known as the unconstrained optimization problem.

In most practical problems, the surfaces of objective function have more than one peak or trough. The graph in Fig. 4-4 shows the variation of two objective functions with the decision variable for a problem which has only one decision variable. The objective function shown with solid lines (\( Z_1 \)) has only one extreme point. If the second objective function shown by dotted lines (\( Z_2 \)) is to be minimized, points A and B are known as local optimum because the value of the objective function is lowest only in the vicinity of these points. At point C, the value of the objective function is lowest among all the points and hence this point is termed as the global optimum. The value of the objective function at a local optimum is more than the global optimum in case of minimization problem and vice versa for the maximization problem. In problems where the objective function has this type of behaviour, the solution algorithm may end up at a local optimum. In an optimization problem, the constraints force the solution to lie within a limited region which is known as the feasible region. It is to be noted that usually real-life problems have a large number of decision variables and constraints. Therefore, in such problems, it is helpful to understand the nature of the objective function and constraints.

![Graph showing variation of two objective functions with decision variables](image)

**Fig. 4-4:** Variation of two objective functions with decision variables

### 3. Classification of optimization techniques

Optimization techniques are also known as mathematical programming techniques. They can be classified in several ways, such as on the basis of the existence of constraints, the nature of the problem, the nature of the equations involved, the permissible values of the design variables, the deterministic nature of the variables involved, the separability of the functions, the number of objective functions involved, etc. The usual way of classifying optimization techniques is based on the nature of the problem or equations involved. These techniques can be classified as Linear Programming (LP), Nonlinear Programming (NLP), Geometric Programming (GP), Dynamic Programming (DP), etc. This classification is useful from a
computational point of view, since many methods have been developed solely for the efficient solution of a particular class of problems.

In the classification which depends on the existence of constraints, the problem can be classified as constrained optimization or unconstrained optimization. The input variables to a problem of water resources could be either deterministic or stochastic and depending upon that, the technique can be classified as deterministic optimization or stochastic optimization. According to Yeh and Becker (1982), stochastic optimization is useful for planning purposes, while deterministic optimization is a viable approach for real-time reservoir operation with frequent updating of streamflow forecasts. Recently, many new optimization techniques have been used in studies dealing with water resources. Genetic Algorithm (GA) is one such approach whose use began in the 1970s (see Goldberg 1989; Dandy et al. 1996; Wardlaw and Sharif 1999). Another technique that has become popular in systems control is fuzzy programming (see Pedrycz 1993; Russell and Campbell 1996).

Although optimization encompasses a very wide range of subjects, keeping in view the current status of the application of optimization techniques in water resources, the discussion in this chapter is limited to LP, NLP, and DP only.

4. Linear programming

Optimization problems in which the objective function and constraints are linear functions of decision variables and the decision variables are non-negative are termed as linear programming (LP) problems. Dantzig and Thapa (1997) defined LP as a technique that "is concerned with maximization or minimization of a linear objective function in many variables subject to linear equality or inequality constraints." An optimization problem can be classified as an LP problem if it meets the following conditions:

- The decision variables of the problem are non-negative, i.e., positive or zero.
- The criterion function or objective function is described by a linear function of the decision variables, i.e., a mathematical function involving only the first powers of the variables with no cross products.
- The operating rules governing the processes, commonly known as constraints, are expressed as a set of linear equations or linear inequalities.

The LP type of optimization problem was first recognized in the 1930s by economists while developing methods for optimal allocation of resources. During the World War II, the United States Air Force sought more effective procedures to allocate resources and this led to the development of LP. G.B. Dantzig, who was a member of the Air Force Group, formulated the general LP problem and devised the simplex method of solution in 1947. This was a significant step in bringing LP into wider usage. Since then, LP models have been widely used to solve a variety of military, economic, industrial, social, engineering and hydrological problems. The number of applications of linear programming has grown immensely in the past few decades.

The LP models have been extensively used to solve water resources problems. Although the objective function and the constraints are not linearly related with the decision variables in
many real-life water resources problems, these can be approximated by linear functions and the LP technique can be used to obtain the solution.

5. Dynamic programming

Dynamic Programming (DP) is an enumerative technique developed by Richard Bellman in 1953. This technique is used to get the optimum solution to a problem which can be represented as a multistage decision process. The entire DP formulation is based on the Bellman principle of optimality. According to this principle, an optimal policy has the property that whatever the initial state and decisions are, the remaining decisions must constitute an optimal policy with respect to the state resulting from the first decision. The proof of this theorem can be obtained by contradiction. In Fig. 4-5, let the optimal path for going from A to D be ABCD. According to Bellman's theorem, the optimal path from B to D will be BCD and not BED. If the optimal path from B to D is BED then the optimal path from A to D will be ABED and not ABCD.

Fig. 4-5: Illustration of the principle of optimality

Dynamic programming is not a class of optimization techniques, but as an algorithm it is a powerful procedure to solve sequential decision problems. Many problems in water resources involve a sequence of decisions from one period to the next period and are known as sequential decision problems. Such problems can be decomposed into a series of smaller and easily solvable problems that can be conveniently handled by DP. For example, the operation of a reservoir proceeds in a sequential manner from one time period to another. An important feature of DP is that non-linearities and constraints can be readily accommodated. In fact, constraints serve to reduce the region to be covered in computations and are helpful in that sense. In a DP problem formulation, the dynamic behavior of the system is expressed by using three types of variables:

**State variables** - define the condition of the system. For example, the amount of water stored in the reservoir may represent its state. If a problem has one state variable per stage, it is called a one-dimensional problem; a multi-dimensional problem has more than one state variable per stage. Thus, the optimization of operation of a system of two reservoirs will have two state variables, one for each reservoir.
**Stage variables** - define the order in which events occur in the system. Most commonly, time is the stage variable. There must be a finite number of possible states at each stage.

**Control variables** - represent the controls applied at a particular stage and transform the state of the system. For a reservoir operation problem, the release of water from the reservoir is a typical control variable.

The dynamic behaviour of the system is expressed by an equation known as the system equation. It can be written in discrete form as:

\[ s(t+1) = f[s(t), u(t), t] \quad t = 1, 2, ..., N \]

where \( s(t) \) is the state variable at time \( t \), \( u(t) \) is the control applied at time instant \( t \), which lasts for a finite duration and \( f[.] \) is the given functional form. The state of the system at any stage should lie in the domain of admissible states at that stage; the controls should also lie in the admissible domain at that stage:

\[ s(t) \in S(t), \quad u(t) \in U(t) \]

where \( S(t) \) and \( U(t) \) are the domains of admissible states and controls at stage \( t \). The function \( f[.] \) should be invertible, i.e., it must be possible to express the decision variable as an explicit function of state variables:

\[ u(t) = f^{-1}[s(t+1), s(t), t] \]

For an invertible system, the order of the state vector is equal to the order of the control vector. Thus, the knowledge of stage variables enables one to compute the decision variables. For instance, in reservoir regulation problems, the mass balance equation (which is also the state equation) is invertible.

With each state transformation, a return is associated which may either represent benefits or costs. Typically the benefits are maximized and the costs are minimized. The optimal decision made at a particular stage is independent of decisions made at the previous stage, given the current state of the system. It is necessary that the objective function of a DP problem should be separable. It should be possible to write individual objective functions at each stage as functions of state and/or decision variables at that stage. Likewise, the constraints should also be separable or each constraint should be associated with an individual stage only. For a multi-dimensional problem, it would be necessary to evaluate the objective function for all discrete combinations of state variables.

A set of decisions for each time period is called a policy and the policy which optimizes the objective function is called the optimal policy. The set of states resulting from an application of the policy is called the state trajectory. For example, the volume of water stored in a reservoir can be considered to be its state. The state of a reservoir is transformed due to
inflows and can be controlled by releasing water from the storage. This water can be used for
some useful purpose (e.g., irrigation) to yield monetary returns or it may also cause flood
damage downstream and a cost is associated with this damage. A problem of optimizing the
operation of a reservoir could be to free the releases (controls) which yield the best returns.

6. Stochastic optimization

The system behaviour and input of water resources projects display stochasticity which needs
to be appropriately accounted for. Depending on the way the stochastic nature of the system
and inputs are treated in an optimization formulation, the solution techniques are classified as
implicit stochastic optimization (ISO) or explicit stochastic optimization (ESO). In ISO, the
system and the stochastic nature of the input are represented by statistical models and these
models are used to generate realizations of the inputs time series over the operation horizon. A
suitable deterministic optimization technique is applied to the optimum decision variables for
each input realization. Since data generation techniques and simulation are used, the problem
need not be solved analytically. This approach is known as Monte Carlo technique.

In this approach, inputs are represented by a time series model or probability distribution and
the system behaviour is modeled. Inputs are transformed into system outputs and statistical
characteristics of the outputs are gathered. This enables estimates of various output
probabilities to be made which can be related to risk. A regression analysis is carried out to
establish relationship among the system inputs, state variables, outputs, and optimum
decisions for all of the generated sequences. This relationship can be used to take operation
decisions when the future is unknown. This strategy was used by Yotmg (1967) to derive
reservoir operation rules. Since deterministic DP was used, the procedure was termed as
Monte Carlo Dynamic Programming (MCDP).

A drawback of ISO is that it requires considerable computational time and efforts to generate
a large number of synthetic input sequences, solve a large number of optimization problems,
and do multivariate regression analysis. Furthermore, one may not always get a good
relationship between the variables involved.

In contrast to ISO, ESO directly uses the probability distributions of inputs in optimization.
The objective function is the sum of benefits over all states, stages, inputs, and decisions
multiplied by the probability that these conditions occur. Thus, the objective function
represents the expected total benefit for the system. Computations are performed to find that
set of probabilities which maximize the expected total benefit. These probabilities are then
used to calculate the conditional probabilities of making a decision given that the system is in
a certain state at a given stage and it receives certain inputs. Ideally, the solution should yield
a pure strategy, i.e., one decision should have a probability of unity and all other decisions
should have zero probability. Unfortunately, one does not always obtain pure strategies;
"mixed" strategies are occasionally obtained and are suitably used to arrive at the decisions. In
the ESO, if the optimization technique used is LP, this problem is known as stochastic LP.
The linear decision rules are used in LP to disallow the possibility of the mixed strategy.

The advantage of ESO procedures over ISO is that the results obtained from ESO are based
on a conditional probability distribution at each stage. Therefore, more information is utilized
for the choice of a decision at each stage. Instead of just a single estimate, the probability
distribution of inputs is used. The method involves a great deal of computation time and storage so that its application to complex systems is severely limited. The common assumption is that the inputs at each stage have a steady-stage probability distribution and the system can be represented by a cyclic (repetitive) operation. Thus, only one cycle needs to be analyzed, and the system properties can be represented using a small number of discrete values for states, inputs, and decisions.

**Example problems in Optimization**

**Problem-1:** The following two-objective two-decision variable problem by Cohon and Marks (1975) is used to illustrate the concepts of multi-objective optimization.

\[
\text{Max } Z(x) = [Z_1(x), Z_2(x)] \\
Z_1(x) = 5x_1 - 2x_2 \\
Z_2(x) = -x_1 + 4x_2
\]

subject to
\[
g_1(x): -x_1 + x_2 - 3 \leq 0 \\
g_2(x): x_1 + x_2 - 8 \leq 0 \\
g_3(x): x_1 - 6 \leq 0 \\
g_4(x): x_2 - 4 \leq 0 \\
g_5(x): x_1 \geq 0 \\
g_6(x): x_2 \geq 0
\]

**Solution:** In this example with two decision variables and two objectives, the feasible region in the objective space can be found by enumeration of all extreme points and computation of the values of each objective at each of these comer solutions. These points and the values of the objective functions are listed in the Table 4-3.

Table 4-3: Extreme points and values of objective functions.

<table>
<thead>
<tr>
<th>(\bar{x})</th>
<th>(x_1)</th>
<th>(x_2)</th>
<th>(Z_1)</th>
<th>(Z_2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>4</td>
<td>-3</td>
<td>15</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>4</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>2</td>
<td>26</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>0</td>
<td>30</td>
<td>-6</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>3</td>
<td>-6</td>
<td>12</td>
</tr>
</tbody>
</table>

The non-inferior set \(Z(X^*)\) can be found by applying the definition of non-inferiority. The set of non-inferior solutions contains four extreme points: \(Z(x_1), Z(x_2), Z(x_3)\) and \(Z(x_4)\). The point \(X^*\) (4,4) is the best-compromise solution. Note that this enumeration procedure is computation any feasible only for very small problems. The feasible region in the decision space and the set of non-inferior solutions are shown in Fig. 4-6. Fig. 4-7 shows the feasible region and the non-inferior set \(Z(X^*)\) in the objective space \(Z(X)\).
In the absence of preference information, no particular non-inferior solution can be identified as preferable to any other non-inferior solution. Of course, if preferences are known as represented by an indifference surface, then one of the non-inferior solutions can be identified as the best-compromise solution. The term 'best-compromise solution' indicates that a non-inferior solution so identified is optimal only in terms of a particular set of value judgments.

Fig. 4-7: The feasible region in objective space $Z(X)$, the non inferior set ($Z(X^*)$), and the best compromise solutions
(After Cohon and Marks, 1975)
The use of enumeration method as a means of defining the feasibility frontier and the corresponding trade-offs between each efficient decision vector cannot be adopted as the number of variables and objectives increases. For these reasons, optimization techniques are usually suggested as a means of estimating feasible and efficient decision vectors X.

4.3.2 Simulation

1. Simulation in river basin management

Simulation is the process of duplicating the behaviour of an existing or proposed system. It consists of designing a model of the system and conducting experiments with this model either for better understanding of the functioning of the system or for evaluating various strategies for its management. The essence of simulation is to reproduce the behaviour of the system in every important aspect to learn how the system will respond to conditions that may be imposed on it or that may occur in the future. The main advantage of simulation models lies in their ability to accurately describe the reality. If a simulation model can be developed and is shown to represent a prototype system, it can provide insight about how the real system might perform over time under varying conditions. Thus, proposed configurations of projects can be evaluated to judge whether their performance would be adequate or not before investments are made. In a like manner, operating policies can be tested before they are implemented in actual control situations. Hufmschmidt and Fiering (1966) describe the simulation technique for design of water resources systems. James and Lee (1971) have noted that simulation is the most powerful tool to study complex systems.

Usually, the structure or behaviour of the system being simulated is so complex that its analytical expression is not possible. A simulation model of a water resource system duplicates its operation with a defined operational policy, using the parameters of physical and control structures, time series of flows, demands, and the variables describing water quality, etc. The evaluation of the design parameters or operation policy is through the objective function (flow or demand related measures or economic indices) or some measure of reliability.

Since simulation models do not use an explicit analytical procedure for determination of the best combination of the controlling variables, it is necessary to proceed by trial and error or follow a strategy of parameter sampling. Since models are abstractions of reality, they usually do not describe all the features that are encompassed by a real-world situation. Only those aspects of the system that are relevant to the objective of the study are modeled so that solution is obtained at a reasonable cost and within a prescribed time frame. If the simulation model has to reproduce all the complexities of the prototype, it will be as complex as the prototype. Therefore, the model builder should attempt to model the detailed functioning of individual components to the necessary extent so as to meet the overall accuracy requirements while not making it unnecessarily complicated. To illustrate, if the objective is the design of a large storage reservoir for irrigation and municipal water supply, it is quite unnecessary to model the complete runoff process. On the other hand, a monthly flow-generation model is entirely unsuited for modeling the peak discharges. An important aspect of model building in the context of simulation is to find the best permissible simplifications. When, for example, should the engineer responsible to issue flood forecasts use a simple routing model and when
he should employ a dynamic wave model, using the complete St. Venant equations? The
difference in efforts and computer time for the two methods is very large. The main reasons
for searching for a simple model may be a lack or low quality of data. For example, consider
that there are only a few rainfall and discharge data stations in a large catchment. In this
scenario, there is no justification to set-up a detailed model which requires huge data, long
time to calibrate and run, and skilled manpower.

The main advantage of simulation models lies in their ability to closely describe the reality. If
a simulation model can be developed and is shown to represent the prototype system
realistically, it can provide insight about how the real system might perform over time under
varying conditions. Thus, proposed configurations of projects can be evaluated to judge
whether their performance would be adequate or not before investments are made. In a like
manner, operating policies can be tested before they are implemented in actual control
situations. Simulation is widely believed to be the most powerful tool to study complex
systems.

2. River basin modelling and components
The various include the watersheds that drain into the surface water bodies and underlying
aquifers of river systems. They include the streams, rivers, lakes, reservoirs and wetlands that
can exist in river basins and that are affected by water management policies and practices.
First, each of these components will be examined and modelled separately. The management
of any single component, however, can affect the performance of other components in a river
basin system. Hence, for the overall management of river basin systems, a systems view is
needed. Typically, this systems view requires the modelling of multiple components. These
multi-component models can then be used to analyse alternative designs and management
strategies for integrated multi-component systems.

River basin planning is a prerequisite for integrated water resources management (IWRM).
IWRM requires the integration of the natural system components (surface water–groundwater,
quantity–quality, land- and water management, etc.) and the upstream and downstream water-
related demands or interests. Water resource planning is increasingly done on a river basin
scale. The European Water Framework Directive, for example, imposes the development of
basin plans in Europe, forcing riparian countries to work together on the development and
management of their river basins.

3. Major water resource elements and mathematical formulation
Hydrological models are classified as either theoretical or empirical models. A theoretical
model is based on physical principles. If all the governing physical processes are described by
mathematical functions, a model containing those functions is a physically based model.
However, most existing hydrological models simplify the physics and often include empirical
components. For example, the conservation of momentum equation or Manning’s equation for
predicting surface flow include empirical hydraulic resistance terms. Darcy’s equation, used
to predict subsurface flows, requires an empirical hydraulic conductivity parameter value.
Thus they are considered at least partially, if not fully, empirical. Purely empirical or
statistical models omit the physics and are in reality representations of the observed data.
Depending on the character of the results obtained, hydrological models can also be classified
as deterministic or stochastic. If one or more of the variables in a mathematical model are regarded as random variables whose values can change unpredictably over time, then the model is stochastic. If all the variables are considered to be free from random variation, the model is deterministic. Of course some ‘deterministic models’ may include stochastic processes that capture some of the spatial and temporal variability of some of the sub-processes, such as infiltration. Most hydrological models are deterministic in spite of a host of random processes taking place in the watersheds to which they are applied. The rather simple modelling approach outlined below for estimating the relative surface and groundwater runoff to surface water bodies is an example of a deterministic model. Hydrological models can also be classified as event-based models or as continuous-time models. An event-based model simulates a single runoff event, such as a single storm, usually occurring over a period of time ranging from about an hour to several days. The initial conditions in the watershed for each event must be assumed or determined by other means and supplied as input data. The accuracy of the model output may depend on the reliability of these initial conditions. A continuous-time watershed model includes a sequence of time periods and for each period determines the state of the watershed, whether or not any events take place that will produce surface runoff. The model keeps a continuous account of the watershed surface and groundwater conditions. The effect of any assumed initial conditions decreases rapidly as time passes.

4. Watershed models

Hydrological modelling is used to predict runoff from land areas, infiltration into soils and percolation into aquifers. Rainfall–runoff models are often used when streamflow gauge data are not available or not reliable, or cannot be made representative of natural flow conditions (that is, what the flows in a stream or river would be without upstream diversions or reservoirs that alter the flows downstream). They are also used to provide estimates of the impact that changing land uses and land covers have on the temporal and spatial distribution of runoff.

5. Water quality models

River basin models focusing on water quantities are mostly used to investigate whether sufficient water is available to satisfy the various use functions (off-stream and in-stream), and to identify measures to match supply and demand. The core of most river basin models consists of keeping track of the water balance of the whole river basin. The analysis of water quality and ecology is mostly done ‘off-line’, using another model for a specific part of the system, e.g. a river stretch, reservoir or groundwater system. There is little feedback from water quality to quantity (except in cases where minimum flows are required to maintain a minimum water quality level). Using separate water quality models for parts of the system makes it possible to include more temporal and spatial detail and to include more complex water quality processes. Environmental flow requirements can be included in river basin models by defining specific flow regime demands (quantity, velocity, dynamics and the like) at certain locations in the river basin.

4.3.3 Multi-criteria and Evaluation Techniques

In water resources development problems, where there are competing development multi-objectives, prioritizing of and ranking the objectives is very essential to come up to feasible solution. Typical multi-objective water resources development includes operation of a water
storage reservoir for power production, irrigation and fulfilling downstream environmental requirement under water stress condition. Other examples such as agricultural production should be increased and at the same time adverse outcomes like pollution of water bodies should be minimized; or a hydropower station should be planned in such a way that electric power production is as large as possible while the environmental impacts should be as small as possible; or mining activities should be developed in the most economically efficient way, providing labour and utilizing all the resources in an environmentally sound way. There are several methods of multi-objective methods in water resources and few of them are described in subsequent sections.

1. Multi-objective and multi-criteria methods

Outranking MCDM techniques

These techniques use outranking relationships among alternatives to select the most "satisfying" alternative. An outranking relation represents the pair wise preference ordering of a finite set of alternatives. Four different preference relations between a pair of alternatives can be defined: a strict preference, indifference, weak preference, and incomparability (Roy and Vincke, 1984).

Given two alternatives A1 and A2 belonging to the full set of alternatives A, a strict preference between A1 and A2 implies that one of them is significantly preferred to the other, that is, A1>A2 or A2>A1, but not both. Here, ‘>’ stands for the strict preference relation. In contrast, we have the indifference relation when the difference between alternatives A1 and A2 becomes too small to be recognizable. In this case, the two actions are indifferent in the sense that A1=A2 and A2=A1, where ‘=’ represents the equivalence relation. When the difference between alternatives is neither sufficiently small, so as to be indifferent, nor sufficiently large, as to constitute a strict preference, they are known as a weak preference, a concept introduced by Roy (1973) to describe the situation. A possible way of formal description can be A1(>><)A2 or A2(<<>)A1. On the other hand, when the attributes between alternatives are significantly different from each other and the DM does not have adequate information to compare them, then the alternatives are said to be incomparable with each other. The relation of incomparability can be represented by A1.ic.A2 or A2.ic.A1.

Using the above four distinct preference relations, the outranking relation between any two alternatives A1 and A2 in A can be defined. Two types of outranking relations are recognized: a deterministic outranking relation, and a fuzzy outranking relation (Roy 1977; see also Nachtebel, 1992). A deterministic out-ranking relation asserts that, given alternatives (A1,A2) ∈ A, A1 outranks A2 (A1>=A2) if there exists sufficient evidence that alternative A1 is at least as good as alternative A2 and there is no good reason to reject it. As far as deterministic outranking relationships are concerned, there is no discrimination between strict preference and weak preference. On the other hand, a fuzzy outranking relation provides more information than the deterministic one, since the credibility of the outranking of one alternative on another is also given (see Roy, 1977).

An example of an outranking method is ELECTRE I (Benayoun et al., 1966). An alternative A1 is said to outrank A2 if A1 is better than A2 in a sufficient (weighted) number of criteria, and if A1 is not too much worse than A2 in any of the other criteria. This means that two columns 1 and 2 are selected for comparison from the payoff table. Each criterion has a weight expressing its importance. Two indicators, the concordance index CI and the discordance index DI are defined to express this
fact more precisely. The Concordance Indicator expresses the dominance and the Discordance Indicator describes how strong an alternative fails in the comparison. Both indicators have the range (0,1). So an ‘alternative i is better than j’ when the CI is as close as possible to 1 and the DI as close as possible to 0.

This approach will result in a partial outranking and by defining some threshold levels for CI and DI, namely p and q, those alternatives are considered where CI(i,j)>p and DI(i,j)<q. Extensions of the method can be found in Roy (1971;1973;1974,1975;1978). Some examples and details of the methodology can be found in Nachtnebel (1994). This group of outranking techniques is only applicable in the case of discrete alternatives. The strength is in the fact that also qualitative criteria can be treated.

Table 4-4: Extended pay-off table with weights and scales

<table>
<thead>
<tr>
<th>Criteria</th>
<th>( A_1 )</th>
<th>( A_2 )</th>
<th>( A_3 )</th>
<th>( A_4 )</th>
<th>( A_5 )</th>
<th>Worst</th>
<th>Best</th>
<th>Weight</th>
<th>Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>( C_1 )</td>
<td>( a_{11} )</td>
<td>( a_{12} )</td>
<td>( a_{13} )</td>
<td>( a_{14} )</td>
<td>( a_{15} )</td>
<td>( C_{1\text{Min}} )</td>
<td>( C_{1\text{Max}} )</td>
<td>( W_1 )</td>
<td>( S_{c_1} )</td>
</tr>
<tr>
<td>( C_2 )</td>
<td>( a_{21} )</td>
<td>( a_{22} )</td>
<td>( a_{23} )</td>
<td>( a_{24} )</td>
<td>( a_{25} )</td>
<td>( C_{2\text{Min}} )</td>
<td>( C_{2\text{Max}} )</td>
<td>( W_2 )</td>
<td>( S_{c_2} )</td>
</tr>
<tr>
<td>( C_3 )</td>
<td>( a_{31} )</td>
<td>( a_{32} )</td>
<td>( a_{33} )</td>
<td>( a_{34} )</td>
<td>( a_{35} )</td>
<td>( C_{3\text{Min}} )</td>
<td>( C_{3\text{Max}} )</td>
<td>( W_3 )</td>
<td>( S_{c_3} )</td>
</tr>
</tbody>
</table>

\[
CI(i, j) = \frac{\sum_{k=1}^{n} w_k + \frac{1}{2} \sum_{k=1}^{n} w_k}{\sum_{k=1}^{n} w_k}
\]

\[
DI(i, j) = \max_{k=1, j} \left\{ \frac{Z_{k,i} - Z_{k,j}}{\max(Sc)} \right\} \text{ for all } A_j > A_i
\]

**Distance-based MCDM techniques**

Some MCDM techniques use the concept of distance to choose a satisfying solution. Most of these methods choose the alternative that minimizes some measure of distance between the alternative and reference set of criteria values. Distances are used as a proxy measure for human preference (Zeleny, 1981). Distances show the degree of resemblance, similarity, or proximity of alternatives with respect to individual criteria.

There are several distance-based techniques that have been developed. Generally, these techniques proceed first by defining some reference point, which, in most cases, should be an infeasible alternative to which the alternatives are related. One major difference among the techniques that belong to this group is the way they relate to the reference point. Compromise programming (CP) finds the feasible solution that is closest to an ideal solution. Other techniques, such as co-operative game theory (CGT), on the other hand, use quite a different concept of distance to determine an acceptable solution. Another group of techniques, which also use the concept of minimum-distance, are goal programming and its variants.

**Compromise programming**
As an example of a distance-based method, the compromise programming technique is summarized. In determining the most satisfying solution by this method, the ideal solution can be defined as the vector $C^* = (C_{1,max}, C_{2,max}, C_{3,max}, C_{4,max})$, where the $C_{i,max}$ is the best value (See Table 4-4) across alternatives $X \in A$, of criterion $i$. A commonly used measure of closeness in this method is a family of $L_p$ metrics (Duckstein and Opricovic 1980; Zeleny 1973; Zeleny 1981; Szidarovszky et al. 1986) which measure the distance of alternative $A_i$ from the ‘Ideal Point’ $C^*$.

\[ L_p(i) = \sum_{k=1}^{J} (w_k (C_{ki} - a_{ki}))^{\frac{1}{p}} \]

where the weights $w_k > 0$ indicate the relative importance of the objectives to the DM and the value $p$, which has nothing to do with the $p$-value being used as a concordance threshold, may range from $1 < p < \infty$. The exponent $p$ defines the metrics of the system. For instance, using a value $p=1$ would correspond to defining the distance by the mean distance, while $p=2$ corresponds to a metric distance. For $p = \infty$, the largest of the deviations completely dominates the distance measure, or in other words, the distance of an alternative to the ‘ideal solution’ is dependent on its largest component. Consequently, Eq. 3 reduces to the expression:

\[ L_{p=\infty}(i) = \max_k w_k [C_{ki,max} - a_{ki}(x)] \]

Independent from the value $p$ which is related to the attitude of the DM towards risk, the ‘best alternative’ is identified by its smallest distance from the ideal point.

4.3.4 EIA

Is a fundamental tool to evaluate the feasibility of water resources development projects. Recently, World Bank is increasingly using the term social and environmental assessment tool as means of evaluating water projects. Please elaborate the major differences of these two methods.

4.3.5 Decision support tools

A DSS is a multi-disciplinary tool, which may contain a number of technical/analytical components linked together within an interactive and user-friendly framework. Depending on the envisaged functions of the DSS various degree of emphasis can be put on the individual technical components (NBI-WRPMP, 2001). The main difference between DSS and decision support tool is that DSS will have a system of tools that interact to each other and provide comprehensive support to the state of water development while Decision support tool facilitates decision on a particular water development problem.

Principal components, included in water resources based DSS for an international river basin may comprise among others:

- An interactive graphical user interface
- An effective communication system
- A comprehensive information management system (IMS)
A basin-wide river systems model (RBM)
A toolkit with a range of technical and analytical tools.

Each of these components is briefly described in general terms below. For the purposes of the Water Resources project, the components of the Nile Basin DSS may be grouped into an information management system (IMS) and a river basin model (RBM); while the graphical user interface and communication system is the environment which serves both of these systems, supported by a toolkit of analytical tools.

**Interactive Graphical User Interface:** The graphical user interface provides the interface, or computer screens and graphic displays, through which the user interacts with the various components of the DSS. The ease with which the DSS can be accessed, its programs applied, and its results interpreted, is critical to the long-term usefulness and effectiveness of the DSS. To provide valuable results, the graphical user interface and its post-processing capability should be designed to meet the requirements of the users, particularly the decision makers. A geographical information system (GIS), which can provide the capacity for visually displaying spatial and temporal data, may be imbedded in the interactive graphic user interface.

**Communication System:** An important component in international river basin management is an efficient communication system between technical staff, managers, decision makers, major stakeholders, and the public. Modern technology such as internet resources or other appropriate communication links can support direct and efficient international communication and exchange of information, and the use of the DSS by users in the Nile riparian countries. Using the internet as a platform, users can access the DSS by entering the graphical user interface at a web page.

**Comprehensive Information Management System:** An information management system (IMS), which provides an overall storage, overview, and some data processing capability, is a fundamental part of a DSS. Data may include a wide variety of information, and the IMS should provide the possibility to integrate social, economic and environmental data together with the traditional water resources information. An appropriate IMS, including both meta database and database components, would utilize GIS to display, for example, geographical locations of information as well as spatial views of processed data.

An information management system can also function as a knowledge base and include libraries of reports, maps, and other materials of common interest. This provides easy access to existing knowledge accumulated over the years in numerous projects and studies which are often difficult to access. In places with a low level of IT access, such as in sub-Saharan Africa, conscious efforts need to be made to provide options for dissemination of information to users with limited connectivity.

**River Basin Model:** Simulation of water quantity and quality, as a function of climate and human interventions, to assess river system response to alternative development schemes is a well established discipline and provides an important part of a DSS. River basin models provide the hydrological and hydraulic framework to describe the functioning of the physical system, and serve as a precursor to understand and describe water balances and flows at the river basin scale.
Such models may be developed as pure or rule-based simulation models, optimization models, or a combination and can incorporate socio-economic and environmental factors into water resources management. Optimization/ranking procedures can be useful to identify optimal strategies based on given objective functions and defined constraints. The optimization may focus on different single or multi-objective criteria, such as satisfying specified water demands, increasing energy production, cost/benefit criteria, preservation of sensitive ecosystems, and protection of vulnerable watersheds. DSSs often include a suite of models operating on different scales and focused on a range of hydrologic, hydraulic, environmental, and socio-economic issues, depending on the intended use and types of decisions to be supported by the DSS.

Toolkit: A variety of analysis tools are generally available in a DSS. These can include a range of statistical analysis tools to assist in evaluating past performance or predicting future trends, such as related to rainfall or streamflow patterns. Procedures for conducting trade-off analyses, risk analyses, ranking alternatives, or evaluating performance, along with the means to graphically display information, are often incorporated into the DSS and linked to modeling components. In order to satisfy specific national needs it is important to expand the water resources modeling capabilities beyond a basin-wide river systems model, which may not be able to accommodate specific characteristics in every part of the Basin. A number of generic water resources model codes would therefore have to be available for specific national usage in a DSS.

Fig. 4-8: A simplified block diagram showing the relationship between DSS components
Source: NBI-WRPMP)
4.3.6 Example Models in Decision Support System (DSS)

Some of the famous models usually cited as typical decision support systems include RIBASIM, WEAP, MIKEBASIN,

**RIBASIM**

RIBASIM (River Basin Simulation Model) is a generic model package for analyzing the behaviour of river basins under various hydrological conditions. The model package is a comprehensive and flexible tool which links the hydrological water inputs at various locations with the specific water-users in the basin. RIBASIM is developed and maintained by Delft Hydraulics in the Netherlands ([http://www.wldelft.nl/soft/ribasim/int/index.html](http://www.wldelft.nl/soft/ribasim/int/index.html)).

RIBASIM enables the user to evaluate a variety of measures related to infrastructure, operational and demand management and the results in terms of water quantity and water quality. RIBASIM generates water distribution patterns and provides a basis for more detailed water quality and sedimentation analyses in river reaches and reservoirs. It provides a source analysis, giving insight in the water's origin at any location of the basin.

RIBASIM has been applied for river basin planning and management in a great number of countries in a variety of projects. Water management organizations use it to support their management and planning activities. Large and complex river basins have been modeled and simulated with RIBASIM. Separately modeled sub-basins can be combined into one main-basin. A recent application of RIBASIM is the use of the model as flow routing component within a Flood Early Warning System (FEWS).

RIBASIM has links to other Delft Hydraulics software programs. It can link with the HYMOS hydrological database and modeling system. For detailed water quality process RIBASIM can link with the DELWAQ water quality model.

Various hydrologic routing methods are available in RIBASIM e.g. Manning formula, Flow-level relation, 2-layered multi segmented Muskingum formula, Puls method and Laurenson non-linear “lag and route” method. The flow routing is executed on daily basis starting at any selected day for any number of days ahead.

**WEAP**

WEAP ("Water Evaluation And Planning" system) is a user-friendly software tool that takes an integrated approach to water resources planning. Freshwater management challenges are increasingly common. Allocation of limited water resources between agricultural, municipal and environmental uses now requires the full integration of supply, demand, water quality and ecological considerations. The Water Evaluation and Planning system, or WEAP, aims to incorporate these issues into a practical yet robust tool for integrated water resources planning. WEAP is developed by the Stockholm Environment Institute's Boston Center at the Tellus Institute ([http://www.weap21.org/](http://www.weap21.org/)).

**WEAP Highlights**
**Integrated Approach:** Unique approach for conducting integrated water resources planning assessments

**Stakeholder Process:** Transparent structure facilitates engagement of diverse stakeholders in an open process

**Water Balance:** A database maintains water demand and supply information to drive mass balance model on a link-node architecture

**Simulation Based:** Calculates water demand, supply, runoff, infiltration, crop requirements, flows, and storage, and pollution generation, treatment, discharge and instream water quality under varying hydrologic and policy scenarios

**Policy Scenarios:** Evaluates a full range of water development and management options, and takes account of multiple and competing uses of water systems

**User-friendly Interface:** Graphical drag-and-drop GIS-based interface with flexible model output as maps, charts and tables

WEAP is a microcomputer tool for integrated water resources planning that attempts to assist rather than substitute for the skilled planner. It provides a comprehensive, flexible and user-friendly framework for planning and policy analysis. A growing number of water professionals are finding WEAP to be a useful addition to their toolbox of models, databases, spreadsheets and other software. Over the last decade, an integrated approach to water development has emerged which places water supply projects in the context of demand-side management, and water quality and ecosystem preservation and protection. WEAP incorporates these values into a practical tool for water resources planning and policy analysis. WEAP places demand-side issues such as water use patterns, equipment efficiencies, re-use strategies, costs, and water allocation schemes on an equal footing with supply-side topics such as stream flow, groundwater resources, reservoirs, and water transfers. WEAP is also distinguished by its integrated approach to simulating both the natural (e.g., evapotranspirative demands, runoff, baseflow) and engineered components (e.g., reservoirs, groundwater pumping) of water systems, allowing the planner access to a more comprehensive view of the broad range of factors that must be considered in managing water resources for present and future use. The result is an effective tool for examining alternative water development and management options.

Water balance database: WEAP provides a system for maintaining water demand and supply information.

**MIKE BASIN**

MIKE BASIN addresses water allocation, conjunctive use, reservoir operation, or water quality issues. It couples ArcGIS with hydrologic modeling to provide basin-scale solutions. The MIKE BASIN philosophy is to keep modeling simple and intuitive, yet provide in-depth insight for planning and management. In MIKE BASIN, the emphasis is on both simulation and visualization in both space and time, making it appropriate for building understanding and consensus. MIKE BASIN is developed by DHI in Denmark.

For hydrologic simulations, MIKE BASIN builds on a network model in which branches represent individual stream sections and the nodes represent confluences, diversions, reservoirs, or water users. The network elements can be edited by simple right-clicking. MIKE BASIN is a quasi-steady-state mass balance model, however allowing for routed river flows. The water quality solution assumes...
purely advective transport; decay during transport can be modeled. The groundwater description uses the linear reservoir equation.

Typical areas of application include water availability analysis, conjunctive surface and groundwater use, infrastructure planning, assessing irrigation potential and reservoir performance, estimating water supply capacity, determining waste water treatment requirements. The model has also been used to analyze multisectoral domestic, industry, agriculture, hydropower, navigation, recreation, ecological demands and find equitable trade-offs among them. It has analyzed ecosystems and water quality, minimum discharge requirements, sustainable yield, effects of global change, regulation and water rights and priorities (http://www.dhisoftware.com/mikebasin/Description/).

**MODSIM**
MODSIM is a generalized river basin Decision Support System and network flow model developed at Colorado State University designed specifically to meet the growing demands and pressures on river basin managers today. MODSIM’s graphical user interface (GUI) allows users to create any river basin system topology by simply clicking on various icons and placing system objects in any desired configuration on the display. Data structures embodied in each model object are controlled by a database management system, which is also queried by simple mouse activation.

Formatted data files are prepared interactively and an efficient network flow optimization model is automatically executed from the interface without requiring any direct intervention by the user. Results of the network optimization are presented in useful graphical plots. MODSIM can also be used with geographic information systems for managing the intensive spatial data base requirements of river basin management.

MODSIM data sets can be developed for daily, weekly, and monthly time steps. Streamflow routing can be handled through the use of lag coefficients. There is considerable flexibility in representing consumptive use demands and flow requirements and their associated water rights, including exchanges. Reservoir operations include target storage, hydropower, tailwater effects, evaporation, and seepage.

MODSIM can simulate reservoir storage contract arrangements such as accrual rights, ownership contracts, water service contracts, and rental pool or water banking. Prioritized reservoir balancing allows the user to control the distribution of system storage throughout the simulation season. MODSIM has a Glover equation groundwater model built in the model's code that has been used in systems with fairly simple unconfined aquifer / river streamflow interactions. MODSIM has been linked with stream-aquifer models for analysis of the conjunctive use of groundwater and surface water resources, as well as water quality simulation models for assessing the effectiveness of pollution control strategies.

**WBalMo**
WBalMo (Water Balance Model) is an interactive simulation system for river-basin management. WaBalMo has been used to identify management guidelines for river basins, design reservoir systems and their operating policies, and perform environmental-impact studies for development projects. Using an ArcView user interface, a representation of the river basin (“system sketch”) is constructed
or derived from an existing digital stream network. Model data can subsequently be modified in various scenarios. WaBalMo is developed by WASY Ltd in Germany
http://www.wasy.de/english/produkte/wbalmo/index.html

The natural processes of runoff and precipitation are stochastically (Monte-Carlo) simulated and the respective time series are balanced with monthly water use requirements and reservoir storage changes.

By recording of relevant system characteristics during the simulation, probability estimates can be provided for water deficits, maintaining minimum runoff levels, or reservoir levels. Simulations can be performed both for stationary and transient (e.g., changes in climate) conditions. By comparing various plausible scenarios an approximately optimal water resources management can be obtained.

Reference
Jain, S.K. and Singh, V.P. (2003) Water resources systems planning and management, Elsevier science b.v., Sara Burgerhartstraat 25, ro. Box 211, 1000 ae Amsterdam, the Netherlands

4.4 Tutorials/Examples/Case studies

Exercise:
Using the monthly data series to be given, attempt the following exercises Calculate the statistics of the data and present your interpretation, plot the histogram of the monthly season distribution and comment on the data.

Exercise: Using the monthly data provided for rainfall and flow series, develop monthly regression equation and show the degree of correlation between the two variables.
5. Governance Issues (Policy/Institutions)

By: Mr. Habtmu Temesgen

5.1. Introductory Background

5.1.1 Water governance

Water has local, regional, national, and international characteristics. Water is local in its network, as each municipality around the world is, for example, responsible for supplying water to its inhabitants. It also is, at this level, an important vehicle for social and economic development. Water is regional and/or international in its natural setting, and as such cuts through different political frontiers. Water could also become international with its possible co-modification. Finally, water is national in that the owner of the resources is generally the nation-state. This last characteristic is clearly artificial and has been introduced by human beings. The major governance challenge therefore lies in relating these natural characteristics with the humanly imposed one.

Water governance is defined by the political, social, economic and administrative systems that are in place, and which directly or indirectly affect the use, development and management of water resources and the delivery of water service delivery at different levels of society. Or put more simply, water governance is the set of systems that control decision-making with regard to water resource development and management. Hence, water governance is much more about the way in which decisions are made (i.e. how, by whom, and under what conditions decisions are made) than the decisions themselves (Moench et al., 2003). Importantly, the water sector is a part of broader social, political and economic developments and is thus also affected by decisions outside of the water sector.

Water governance covers the manner in which allocative and regulatory politics are exercised in the management of water and other natural resources and broadly embraces the formal and informal institutions by which authority is exercised. The relatively new term for discussing this combination of formal and informal institutions is distributed governance. There is a profoundly political element to water governance and as such systems of water governance usually reflect the political realities at international, national, provincial and local levels. As a result, the more general definition of governance (as opposed to water governance) is also contested as those who promote different visions of the future tend to define governance in terms which are consistent with their own vision and no other (Green, 2007). So, Neo-Liberals define bad governance very specifically in terms of the existence of inadequate markets and excessive government. The problems of governance are to Neo-Liberals limited to removing the constraints which prevent the operation of a market-based economy and of minimising the role of government. Conversely, others define governance from the perspective of a democratic deficit, defining governance therefore in terms of transparency, accountability and subsidiarity. Consequently, there are obvious benefits in adopting a definition of governance which describes what it is without prescribing what it should be. One of the most frequently cited definitions of governance is thus:

“The exercise of political, economic and administrative authority in the management of a country’s affairs at all levels. Governance comprises the complex mechanisms, processes, and institutions through which citizens and groups articulate their interests, mediate their differences, and exercise their legal rights and obligations” (UNDP 1997).
An international commission called Commission on International Governance, on their published report entitled “Our Global Neighbourhood”, defined governance in more detailed and complex manner as follows:

**Governance** is the sum of the many ways, individuals and institutions, public and private, manage their common affairs. It is a continuing process through which conflicting or diverse interests may be accommodated and co-operative action may be taken. It includes formal institutions and regimes empowered to enforce compliance, as well as informal arrangements that people and institutions either have agreed to or perceive to be in their interest (Commission on global governance, 1995).

With such a definition of governance, it is indeed possible to capture about everything, from individuals working together to cooperation among nation-states. Furthermore, it must be highlighted that this conceptualization of governance mixes together institutions and individuals, and does not account for their relative power, nor for their different strategic interests.

In general, the notion of water governance is concerned with the functions, balances and structures internal to the water sector and includes the ability to design policies and institutional frameworks that are socially acceptable to mobilize resources in support of them. It is concerned with those political, social and economic organization and institutions that are necessary for water development and management. However, this still remains rather vague, and governance cannot mean all things to all people. What is missing in the discussion on water governance is the type of strategies that need be formulated to implement adequate governance in more realistic terms, as opposed to more generalized statements requiring “changes in attitudes and behavior among individuals, institutions, professionals, decision-makers; in short, among all involved.” Unless the water profession can define a functional and implementable concept of governance, its popularity is likely to be only transitory.

Among other things, water governance addresses:

- Principles such as equity and efficiency in water resource and services allocation and distribution, water administration based on catchments, the need for integrated water management approaches and the need to balance water use between socio-economic activities and ecosystems.
- The formulation, establishment and implementation of water policies, legislation and institutions.
- Clarification of the roles of government, civil society and the private sector and their responsibilities regarding ownership, management and administration of water resources and services, for example:
  - Inter-sectoral dialogue and co-ordination
  - Stakeholder participation and conflict resolution
  - Water rights and permits
  - The role of women in water management
  - Water quantity and quality standards
  - Bureaucratic obstacles and corruption
  - Price regulation and subsidies
  - Tax incentives and credits.
5.1.2 Why is river basin (Water) governance important?

Ever increasing water demand
Rapid economic development and societal change are putting increasing pressure on water ecosystems and other natural resources. In a number of countries or regions, demand is outstripping supply to the extent that water resources are fully allocated in all but the highest rainfall years. Under such conditions, which are often referred to as river basin “closure”, available water resources are fully allocated and the political importance of effective water governance increases.

Question of access to water
Scarcity of water, whether absolute or induced, is not, however, the only fundamental reason for improving the effectiveness water governance. Pollution also contributes to scarcity and the challenge of meeting demand for good quality water. Less publicized, however, are problems of access to water that are as much a product of the social, economic and institutional context as they are of the technical factors governing water resource availability. For people who are able to pay or who belong to elite social groups, water is not scarce, even in situations where the available supply is extremely limited. Since water is a cornerstone for most economic activity, equitable distribution under changing patterns of supply and demand is often more of a challenge than absolute limitations on the available resource (Moench et al, 2003). Stakeholder involvement, political priorities and even issues such as political interference and corrupt practices all have a major bearing on design of infrastructure and the strategic and day to day allocation of water for both domestic and productive purposes. Hence, systems of effective water governance are needed that ensure that all sectors of society have equitable, reliable and sustainable access to water.

Lack of accountability and transparency
Corruption remains one of the least addressed challenges in relation to water governance and water service delivery (UNDP, 2007a). Until recently, governments, bilateral and multilateral organizations have tacitly accepted corruption in the way water is governed. Corruption has been seen as something that could ‘grease the wheels’ of development efforts. However, thinking is shifting and anti-corruption measures are now perceived as central to equitable and sustainable development water service delivery. Corruption is a symptom of governance deficiencies in both the private and public spheres. In many countries, enforcement of legislation is weak and judicial systems are inadequate. When these are combined with, for example, low wages, huge income disparities (both within and between countries) and accountability and transparency shortcomings, personal economic gain is more attractive than concern for the well-being of citizens. New research and case studies increasingly show how corrupt practices are detrimental to sustainable water use and service provision. Corruption ultimately limits the scope for improving poor people's livelihood opportunities it also:

- Reduces economic growth and discourages investments within the water sector;
- Undermines performance and effectiveness of both public and private sectors; leading to inefficient and unequal allocation and distribution of water resources and related services,
- Undermines and frustrates stakeholder participation in decision-making processes;
- Decreases and diverts government revenues that could be used to strengthen budgets and improve water and other services, especially for poor people,
Makes existing legislation, rules and regulations ineffective. Dilutes the integrity of the public service sector, since discretionary decision making creates unpredictability and inequalities and can circumvent the rules of law and justice.

If the water-related Millennium Development goals are to be achieved, a large increase is financial support is required for the water, sanitation and hygiene. But still, in the absence of improved water governance, it is difficult to justify such large levels of investment not least because positive outcomes in terms of improved service delivery cannot be guaranteed.

**Sector Reform**

Decentralization and other aspects of IRBM are considered to be important component of sector reform programs that, to be effective, require improvements in water governance systems (Moriarty et al, 2004). Through decentralization the government gives up some of its decision making powers and management responsibilities, in principle at least, to lower level of government, private sector or community and civil society organizations.

Many countries are currently moving away from conventional forms of water governance, which usually have been dominated by a top-down supply-driven approach, towards bottom-up demand-driven approaches, which combine the experience, knowledge and understanding of various local groups and people (UNDP, 2007a). Many governments are also moving towards better policy alignment in recognition of the fact that many policies outside the water sector can have a major bearing on levels and patterns of water demand and use (e.g. agricultural, trade and energy policies). These changes require improvements to water governance systems that include: more effective stakeholder dialogue, better vertical and horizontal sharing of information amongst stakeholders, conflict resolution at a range of different scales and planning procedures that are based on a vision that is common to relevant stakeholders.

**Water Rights**

Ownership or the right to use a water resource or water supply infrastructure means power and control (UNDP, 2007a). The various roles and responsibilities, such as those encapsulated in legislation on water rights and ownership, have a complex relationship with water governance. How property rights are defined, who benefits from these rights and how they are enforced are all central issues that often require clarification as patterns of supply and demand change.

The State has an important role to play through its core function of defining property and use rights and responsibilities. Discussions of water rights usually focus upon the rights of the property right holder and ignore the contingent responsibilities which that holder has with regard to others in society who do not share the rights. Any discussion on water rights must take account of land use and land ownership as they are often closely linked, sometimes formally through riparian rights, and land owners can affect water through land use changes such as reforestation.

Insecurity of water rights, mismatches between formal legislation and informal customary water rights, and an unequal distribution of water rights are frequent sources of conflict (UNDP, 2007a; Hodgson, 2004). In contrast, the establishment of well-defined and coherent roles and responsibilities through legislation of formal and informal water rights may lead to a number of social, economic and environmental benefits:
– Equitable water use between existing user groups.
– Access to water by groups that were previously denied formal or informal water rights.
– Improved efficiency and productivity of existing water supply allocations. In some cases, by providing legal support for reallocation of water from lower to higher value water uses.
– An increased willingness of users to take economic risks by investing in improved water management and practices in both rural and urban contexts.
– Reduce the pressure on water resources because those with water rights have incentives for managing resources sustainably

**Gender**

Current writing on governance, and particularly water governance tends to be gender blind (Cleaver, 2007). It is clear that effective, efficient and equitable water resources management is only achieved when both women and men are involved in IRBM (UNDP 2006 and 2007). Gender mainstreaming is the process of assessing the implications for women and men of any planned action, including legislation, policies and programs in all areas and at all levels. It is a strategy for making women's as well as men's concerns and experiences an integral dimension of the design, implementation, monitoring and evaluation of policies and programs in all political, economic and societal spheres, so that women and men can benefit equally and inequality is not perpetuated. The ultimate goal is to achieve gender equality.

**Box 5.1: Examples of different property rights regimes, with their associated rights and obligations, include:**

**Open Access**
Open access is a regime where no defined group of users or owners are identified and the benefits are available to anyone. Individuals have both privilege (the ability to act without regard to the interests of others) and no right (the incapacity to affect the actions of others) with respect to usage and maintenance of the asset.

**Common Property**
A management group has been defined and the group has a right to exclude non-members and define the rules of appropriation. Non-members have a duty to abide by the rules. Individual members of the management group have both rights and duties with respect to usage and maintenance of the property and thus hold rights to manage the resource.

**Private Property**
Individuals own the resource and have the right to exclude others and transfer rights. They have a duty to refrain from socially unacceptable uses. Others (non-owners) have a duty to respect decisions by the owners and expect that only socially acceptable uses will occur.

**State Property**
Water is vested in the State – acting for citizens – individuals have a duty to observe use and access rules determined by the controlling agency of the State.

The obvious benefits of gender mainstreaming include:
– Involving both women and men in integrated water resources initiatives can increase project effectiveness.
Using a gender perspective and ensuring women's involvement can support environmental sustainability.

Social and economic analysis - as well as documenting natural resource uses - is incomplete without an understanding of gender differences and inequalities.

Without specific attention to gender issues, initiatives and projects can reinforce inequalities between women and men and even increase imbalances.

Two dimensions of human capacities are particularly important in enabling and constraining mechanisms of access to water; these being physical embodiment (embodiment here is used as a concept which incorporates an individual’s physical manifestation as a gendered person as well as the capabilities this confers) and voice (the ability of individuals to have influence at public fora). Water governance is conducted through formal and informal institutions, social relationships and more specifically through the ‘rules in practice’ of everyday water use (Cleaver, 2007). Physical labour is often required to access water by those who are physically present at water sources are most likely to shape the rules-in-practice – the conventions of queuing, rationing, and charging based on estimations of quantities used and so on. Physical presence and the exercise of public voice are also elements of the formal institutions of water resource management, although not necessarily sufficient to secure water access (Cleaver, 2007).

Even when women participate in village-level meetings, they are often there to make up the numbers as a token gesture to gender inclusiveness. For example, in a survey of approximately 100 villages in southern Andhra Pradesh, Rama Mohan Rao et al (2003) found that women participated in community decision making in less than 10% of the villages and, even when they participated, they were rarely able to influence decisions affecting them. The participation of poor women was even lower. Clearly water governance systems need to take better account of the roles of women managing water service delivery and in water related decision-making.

5.1.3 Fundamental requirements for good river basin governance

**Combined commitment:** Effective governance of water resources and water service delivery requires the combined commitment of government and various groups in civil society, particularly at local/community levels, together with the private sector.

**Ethical issues - transparency, equity and fairness** are fundamental requirements. All policy decisions should be transparent so that both insiders and outsiders can easily follow the steps taken in policy formulation especially with regard to financial transactions. Equity between and among the various interest groups, stakeholders and consumers, needs to be carefully monitored throughout the process of policy development and implementation. Good water governance is also based on the rule of law, which manifests itself most strongly in the issue of justice, property rights for use, access and ownership of water.

**Responsibility and accountability:** Each institution must know and take responsibility for what it does. The “rules of the game” need to be explicit and should have an in-built arbitration enforcing mechanism to ensure that satisfactory solutions can still be reached when seemingly irreconcilable conflicts arise among the stakeholders. In terms of responsiveness (and sustainability) an effective and reliable governance system must deliver what is needed on the basis of demand, clear objectives, an
evaluation of future impact and, where available, past experiences. Policies should also be incentive-based.

**Inclusiveness, participation, predictability and responsiveness:** Decision-making and implementation must be inclusive and communicative with government, civil society and the private sector each having clear roles to play with shared responsibilities on the basis of public-private partnerships. Improved participation is likely to create more confidence in the end result and in the institutions that deliver policies. The governance system becomes a poor and ineffective one when it does not fulfil these conditions, which in turn leads to increased political and social risks, institutional failure and rigidity and deterioration in the capacity to cope with shared problems instead of facilitating action on and enhancing the development of water resources and water delivery services.

**Coherence:** Policies and actions must also be coherent. Coherence requires political leadership and a strong responsibility on the part of the institutions at different levels to ensure a consistent approach within a complex system.

### 5.1.4 Rules, regulations/ Policies and laws

Theoretically, *policy* and *law* can easily be distinguished from each other. However, in reality they are inter-related like two sides of a coin in an ongoing process that builds water governance structures. *Policy* is a blueprint for drafting and amending laws, as well as an opportunity for meaningful public consultation in the reform and development of new laws. Because a policy document is usually a ‘living document’ it can easily be revised to cater for developing international and national environmental norms and values. The role of policy is to facilitate institutional and legislative reform. It also promotes the coordination of actions and activities of other government agencies regulating issues that are relevant to water management and water protection. Policy can also facilitate a smooth transition during times of legal and regulatory reform by indicating expected changes in law, and allows for implementation planning and capacity building to commence.

**Policy provides guidelines:**
- To help interpret environmental statutes by decision makers and the courts
- For the application and enforcement of environmental statutes;
- For compliance with environmental statutes (for example, assisting in the detailed nature of information to be submitted for a particular environmental license application)

**Legislation** is distinct from, but complementary to, policy. It establishes and clarifies rights and obligations. It creates legal certainty thereby facilitating orderly compliance and enforcement of laws. Greater legal certainty facilitates more efficient economic (for example, budget allocations) and financial planning (for example, financial provision made in the private sector to meet new compliance requirements), and thereby contributes to market stability and potential growth. Legislation protects against capricious administrative decision making and ensures a rights-and risk-based approach that provides a more effective framework for integrating the economic, social and environmental dimensions of decision making. It defines complex technical, scientific and economic terms; defines roles and responsibilities of regulatory agencies and civil society and establishes rules for accountability; and creates binding rules for dispute resolution.
Policy provides a set of guidelines for how an issue is to be handled by the government but it is ordinarily non-binding on the State and members of civil society (unless it is given the force of law through legislation). Conversely, legislation is binding on members of civil society and usually the State, and creates positive and negative rights and corresponding obligations.

Policy development should ideally be the first step on the path to regulatory reform. The policy development process provides an opportunity to engage experts and research in order to ensure the effectiveness and efficiency of the water statute/act/regulation that will ultimately be enacted. This process affords an important opportunity for considering how to integrate laws in order to avoid conflicts, contradictions and duplications in administrative requirements (for example, double permitting). A well conducted and highly participatory process of policy development has the advantage of building public awareness and building capacity at an early stage. A well conducted policy becomes an instruction manual for the drafters of the new legislation. Because it is non-binding, it is more easily changed and can inform changes to draft legislation at an early stage and prior to enactment (when it becomes more time-consuming to change). Potential water policy reformers must have a good understanding of how to structure a water policy reform process. Because more stakeholders are becoming involved in governmental processes, water reformers need to create a widely shared understanding of what water policy is and how it can be used in water governance. Understanding of the components of water policy is needed to support use of policy to make water reform processes effective.

A water policy is a country’s strategy to deal with water-related issues. Water policies are often prepared by governments to guide governance, management and investments in the water sector or in relation to water resources. A policy can be the culmination of a long period of public involvement. Preferably the policy is straightforward and understandable and formulates a clear vision of the country’s priorities. A water policy is a country’s plan to attain its vision for water outcomes consistent with broader policy objectives on, for example, economic development, health, security and the environment. Water policy usually defines the key water issues the country is facing or will be facing in the near future. It further outlines a number of principles that provide strategic guidance to the nation and local government on how its institutions will develop, govern and manage water resources and provide water services. Similarly, “Rules” are specific prescriptions or proscriptions for action.

Water policy needs to address basic questions such as:

− How much water is available for use, while also protecting the environment?
− What are the priority uses for this water?
− How much water should be allowed for each use?
− Who determines the priorities and allocations?
− How can those who cannot effectively participate in the political and legal systems nevertheless have their needs recognized and served?
− How should water be administered to avoid conflicts, account for flood and drought, and stretch the available water resource to serve as many purposes
Box 5.2 Overall goals of the national water resources management policy of Ethiopia:

The overall goal of the national water resources management policy is: to enhance and promote all national efforts towards the efficient, equitable, and optimum utilisation of the available water resources of Ethiopia for significant socio-economic development on sustainable basis. To realise this goal, the Government has spelled out a wide range of policies to achieve the following five major water management policy objectives.

Development of the water resources of the country for economic and social benefits of the people, on equitable and sustainable basis.

Allocation and apportionment of water resources based on comprehensive and integrated plans and optimum allocation principles that incorporate efficiency of use, equity of access, and sustainability of the resource.

Managing and combating drought as well as other associated slow-on-set disasters through, *interalia*, efficient allocation, redistribution, transfer, storage, and efficient use of water resources.

Combating and regulating floods through sustainable mitigation, prevention, rehabilitation and other practical measures.

Conserving, protecting and enhancing water resources and the overall aquatic environment on sustainable basis.
5.2 Institutional Setups and ROBs

5.2.1 Introduction

Institutions are a combination of policies and objectives: laws, rules and regulations; organizations, their bylaws and core values; operational plans and procedures; incentive mechanisms; accountability mechanisms; and norms, traditions, practices and customs (Bandaragoda 2000). ‘Institutions’ in the context of this document, is defined broadly to include not only formal organizations, but also informal organizations, laws, customs and social practices that influence people’s behavior in a society or economy. Organizations are groups of individuals with defined roles and bound by some common purpose and some rules and procedures to achieve set objectives. Accordingly, the institutional framework for water resources management in a river basin context consists of established rules, norms, practices and organizations that provide a structure to human actions related to water management (Bandaragoda 2000).

Institutions reflect the way people interact with one another and the way they interact with their environment. One person cannot interact with another without some shared understanding about how the other will respond and some sanction if the other responds arbitrarily and contrary to agreements. People cannot transact without cost and frictions. Human interactions, including those in economic life, if left unregulated, tend to be unpredictable and opportunistic. We call such rules institutions. Institutions can, therefore be defined as manmade rules that constrain possible arbitrary and opportunistic behavior in human interaction. They are shared in a community and are always enforced by some sort of sanction without which they are useless. When sanctions are no longer applied institutions lapse.

The best way to protect and manage water is by close international co-operation between all the countries within the river basin as water does not stop at administrative or political boundaries, within the natural geographical and hydrological unit of the river basin— bringing together all interests upstream and downstream. This is becoming more popular among all countries of the European Union as they are using a river basin approach for water management since the adoption of the EU Water Framework Directive.

5.2.2 Functions of institutions in river basin environment

The definitions given above highlight that the institutions are humanly devised constraints to shape human action. However, the institutions inherently have dual facilities to both constrain and liberate individual and group action (Bromley 1987). A good example is how the laws and the courts system restrict some human actions, and also provide freedom for action in some other instances. Most water-related rules are meant to constrain the socially undesirable behavior by individuals and groups in the distribution and use of water. Basically, water allocation rules serve this purpose. Some water-related institutions, such as those governing water user associations, are designed to promote organized behavior and equity and provide various opportunities for individual and group advancement, thereby serving to liberate human action.

The institutional framework serves to reduce the uncertainty of human actions, and thereby they have a stabilizing effect on society. For example, established water allocation rules tend to bring about
equitable distribution of water, provided that these rules are applied along with other related rules and norms, such as mechanisms to monitor water-delivery systems and laws relating to violation of commonly accepted allocation practices. Centrally imposed or externally mandated institutions are particularly meant to bring about stability. Stabilizing effects of institutions can be seen in such instances. For example, many multilateral institutions such as the United Nations (UN) and World Trade Organization (WTO) build on, homogenize and reproduce standard expectations worldwide, thereby stabilizing international order.

Five main external factors can be identified as either constraints or enabling situations that affect the water management institutions in a river basin. The overall political system, national economic policies, legal framework, socioeconomic environment and the physical resource base are these external influences. For instance, the overall national policies play a significant role in fashioning the institutional framework for any given social context. The overall legal framework and the general “law and order” situation in a country, particularly the social conditions that determine how the laws and rules are applied and adjudicated have a significant effect on water management institutions. In some instances, the culture, traditions and practices inhibit the effective functioning of water management institutions, whereas, in some other instances, they tend to promote them. In order to assess the actual impact of these external influences, it is useful to have an understanding about the social conditions, traditions and practices (both formal and informal institutions) in the given context.

5.2.3 Institutional structures in IRBM

In IRBM, four different levels can be distinguished: planning, operational management, analytical support and the organizational and institutional framework. Planning, operational management and analytical support take place in and are influenced by the organizational and institutional framework. This is depicted in Figure 5-1.

![Fig. 5-1: Levels in river basin management](image)

**Three levels of rules in Institutional structure:**

Institutional structures consist of three levels of formal and informal working rules:
− **Operational rules** provide a framework for operational management. Examples are statutory emission standards and policy directives.

− **Collective choice rules** deal with how operational rules should be developed. Examples include permitting and planning procedures.

− **Constitutional rules** determine who is entitled to make collective choice rules. They set up the organizational structure for IRBM and allocate tasks and competencies (cf. Ostrom 1990).

This section discusses the constitutional level and presents three basic models for IRBM. Moreover, three issues deserving special attention are discussed: decentralization, privatization, and local institutions as an alternative to IRBM by government and privatization.

**Three models important in IRBM governance:**

Roughly speaking, three different models exist for IRBM; namely: **Hydrological model**, **Administrative model** and **Coordinated model** (Mostert 1998a). In the **hydrological model** the organisational structure for water management is based on hydrological boundaries. In its extreme form all water management is in the hands of a single entity: the “river basin authority”. The **administrative model** is in many respects the opposite of the hydrological model. In this model water management is the responsibility of provinces, municipalities and other bodies not based on hydrological boundaries. The **coordinated model** falls somewhere between the hydrological and the administrative model. In this model water management is not performed by river basin authorities, but there are river basin commissions with a coordinating task.

Each model has advantages and disadvantages. In the hydrological model administrative boundaries coincide with hydrological boundaries and there is the least chance of upstream-downstream conflicts. However, since river basin authorities usually deal with water management only, this model may isolate water management from other relevant policy sectors, and inter-sectoral coordination may become a problem. Moreover, in countries with decentralized water management the adoption of this model would imply centralization, and in international river basins it would imply the establishment of a supranational authority. Consequently, river basin authorities are often only an option for smaller national basins and for operational, not politically sensitive tasks with a narrow scope, such as buoying.

In the administrative model water management, land-use planning and other relevant policy sectors can be kept together (but are not necessarily kept together). A major disadvantage is the serious risk of upstream-downstream conflicts and the lack of a platform to discuss these problems. In the coordinated model such platforms exist: river basin commissions. The different bodies participating in these commissions could each individually ensure coordination between water management and other policy sectors, and together, in the commission, they could co-ordinate their water management.

**Decentralization:**
The participation of different water users brings us to the issue of decentralization. Several good reasons can be given for decentralization. It is democratic to bring government as close as possible to individual citizens and allows for local variation in response to local circumstances and preferences (cf. the notion of “subsidiarity”: Brinkhorst 1992, Leenknecht and Bekkers 1993, Kraemer 1998a). Moreover, decentralized government tends to be less bureaucratic - simply because of its size - and
better informed about local circumstances. Decentralization is also possible for tasks with a supralocal character, provided the decentralized governments co-operate with each other or are supervised by a higher level government. Supervision may also improve enforcement of regulations in case the decentralized governments have too close relations with the persons and organizations they regulate. Decentralization is not possible for tasks such as establishing the institutional structure and formulating policies that apply to a country as a whole. However, decentralized governments should be involved because of their superior information on local conditions and because of their (usually) closer contacts with the population. Decentralization may also not be possible if the decentralized governments lack the necessary management capacity. Solutions could include local capacity building and advisory services by specialized central governments.

Privatization
Privatization could be another solution for the shortcomings of large bureaucracies. Privatization is only possible for specific services such as the construction and operation of water supply and wastewater treatment infrastructure - not for regulatory functions and policy making. Different forms exist. A very common form is contracting out specific activities such as construction, billing, and laboratory services. Privatization may also imply that private firms get a contract to operate and/or maintain the infrastructure for a specific water service. The infrastructure remains in the hands of government, and after expiration of the contract another firm may be contracted. The opposite also occurs: government is responsible for operation and maintenance, but for budgetary reasons it does not own the infrastructure but rents it from a private firm. Finally, private firms may own, operate and maintain the infrastructure (cf. Kraemer 1998b).

The private provision of services can be efficient. Private companies have a strong incentive to minimize costs in order to stay in business and raise profits. However, many water services are a “natural monopoly”: the necessary infrastructure is so expensive that there can be only one provider. To prevent misuse of this monopoly, a well-functioning economic regulator controlling prices and the quality of the service is necessary. Moreover, the environmental performance of the service provider should be assessed and regulated since its prime motive will be cost minimization, not environment improvement. In case competition is possible (e.g. competition for a government contract), anti-cartel rules and strict procedures for awarding contracts may be necessary.

A midway option between the public and private provision of water services is the provision by publicly owned private companies. These are not dependent on the government budget, can apply commercial double-entry bookkeeping, and can take out the necessary loans. In theory they can function as efficiently as private firms. Since their shareholders are public authorities, the incentive to misuse their monopoly position and save on environmental measures may be smaller. The incentive to minimise costs may also be smaller, but benchmarking of a complete sector may provide an additional incentive. Finally, publicly owned private companies could be used as a “milk cow”, providing the shareholders with financial resources without having to increase taxes.

Local institutions:
Last but not least, the importance of local institutions for managing river basins should be mentioned. River basins and river-related infrastructure provide several goods and services to society. Unless there are means to exclude potential beneficiaries from these goods and services, they will have a temptation to “free-ride”. They may not contribute to the development or upkeep of the
resource and may not limit the use they make of the resource, since they benefit anyway. The result is an overexploited resource in bad shape, providing less or no goods and services, to the detriment of all (“common pool resources” and “public goods”: Ostrom 1990).

To solve the free-rider problem, two solutions are often proposed: government intervention (government provision or regulation), or privatisation of the resource and its use. As may be clear from the foregoing discussion, these solutions are not always feasible or effective. Yet, there is also a third alternative. There are many examples of beneficiaries organising themselves for developing or managing the resource concerned and preventing overexploitation. Based on their intimate knowledge of the resource, they may devise rules to limit use and may set up self-financing systems, self-monitoring systems and conflict-resolution procedures. The results are local institutions that are neither totally public nor private but have a mixed character (Ostrom 1990, cf. Kraemer 1997, cf. Barraque 1998).

**River Basin Institutional arrangements in developing countries**

Fundamental questions related to institutional arrangements in developing countries are: “How IRBM should be implemented?” and “Which arrangements can be made to bring IRBM theory in to practice?” In order to bring integrated river basin management in to effect, institutional arrangements are needed to enable:

- The functioning of a platform for stakeholders involved in decision making;
- Water resources management on hydrological boundaries;
- An organizational set-up in river basin and sub-basin authorities with their respective by-laws to incorporate decision making at the lowest appropriate level;
- A planning system oriented at the production of integrated river basin plans;
- The introduction of a system of water pricing and cost recovery.

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**Box 5.3 Issues and constraints from analysis of institutional issues within the water sector of Ethiopia,**

**Institutional instability.** Water-sector institutions frequently undergo restructuring and reorganization, creating uncertainty and complicating the task of institutional capacity building. *Management problems.* Such problems are typically caused by inefficient organizational structure, understaffing, and underequipping; lack of organizational units at the lowest levels like *woreda* and zones that could cater to local needs; absence of career paths for staff; low salaries and lack of staff motivation; and inability of the Government to retain trained and experienced staff.

**Lack of institutional coordination.** Major stakeholders in water-sector activities include MoWR, Regional water bureaus, non-governmental organizations (NGOs), local communities, and the private sector. However, no structural and coordinated linkages exist among them, even between the two key institutions: MoWR and the water bureaus. Poor institutional coordination often defeats the efforts to achieve sectoral goals.

**Problems of capacity.** Shortage of skilled manpower is the critical issue facing all institutions. Every regional government has identified this constraint as the most limiting in the fulfillment of its 5-year plan. Moreover, inadequate office and equipment facilities, including insufficient vehicles, further compound the nature of problem.

**Limited funds/budget.** Water-sector development projects require a high level of investment. Lack of sufficient funding has imposed limits on the quantity and quality of outputs and services of the sector.
Moreover, lack of effective cost-recovery mechanisms often inhibits institutions from sustaining themselves and fulfilling their mandates.

**Lack of an integrated management information system (MIS).** Water-sector institutions generate and utilize a wide range of data. Nevertheless, the sector lacks a centralized and integrated MIS. There are no standard procedures for gathering and storing of data and information, as well as deficiencies in regional institutions at all levels in keeping proper data and information records.

**Weaknesses in O&M systems.** Considerable drawbacks exist in managing, operating, and maintaining facilities, especially in rural areas. Several water supply and sanitation services are not functioning in almost every region. Operations and maintenance usually have a “low profile” and are underfunded and underequipped, in comparison with design and construction functions.

**Absence of equipment standardization.** Several NGOs help rural communities in constructing and developing water supply and irrigation schemes, installing various types of pumps and generators. When equipment items begin to fail, the communities often face difficulty in finding replacements or spare parts. Standardizing equipment specifications should therefore be on the development agenda of the water sector.

**Low community participation.** Sectoral assessments indicate a low level of community participation in project identification, construction, and O&M of schemes. Participatory and consultative approaches with stakeholders are key to effective and responsive development activities.

**Policy and legislative issues.** Enabling legislation appears to be missing from such issues as formation of water users’ associations (WUAs); cost recovery; O&M, and administration of schemes; and water-use rights of downstream and upstream consumers. Mandates and responsibilities are not clearly delineated between Federal Government agencies and Regional bureaus regarding water-quality management, collection and analysis of hydrological data, and other similar functions. Regarding sewerage, lines of responsibility are unclear between the MoWR and Federal and Regional health and sanitation agencies, and--at Regional level--between bureaus of water resources, urban water supply services, municipalities, and health bureaus. Similarly, land tenure is another area that requires legislative action. The 1975 land reform proclamation conferred land ownership on the State, which may in turn grant land-use rights to individuals and associations. Land may be reallocated by the State, as it deems necessary. Security of land tenure is not guaranteed, even in areas under small-scale irrigation. In the absence of legal guarantees against reallocation or outright eviction, farmers might be discouraged from investing in permanent structures on the land during their tenure.

(Water Sector Development Program: Main Report Volume II; October 2002)

**Stakeholder participation**

Key-concept of IRBM is the participation of stakeholders in decision making or other functions of management notably in water resources planning. Crucial is to set up a platform in which all relevant stakeholders are represented. This platform is meant to discard from sector approaches and to create environmental, institutional, social, technical and financial sustainability. The function of the platform is to serve as a tool for dealing with conflicting interests in the process of water resources planning and implementation of water development. It can also play a pivotal role in effective conflict prevention and resolution.

The platform has the following characteristics:
- It is a platform for weighing all interests and for decision making on the use of water and water systems in the river basin.
- The platform should represent all interests and be under governance of the government to protect the interests of society at large.
- The platform should enable decision making and have controlling and sanctioning powers (through itself or by delegation).
The platform should represent the administrative levels dealing with the applicable tasks and competencies. Depending on the type of decision making or planning the platform will be composed of direct, indirect and potential water users or their representatives, government officials, NGOs, experts, representatives of society at large. At operational level the requirement for water users to be represented is clear. In strategic planning apart from water users also government officials in relevant water related fields of work, interest groups and experts are normally represented.

**Decentralization and subsidiarity**

Within the context of integrated water resources management we are dealing with government functions of which the tasks and competencies (at least initially) are covered by what we could mention the public administration. So under the term decentralization we comprise the process of transferring tasks and competencies durably or for an indicated period of time (but not incidentally) from the centre of authority to other departments, agencies or administrative levels in order to organize or implement a government function. The purpose of the decentralization effort can be manifold. A driving force for decentralization is to guarantee the effectiveness of its measures and also aspects of efficiency are of interest. However, another driving force for decentralization is to create transparency and to stimulate public accountability through participation and appeal procedures. A modern idea behind decentralization of government functions is to put decision making in the hands of people who are well informed, accessible for interested people, capable of making fundamental decisions in a timely manner. Further, for reasons of accessibility decision making is supposed to take place at a level as close as possible to the end-users.

There are various ways to arrange decentralization within the public administration and from public administration to semi-public or private organizations. In case of integrated river basin management the figure of functional decentralization is often applied. The decentralization is not general, but is aiming at specific functions of administration, in this case tasks and competencies that are comprised by the function of water resources management. If we concentrate on the public sector first, we can identify three main methods of implementing decentralization efforts:

1. De-concentration;
2. Delegation; or
3. Devolution.

In case of de-concentration executive tasks and competencies are assigned to other (regional) offices of the central authority or to lower levels within the same administrative structure. This agency can retake the task and competency at any time. It can impose rules or regulations at any time or randomly.

In delegation executive tasks and competencies are assigned to another public or private body with transfer of responsibility but without irreversible transfer of authority. Responsibility is shifted to the surrogate unit or private organization and the central authority will create a regulatory framework in advance. The central agency is not allowed to take up the task or competency itself at least not within the indicated period of delegation or only unless this reservation has been made.

In devolution, executive tasks and competencies are assigned to other administrative levels on a continuous basis with a complete shift of authority and responsibility. The lower administrative levels
responsible for decision making and resource mobilisation. “Devoluted” tasks and competencies are further managed in autonomy by the lower level of administration.

Cases of devolution are rare. To shift authority completely is identical to giving away a caretaker function. No government wants to do that, especially not in case of a sensitive public function as managing a basic need like water. De-concentration is happening often. However, since there is no shift in responsibilities for decision making, this figure is not offering extra opportunities to empower stakeholders. Delegation is also very common. It is probably the most practiced institutional instrument to transfer tasks and competencies. Delegation can be prompt and definitive or gradual and progressive. Progressive delegation is applied over time as the need for delegation arises and on request by the stakeholders. Actual delegation takes place when stakeholders are to a basic extent capacitated and when effective institutional arrangements have been established. For instance, in South Africa and Tanzania the delegation of responsibilities to river basin organizations is progressive. In Zimbabwe delegation has been necessarily prompt. In The Netherlands the Water Boards developed autonomously. Their power was gradually restricted. Contrarily, in France the “Agences de l’eau” gained in importance after 1964 through the absolute need in France to detain central government control. In Turkey the process of delegation is still experimental.

**Management on hydrological boundaries:**

It is advisable to identify river basins in their total sphere of influence and to consider all types of water resources that are feeding into the basin: surface water, underground water, waste water, intruding seawater, seepage, ice melt, etc. Some management functions can only be carried out with the total river basin as object. A comprehensive hydrological measuring network for the monitoring of all types of water resources is needed. Ranges of data should be made available. The network should facilitate water resources planning as well as operational management.

Institutional arrangements for a river basin as the Nile or the Amazon are substantially more complex than of small local river basins, although in essence not different. Various levels of subdivisions are sometimes needed to either subdivide or support the management functions of the entire river basin or to enable operational management per se. The scale of the subdivision will highly depend on the physical characteristics, on the density of occupation, the type of land use, etc. At this stage it is wise to consider administrative boundaries as well. With a few minor adaptations hydrologic subdivisions may effectively coincide with administrative boundaries or vice versa. This may add considerably to the co-ordination potential.

For instance, in Zimbabwe during the process of revising the water legislation the whole water sector was decentralized and commercialized (Jaspers, 2001). The country was subdivided in to 7 river basins (in fact river sub-basins) of approximately 80,000 km². Each of these basins was subdivided in to 5 to 6 logical sub-basins, in essence till now the lowest management unit. A similar process is going on in Tanzania. Nine river basins have been identified that will be subdivided in to various sub-basins (the scale is essentially the same). There is a likelihood that these Catchment Water Organizations will be composed of (lower level), multi-sectoral Water User Associations. In South Africa 12 river basins have been identified. In France the country is hydrologically subdivided in to 5 River Basin Authorities (“Agences de l’eau”: Alaerts, 1995). Water management in the Netherlands is comprised under about 60 Water Boards, administrating small sub-basins, though there is an intention to consolidate those small and independent organizations into approximately 15
units. In Turkey the idea is to subdivide the country into 7 large river basins, to which smaller sub-basins will be added. For the time being the Water Department DSI operates in 26 River Basin Districts, based on rational considerations more than on hydrological boundaries.

**Institutional framework**

The institutional set-up in the previous examples varies from country to country, especially because the package of required tasks and competencies is highly variable. In Zimbabwe the Catchment (River Basin) Authority is composed of a Catchment Council consisting of direct water users and an Executive appointed and employed by the National Water Authority (the water sector in Zimbabwe is decentralized and commercialized). Variation could be that the Executive is appointed and employed by the Catchment Council. The Catchment Council is composed of two representatives of each Sub-catchment (Sub-basin) Council. Further, depending on the working rules expressed in the by-laws of the specific council, some positions may be reserved to specific sector representatives (Town Water Supply Authority, Governor etc.) with a crucial stake. The members of a Sub-catchment Council are elected by the stakeholders organised in the sub-catchment. In Tanzania the situation is comparable. The Basin Water Organisation is subdivided in an Executive and a Basin Water Board, composed of stakeholders (mainly government officials in this case). The Catchment (Sub-basin) Water Organization is still in an experimental stage. A representation per sector is likely until such time that Water Users Associations have been established and capacitated. In South Africa the system of Catchment Authorities hinges on the development of Water Users Associations. At present this an ongoing process. In The Netherlands members of the Water Boards are elected by the organized real estate owners (Mostert, 1998b).

Tasks and competencies of the river basin organizations may differ substantially from country to country. A “common denominating” task distribution is difficult to give because it highly depends on scale, physical, social and other characteristics. One could say that the river basin authority concentrates on collective choice functions and the sub-basin authorities/water users associations on operational functions (cf. Ostrom 1990). Let us imagine a sample country with a two-layer river basin organization and specify a common (non-exhaustive) denominating task distribution:

It is crucial to arrange aspects of representation and task distribution in a clear set of regulations or standard by-laws that can be modified by the users where local circumstances demand. Apart from rules for representation and functioning, by-laws should also cover aspects of water resources planning; allocation and registration of water rights; tariff structures and fee collection; fund development and application; monitoring arrangements; penalties and sanctioning; conflict resolution and appeal procedures.

**Integrated planning system**

An integrated planning process can support a system of integrated river basin management in various ways:

- Planning helps to assess the present and the desired situation in the basin and to develop a comprehensive set of measures to reach the desired situation (van Hofwegen and Jaspers, 1999).
- Planning delivers an opportunity to streamline the participation process and it should increase the transparency of the decision making.
- The production of plans forces the makers of decisions into a process of horizontal and vertical co-ordination.
One of the targeted key-outputs of a system of integrated river basin management is the production of river basin plans in which the aspects of water quantity, water quality and environmental integrity are maximally integrated (horizontal co-ordination). Besides, this planning should contain a full consideration of the interests involved. It should be established according to procedures that enable full stakeholder participation in terms of decision making. The river basin plan is to be composed of lower level sub-basin, catchment or watershed plans, if the scale of the river basin makes them necessary (vertical coordination).

This is easier to be said than done! First of all, planning is not a uniform single level process. Plans can have a strategic or operational character. Sometimes the only objective is communication, sometimes far-going decision making is involved. Plans may address government institutions or citizens or both. Plans may focus on very different time horizons. And then, of course they may differ substantially in subject.

Crucial is that the management of water quantity, water quality and environmental integrity is linked up as far as strategic (policy) planning is concerned. For the sake of uniformity and administrative simplicity it is advisable to reduce the number of plans. Not necessarily, however all these aspects should/could be covered by one plan. The system of (national) environmental planning in The Netherlands is linked up with the system of water resources planning. The separate plans allocate guidelines or tasks to one another and every plan indicates on how the issues earmarked by the other plan are dealt with. Every four years one plan is revised in alternating sequence.

It will not always be possible to link up operational plans in time and in subject, but a legal instruction to the planners to harmonize the implementation could be very viable. In the so called “open planning approach” (The Netherlands) the responsible authority is at all crucial stages of the plan development in contact with partner governmental institutions and interest groups and NGOs. The open planning approach is extensively studied at present (even by unexpected actors e.g. by the American business world).

**Water pricing and cost recovery**

The issues of water pricing and cost recovery have not remained without debate in various countries and between various cultures. Traditional example is that paying for water per se in a moslim culture is not really accepted. The acceptance of cost recovery, however, is widely spread. This acceptance is much related to willingness and capacity to pay.

It is not always easy to recover the total costs directly from water users under all circumstances, especially when large investments in infrastructure are needed (cf. for flood control). The principle, however, is that the price for the service of having access to raw water or being protected against flooding or the price of treating the discharged pollution is paid by the user/beneficiary/polluter. One step further is to recover the full economic costs of the water per se (including externalities and opportunity costs: Rogers et al., 1998). The final stage is that water rights are traded or even that water is auctioned (Lee and Jouravlev, 1998). Water is used as an instrument to maximise the economic output per unit of volume. For the latter modalities a high level of organisation and specific institutional arrangements are needed.
There are many supporters, but in the mean time also some adversaries of the statement that “water is an economic good”. For sure water is also a social good with an ethical dimension. The new EU Water Framework Directive states the following: “Water is not an ordinary economic good, but a (social) inheritance that has to be protected, defended and handled as such” (EU, 2000). However, there is consensus about the need for cost recovery and hence water pricing. On top of that water pricing and charging for pollution is also a very important instrument of demand management. In order to apply effective water pricing and to charge for pollution a comprehensive system of rights and licences is necessary. Clear water allocation criteria and pollution discharge standards as well as quality standards for the recipient water are prerequisite. (To describe effective water rights, pollution discharge licensing and water quality management systems would go beyond the scope of this section.) The registration, administration, monitoring, enforcement and policing of water rights and pollution discharge permits as well as the monitoring and enforcement of water quality protection measures can only be carried out effectively with the river basin as logical unit for management. Above all, a major requirement for implementation is the presence of sufficient human and institutional capacity at the right time and at the right place. The development of human capacity is a long-term effort, complex of nature and very resources demanding. It is not enough to train experts in the relevant technical disciplines only. There is also a need to train and foster experts in integration.

Box 5.4 Ethiopia on PASDEP, 2006

Decentralization of powers and duties to district/woreda level is being made effective along with the build-up of capacities at woreda and kebele levels. The devolution of power to regional states and then to the woreda is a centerpiece of Ethiopia's strategy for ending poverty by improving accountability, responsibility and flexibility in service delivery and increasing local participation in democratic decision making on factors affecting the livelihood of the grassroots population. The major focal areas of the District Level Decentralization Program in the PASDEP period are the following:

- fulfilling the required Woreda manpower for the public institution;
- establishing efficient and effective structure at Woreda level;
- establishing the system for broad-based participation and empowerment of the grassroots population;
- improving woreda block grant, allocation and utilization system and enhancing capacity for planning and execution with the introduction of improved woreda planning manual;
- establishing systems for clear accountability, transparency and relationships of executives;
- establishing minimum standard service indicators and monitoring mechanisms for basic sectors;
- improving revenue sharing system and creating mechanisms for revenue enhancement at woreda level;
- ensuring the effectiveness of budget preparation and control system;
- building capacities of kebeles on all fronts and parallel to the missions of woredas.

In the short period, 2006/07, an integrated approach will be launched to address the problems of the rural population and capacity deficiencies observed in rural woredas and kebeles.
5.2.4 River Basin Organizations (RBOs)

River basin organizations and stakeholder representation

It is clear that the size of the population in most river basins is such that it precludes the direct participation of all stakeholders in basin-level decision-making. The question then is who represent groups of stakeholders in river basin management, once again a political choice. The issue of inequality and difference in stakeholder representation has already been pointed out. In addition, the relationship of the people participating in any multistakeholder process to their constituents is also problematic, especially when third parties are involved. It is a nostrum of development works that third-party facilitators and inform stakeholder groups.

Risk related to river basin organizations:

“RBOs may weaken the effectiveness of existing democratic channels of communication in the interest of finding more efficient technical solutions to complex problems. Social organizations (boards, committees, etc.) created for watershed planning are imposed as it were from the outside, overlaying natural boundaries in a new way on top of existing social and political boundaries. To use a water metaphor, authority, funding, research, and new scientific approaches can all be poured from existing social and political ‘containers’ into the watershed boundary. But we can’t be certain that processes of democratic deliberation that were associated with the older containers will be poured along with the rest or separated out and cast aside unless we give this careful and constant attention” (Barham, 2001).

In river basins, it is the norm that water management stakeholders have:

- Different levels and kinds of education,
- Speak different languages,
- Differ in access to politics, and
- Hold different beliefs about how nature and society

If this is not taken into account when creating rules, roles and rights, the institutional outcome can easily privilege those who are literate and have access to the legal system.

Moreover, it is of little use to establish new institutions for water management without realizing that they are embedded in an institutional ecology, a meta-institution with its own rules, roles and rights. The new institution will need to carve out its niche, demarcate its boundary, defend its mandate and acquire a resource base, which will inevitably create some conflict with those interested in the ancient regime. Resources may be material or intangible – power, knowledge, and occupation of strategic pressure points in decision-making (Warner & Turton 2001).

Basin level organizations in Ethiopia

In Ethiopia, the national water management policy rightly states that the basin should be considered as the basic planning unit for development and management of water resources. According to MoWR (1999: p.13), the major goal of establishing Basin Authorities is to ensure “efficient, successful and sustainable joint management of the water resources of the basins through concerted efforts of the relevant stakeholders. It is so because the basin approach promotes comprehensive development of a large area rather than fragmented development interventions believing that decentralized management requires basin level organizations”. The policy document envisages the establishment of river basin
organizations (RBOs) phase by phase. The establishment of river basin councils and authorities is considered as one of the main instruments to implement integrated water resources management through river basin plans and effective and sustainable joint management by relevant stakeholders. The Awash Basin Water Resources Management Authority is now existing basin authority in Ethiopia. Other River Basin Authorities are expected to be established gradually. However, so far the government has issued a proclamation for the establishment of River Basin Councils and Authorities (FDRE 2007). Based on this proclamation, River Basin High Councils and Authorities shall be established by regulations to be issued by the Council of Ministers (Article 3(1)). When it is deemed necessary, the proclamation stipulates, two or more river basins may be put under the jurisdiction of a single Basin High Council and Authority. The foreseen establishment of the Abay Basin Authority seems to be the most distinguished one in the Abay Blue Nile. There is an ongoing effort to establish a river basin authority for the Abay, which is the major sub-basin of the Nile. An institutional study undertaken for an Abay River Basin Organization (RBO) pointed to the need for: (1) networking between water related actors, (2) coordination of their water related activities, plans and projects, (3) a sound knowledge of water resources, water uses and of their interactions, and (4) a power to administer water resources in the basin. The legal basis for establishing the river basin authority is laid pending the enactment of establishment regulations to be issued by the council of ministers (Proclamation No. 534/2007, Article 3(1)).
5.3 Trans-boundary Issues

5.3.1 Introduction

A wide range of International Relations scholars showed by the mid-1970s that the international system is increasingly characterized by interdependence. As interdependence affects politics and the behavior of states, new forms of rules, procedures and institutions for various activities have been created in order to manage and control transnational relations. These co-operative arrangements are usually referred to as international regimes (Keohane & Nye 1989).

The hydrological interdependence or the transnational nature of international river basins provides a rationale for cooperation. Indeed, an awareness of the positive prospects of basin-wide cooperation through the development of a water regime might spur an increased hydro-solidarity. The sharing of trans-boundary water resources is increasingly becoming one of the most contentious issues confronting sustainable utilization of water resources. While allocation between upstream and downstream users continues to be constrained by:

- lack of adequate data and uncertainties on future availability because of global climate change,
- lack of mutually agreeable water sharing mechanisms.

This constraint appears to be persevering because of failures by the scientific community to formulate water sharing strategies that harmonize the varied interests of numerous stakeholders. Because lack of agreeable sharing arrangements tends to encourage self-centred resource use practices that undermine sustainable utilization.

There are presently about 260 transboundary river basins around the world, covering 45% of the land surface of the earth (Wolf et al. 1999). Unilateral action in these basins is often ineffective, inefficient, or simply impossible, e.g., a dam on a boundary stretches of a river. Moreover, it can harm the other basin countries (UN ESCAP 2003). For this reason, trans-boundary cooperation is necessary.

In the past, river basin management was often the exclusive realm of hydraulic engineers, who managed the river for a single purpose only, such as navigation or hydropower. Nowadays, river basin management is often multi-purpose and basin-wide, and involves many more actors (cf. Ridder et al. 2005). Moreover, river basin management has to deal with increasing rates of human-induced change and increasing concerns about the causes and consequences of these changes (Toffler 1980, Pahl-Wostl 2004). In trans-boundary river basins, differences in legal frameworks, historical and cultural backgrounds, and technical capabilities add to the complexity (Timmerman and Langaas, 2005).

Trans-boundary cooperation is shaped by, and contributes to, the development of trans-boundary management regimes. According to Krasner (1983), a trans-boundary regime consists of “implicit or explicit principles, norms, rules, and decision making procedures around which actors’ expectations converge in a given area of international relations.” Consequently, river basin management regimes are defined as the principles, norms, rules, and decision-making procedures around which actors’ expectations in (trans-boundary) river basin management converge.
5.3.2 The challenges in trans-boundary river basin management

A special type of IRBM is the management of international river basins. International basins are usually larger than national basins and less homogeneous. Natural and socio-economic conditions, culture and language often differ significantly between the different parts of the basin, and consequently upstream-downstream conflicts can occur easily. Most importantly, however, international basins are by definition located in different states. Consequently, international cooperation is needed in order to best manage the basin and prevent or solve upstream-downstream conflicts.

To a large extent, the issues that play a part in international river basins also play a part in trans-boundary river basins, i.e., river basins that cross provincial, county or other administrative boundaries. Hence, the topics that are discussed in this unit can in many cases also be applied to trans-boundary river basins.

A major problem in the management of international basins is the so-called “lowest common denominator”. Few obligations can be imposed on countries without their own consent. Therefore, many international agreements simply reflect the commonalities in the national policies of the states concerned or are very procedural and vague. More ambitious agreements are possible if for instance an issue on which national interests conflict is linked to another issue where the distribution of costs and benefits is the reverse (e.g., pollution reduction in an upstream country and improvement of the shipping channel in the downstream country (cf. Meijerink 1999)). These issues can then be solved together, resulting in net benefits for both basin states.

Overview of international conferences relevant to freshwater resources

For almost three decades the international community has been concerned with freshwater problems. To gain insight into the point that we have reached now, the present section gives a brief overview of the main international conferences relevant to freshwater. In addition, recent developments in the context of the Commission for Sustainable Development (CSD) are mentioned (see Table 5-1).

Overview

The first (global) UN conference on the environment was held in 1972 in Stockholm, but freshwater was not a specific issue on the agenda. The first conference that did pay specific attention to freshwater issues was the global freshwater conference in 1977 in Mar del Plata. This conference established that people have a right to water for their basic needs, which was repeated often in later conferences. Development matters and environmental issues were not yet approached in an integrated manner. For the period 1981 - 1990 an International Decade on water supply and sanitation was established, with the aim of achieving access to clean drinking water and sanitation for all people by the year 1990.

Although the programs of the Decade reach a large number of people in developing countries, the aim is by far not realized. The Conference on water and sanitation in 1990 (New Delhi) concluded, among other things, that to solve the problems a reduction in the costs and the mobilization of additional funds are needed.

In 1992 important steps were taken in the area of freshwater management with the international conference on water and the environment (Dublin) and the UN Conference on Environment and Development (Rio de Janeiro). The need for an integrated approach to the management of water
resources was emphasized that links social and economic development and the protection of natural ecosystems. Also the participation by users/the public, planners and policy-makers at all levels of government was emphasized. Moreover, the role of women in water management is underlined. Furthermore, the principle that water should be considered as a social and economic good was established. These principles reoccur in most later conferences and declarations.

Two years after the Rio Conference, The Netherlands organized a conference on the improvement of access to safe drinking water and sanitation (Noordwijk 1994). Furthermore, in 1997, the progress made in implementing Agenda 21 was evaluated by the United Nations General Assembly (UNGASS). Governments were called upon to place freshwater problems high on the political agenda and to start a dialogue on the necessary actions and measures for implementation under the auspices of the Commission for Sustainable Development (CSD).

Table 5-1: International conferences relevant to freshwater

<table>
<thead>
<tr>
<th>Name of the conference</th>
<th>Place, date</th>
<th>New elements / emphasis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>/ Water is a side issue</td>
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<tr>
<td>United Nations Water Conference</td>
<td>Mar del Plata, 1977</td>
<td>/ First global conference on freshwater</td>
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<tr>
<td></td>
<td></td>
<td>/ Emphasis on development, agriculture drinking water and sanitation</td>
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<tr>
<td>Global Consultation on Safe Water and Sanitation for the 1990s</td>
<td>New Delhi, 1990</td>
<td>/ Drinking water and sanitation</td>
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<tr>
<td></td>
<td></td>
<td>/ Attention to financing, integrated management of water resources, institutional aspects and role of women</td>
</tr>
<tr>
<td>International Conference on Water and the Environment</td>
<td>Dublin, 1992</td>
<td>/ Preparation of the Rio Conference</td>
</tr>
<tr>
<td></td>
<td></td>
<td>/ Sustainability is a key issue.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>/ Four principles: freshwater is a finite &amp; vulnerable resource, participatory approach, the role of women, water as an economic &amp; societal good, water as an environmental good, protection of ecosystems.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>/ Protection of ecosystems.</td>
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<tr>
<td></td>
<td></td>
<td>/ Need for integrated planning and management on the river basin scale is emphasised</td>
</tr>
<tr>
<td></td>
<td></td>
<td>/ Development of strategies &amp; action programs for transboundary waters.</td>
</tr>
<tr>
<td>Ministerial Conference on Drinking Water and Environmental Sanitation</td>
<td>Noordwijk, 1994</td>
<td>/ Drinking water and sanitation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>/ Partnerships between stakeholders</td>
</tr>
<tr>
<td></td>
<td></td>
<td>/ Change behaviour patterns</td>
</tr>
<tr>
<td></td>
<td></td>
<td>/ Technical innovations</td>
</tr>
<tr>
<td>United Nations General Assembly</td>
<td>New York, 1997</td>
<td>/ Evaluation of the implementation of Agenda 21</td>
</tr>
<tr>
<td></td>
<td></td>
<td>/ River basin management</td>
</tr>
<tr>
<td>Event</td>
<td>Location</td>
<td>Notes</td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
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</tr>
<tr>
<td>Expert Meeting on Strategic Approaches to Freshwater Management</td>
<td>Harare, January 1998</td>
<td>Advice of the inter-sessional ad hoc working group of the CSD and CSD VI</td>
</tr>
<tr>
<td>Ad hoc Inter-sessional Working Group on Strategic Approaches to</td>
<td>New York, February 1998</td>
<td>International co-operation</td>
</tr>
<tr>
<td>Freshwater Management</td>
<td></td>
<td>Mainly a repetition/rehearsal of already formulated adopted</td>
</tr>
<tr>
<td>Cooperation for Transboundary Water Management</td>
<td>Petersburg, March 1998</td>
<td>Specific attention to information on policy, institutions, capacity building, participation, technology transfer and co-operation in research, financial resources and mechanisms</td>
</tr>
<tr>
<td>International Conference on Water and Sustainable Development, Sixth Session</td>
<td>Paris, March 1998</td>
<td>Transboundary water management</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Emphasis on regional co-operation, river basin organizations, political</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Little news on principles and points of departure.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Decided on the development of an &quot;agreed statement of principles&quot;</td>
</tr>
</tbody>
</table>

In preparation of the Sixth session of the CSD (April/May 1998) two important expert meetings took place (Harare and Petersburg), as well as a working group of the CSD on strategic approaches for freshwater and an international conference on water and sustainable development in Paris. Taking account of the results of these meetings, CSD VI concluded among other things that lacunas for integrated water management should be filled; that states should co-operate concerning their international watercourses; and that they should set up institutions at the river basin level for the implementation of water management programmes. In addition, governments were encouraged to organize international meetings to solve problems, to set priorities for action, to exchange experiences, and to facilitate progress in the implementation. States were invited to inform the CSD about the conclusions of such meetings.

**Agenda 21**

Most noteworthy among these conferences is probably the UN Conference on Environment and Development, where, among other things, the Rio Declaration and Agenda 21 were adopted. Agenda 21 provides a programme of action for attaining sustainable development, while the Rio Declaration sets out the principles on which such action is to be based. Chapter 18 of Agenda 21, entitled “Protection of the quality and supply of freshwater resources: Application of integrated approaches to the development, management and use of water resources”, contains three main objectives.

Access should be ensured for all people to safe and sufficient water supplies, or at least water supplies to meet the basic drinking and food-growing requirements.

Public participation and management at the lowest appropriate level should be enhanced.
Integrated development & management of water resources should be attained.

5.3.3 The water courses convention and alternatives

*International basins and the global level*

Considering all initiatives that are being or have been taken, and considering furthermore the fact that international river basins constitute some 47% of the earth’s land area (nearly 60% for Africa and Latin America, all excluding Antarctica; Biswas 1991 and Brans et al. 1997), one might be inclined to conclude that the objectives and actions to be taken for managing international river basins are now agreed upon and clearly defined. Moreover, one might suppose that such agreement would be reflected in recent international treaties. However, while important steps towards the codification and development of international water management law have been taken, they have mainly taken place at the regional level and - in some cases at the river basin level.

At the global level the normative system for the management of international river basins focuses on the discretion of states and their sovereignty, rather than on their particular responsibilities in the process towards attaining sustainable water management. This focus also found its way into Chapter 18 of Agenda 21, which in paragraph 18.4 provides as follows: “Trans-boundary water resources and their use are of great importance to riparian States. In this connection, cooperation among those States may be desirable in conformity with existing agreements and/or relevant arrangements, taking into account the interests of all riparian States” (emphasis added by authors) Chapter 18 thus only halfheartedly allows the point that the objectives it seeks to promote should, let alone shall, be implemented by states with respect to international river basins.

*The Watercourses Convention*

The only global legally binding instrument that focuses on the management of international river basins revolves around protecting the discretion of states. The Convention on the Law of the Non-Navigational Uses of International Watercourses (Watercourses Convention) was adopted by the United Nations Assembly on 21 May 1997 and has not yet come into force. It is the culmination of a period of over 20 years of negotiations in the International Law Commission of the United Nations. The Watercourses Convention, while attesting to the relevance of co-operative action among riparian states, does not require that states conclude agreements in conformity with certain minimum standards for purposes of managing international river basins that flow through their territory. Instead, it leaves the conclusion of such agreements to the discretion of states. The Watercourses Convention also does not make securing access for all people to safe and sufficient water supplies a main goal. Instead, it ultimately includes this goal among a long list of goals that may be pursued by states in managing an international river basin, and in doing so, makes this goal subject to the balancing of interests, which is the main concern of many of its provisions. The Watercourses Convention, furthermore, does not provide instruments that may serve to enhance public participation and subsidiarity. Instead, it focuses on state actors and their discretion.

Much of the Watercourses Convention can be explained by the nature of the negotiating process that started over twenty years ago and by the cautious role of states in that process. What remains, however, is a multilateral regime for the management of international river basins that has limited normative content (for further details: Hey 1995, 1998; Nollkaemper 1996). *It should be noted that other assessments of the Watercourses Convention are possible as well. In many river basins no*
treaties have been concluded at all, which places the downstream countries in a difficult position. In these basins ratification and subsequent entry into force of the convention could promote a more equitable use of the water.

A flexible regional framework

Assuming that the interests of individuals, groups within countries and the international community at large supersede the interests of individual states and of the riparian states bordering on a single river, it is high time that a flexible framework be developed at the international level. Such a framework could provide the basis for the development of relevant rules that bind states in their actions vis-à-vis the wider interests involved in international river basin management. Instruments that provide such a framework have been adopted for other policy areas. Relevant examples are in the area of climate change the 1992 United Nations Framework Convention on Climate Change and its 1997 Kyoto Protocol; in the area of the protection of biological diversity the 1992 Convention on Biological Diversity; in the area of ozone depletion the 1985 Convention on the Protection of the Ozone Layer and its 1987 Montreal Protocol; and in the area of fish stocks the 1995 Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 Relating to Straddling Fish Stocks and Highly Migratory Fish Stocks. These agreements, to a lesser or greater extent, provide the basic principles and minimum standards that states are to implement in their mutual relations and a framework within which these principles can be further developed into rules and regulations, where appropriate at the regional level, as e.g. in international fisheries.

An approach as advocated here may give rise to a “significant degree of indeterminacy of the normative landscape” (Handl 1990). However, it is less likely to result in treaties that are devoid of normative content, as the Watercourses Convention. Instead, it is likely to foster continuous interactions between developments in technology, policy and law (Gehring 1990), which eventually may result in enhanced normative content of the regime (for further information on this approach, see Brunnee and Toop 1994, 1997).

Compliance regimes

Part and parcel of the development advocated here is the inclusion of what are generally called compliance regimes. Such regimes aim to establish non-confrontational mechanisms in which parties assess each other’s performance under a given treaty and measures to remedy a situation of non-compliance, both “carrots” and “sticks”. Compliance regimes have now been included or are being developed in most multilateral environmental agreements. Even the Watercourses Convention contains a procedure that could fulfill part of the role of such a mechanism: the independent fact-finding commission (art. 33).

The procedure related to the independent fact-finding commission essentially entails the following. At the request of a state party to the Watercourses Convention a fact-finding commission may be installed, if six months after a request for negotiations the parties to a dispute have not been able to resolve their dispute. The fact-finding commission is to make recommendations for the equitable solution of the dispute. While these recommendations are not binding in law, the parties to the dispute are to consider them in good faith. Such a procedure remains short of the compliance regimes included in multilateral environmental agreements in that it does not provide an automatic peer review system. It may, however, provide a mechanism through which the normative content of the
international regime for river basin management may be enhanced. Preferably a new framework mechanism should be established in which states and other relevant actors, such as international organizations and NGOs, could continue the multilateral dialogue on the management of international river basins. The past and present dialogue on sustainable water management, as it is taking place under the auspices of the UNECE and the European Union, may provide a valuable model for further developments at the international level.

A major aspect of many river basin treaties is the establishment of a river basin organisation. Two types of national river basin organizations can be distinguished: river basin commissions with a primarily co-ordinating task and river basin authorities with decision-making and policing powers. The same type of organizations can be found in international basins.

The importance of international river basin commissions has been widely recognized (e.g. Petersburg declaration and Dieperink 1997). River basin commissions may co-ordinate monitoring and research efforts, add legitimacy to the monitoring and research results and in this way provide a common, generally agreed upon factual basis for management. They furthermore offer the basin states a platform for coordinating their policy and management. River basin commissions can also prepare IRBM plans and programmes, but after adoption by the Commission they still have to be adopted by the basin countries or a “Ministers Conference”. River basin commissions may also oversee the implementation of the plans, programmes, but implementation remains the responsibility of the basin countries. Finally, river basin commissions can play a significant role in resolving river-related international conflicts. They constitute a relatively informal forum for discussion, may help in selecting fact finders and arbitrators, or may even do fact-finding or act as arbitrators themselves. River basin commissions can be organized in different ways, but always there is a plenary commission, usually consisting of national representatives and meeting once or twice a year. Working groups, project groups and/or expert groups can support the work of the plenary commission. Moreover, the commission may have an independent secretariat, in charge of preparing the meetings, publishing annual reports, giving information to the public, etc. Alternatively, the secretarial function can be performed by one of the states concerned or may alternate between the member states.

River basin authorities have decision-making and policing powers. They can independently adopt plans, programmes and bylaws and implement them or enforce their implementation. International river basin authorities usually have a limited scope. They usually do not deal with policy issues, but with specific operational tasks, such as constructing and managing joint infrastructure and enforcing shipping regulations. The structure of river basin authorities can be the same as that of river basin commissions, with a plenary commission, subgroups and a secretariat.

5.4 Conflict Resolution

5.4.1 Why conflict over resources?

Specific Objective(s):
this topic gives an over view of river basin conflicts and approaches of handling disputes in IRBM
Nature of conflict and its functional relation with cooperation.

Human histories are full of conflicts; and in this sense conflicts seems natural. Conflicts occurred between nations, between or among communities and individuals; most conflicts are manageable
through negotiations or by the rule of law, but some resulted in prolonged war where nations were
destroyed and created, communities invaded their neighbors, individuals confronted each other with
force. Most conflicts among human beings in general are over natural resources as they have pulling
and pushing effects on human beings. The more abundant it is the more people it attract; i.e., people
migrate from less endowed areas with natural resources or degraded places to relatively rich resource
areas or localities. Resource-degraded areas, on the other hand “push” out inhabitants. Most major
population movements in Ethiopia and in many parts of the world, more or less followed this pattern.
The word “conflict carries negative connotations. It is often thought of as the opposite of cooperation
and peace, and is most commonly associated with violence. This view of conflict is always not
helpful. In many settings it should be seen as a potential force for positive social change—its presence
as a visible demonstration of society adapting to a new political, economic or physical environment.
The conflicts that arise from environmental problems/stress or scarcity of resources are not something
that can be prevented or concealed. Water resources policy aims to acknowledge these potential
conflicts, manage their extremes, and transform the residual into a positive force.

Scarcity of resources, unregulated resources utilization and or clearly defined national water
laws/international conventions probably leads to conflict among users. Although conflict can be
considered as natural and innate in human associations and may even be considered as stimulants to
society’s development and change, they should be properly managed through adequately organized
institutions.

Conflict over resources often arises from uneven or unjust provisions of access to resources or
undefined and unregulated rights over same. In one way or another conflict consume resources and
should be minimized through various types of formal and informal institutions which society deliberately
establishes. As seen before one of the major purposes of public policies is to help create
circumstances where resources can be used under minimum conflict situation, or reduce the damage
from same. Resources often generate conflict; the state manages conflict through institutions.

A new approach—conflict and cooperation co-exist
Similarly, in the context of hydro-politics, scarcity, or critical dependence on a shared river, often
positions states between the extremes of conflict and cooperation. Realist and neorealist concerns
regarding autonomy, self-interest, and sovereignty are relevant in dealing with cooperation over water.
In fact, scholars have argued that cooperation over international rivers often fails because it challenges
core concerns of states such as sovereignty, territorial integrity, and security. In general, a state does
not like to share its natural resources. Combined with the unpredictability of interstate relations, and
the vulnerabilities associated with interdependence, states are reluctant to enter into binding, long-
term water-sharing agreements with their neighbors (Elhance 1999: 237).

Acknowledging realist concerns, it is striking that cooperation over shared rivers (and by extension
agreements) takes place at all. To be sure, cooperation occurs among those states preoccupied with
their security, sovereignty, and political hostility toward a neighbor. As liberals and neoliberals
contend, countries are able to realize joint gains and pursue cooperative arrangements when it is in
their interest to do so. In the context of an international river, tackling scarcity and coordinating uses
along its course provide this important motion. Having exhausted unilateral options or having realized
that cooperative and integrated projects would produce additional benefits; countries have turned to
cooperation rather than remain in conflict over a shared river. The problem of cooperation, therefore,
centers on assuring that all states will honor their commitments to an agreement. Institutions and regimes are created for this purpose.

The main obstacle to fostering cooperation, therefore, is negotiating the terms of institutional arrangements that bind the parties or that provide mutual benefits for all concerned. Strategic interaction, therefore, becomes instrumental in understanding why and how agreements and regimes take shape. To assess this phenomenon in the context of international rivers, it is necessary to delve even deeper into the hydro-political context for understanding incentives to cooperation. The two dimensional conflict/cooperation nexus is enriched if the transboundary water relations take into account a third dimensions – namely the political economy. Strong and diverse economies can more readily install the very expensive institutions of trans-boundary water governance. They can also avoid the stressful relations that riparian endure when they do not have the options of advanced socio-economic development.

It was believed that conflict and cooperation co-exist. As a result, relations in trans-boundary basins can be defined by the changing intensities of co-existing conflict and cooperation. Adaptive management and integrated water resources allocation and management take place in circumstances of asymmetric power. They also take place in circumstances where the actors enjoy very different levels of economic diversity and strength. For successful water allocation and management, there must be consideration about how (1) the intensities of conflict and cooperation in trans-boundary relations and (2) development of the political economy change over time.

A second purpose is to highlight the means of facilitating adaptation for trans-boundary water governance. First, adaptation is usually achieved without those involved in the conflictual and cooperative trans-boundary relations being aware of the invisible and silent political economy processes. Water governance institutions can additionally facilitate adaptation. However, there are problems associated with such regional public goods like the high costs of developing trans-boundary water governance institutions (Nicol et al. 2000).

Relations of basin states evolve over time, experiencing periods of both interaction and non-interaction. More specifically, relations evolve through co-existing conflictive and cooperative interactions. In some cases, states may not have to go through interactions over water allocation and management, as they can solve their water resources needs by trading in water intensive commodities or manufacturing water. By creating typologies of basin relations, it will also be possible to identify the driving forces shaping conflict and cooperation over trans-boundary waters. Such driving forces can be considered to enhance or frustrate basin water governance initiatives. Considering conflict and cooperation as opposing concepts misleadingly simplifies the complexity of interactions. As Craig (1993:15) explained, conflict is a concept that is independent of cooperation; not always opposite to it. In certain circumstances, conflict may be an integral part of inducing and sustaining co-operative behavior, and the two may coexist in various social settings. Craig’s conceptualization indicates that conflict and cooperation are not just on a continuum progressing from irrational individualistic conflict to rational collective cooperation. An implication of such understanding is how explicit agreements are not necessarily accurate indicators of cooperation. As in the above mentioned BAR project, agreements have been regarded as tangible benchmarks of cooperation in trans-boundary waters. It can be argued that explicit agreements can make the intention of the involved agents clear. However, in international basins, it
is difficult to come to concrete arrangements. In some cases, cooperative outcomes can emerge from situations without agreements. For example, in the Rhine River basin, Verweij (2000) noted how the industrial sector voluntarily acted towards reducing pollutants of the river despite there being no strong enforcement of regulations by the state authorities.

In situations of low cooperation and conflict, there is little interaction between actors. However, once levels of conflict rise, relations become unstable. On the other hand, if levels of cooperation rise, relations become “stable and comfortable” (Craig 1993:16). In cases where both high levels of conflict and cooperation exist, there can be “strong commitment to achieve a goal by the participants, but there may be equally strong disagreement over the precise definition of that goal and particularly over the means of achieving it” (Craig 1993:16). According to Craig (1993:16), the four combination possibilities are “logical combinations”. In international river basins, it seems rare to have riparian states in a situation of both high conflict and cooperation. It may be that independence or territorial disputes may experience high conflict and cooperation.

**Example**: the negotiation process between the Tamil Tiger representatives and Sri Lankan government in 2002 to achieve peace can be considered high in conflict and cooperation. According to Martin (2006), though there were apparent signs of commitment towards cooperation, the two actors were highly divided over how to proceed with the settlement of issues.

### 5.4.2 Conflict resolution

**International Law in Conflict Resolution**

A national framework of laws, legal conventions, treaties, and regulations is ultimately built to codify accepted standards of behavior in that society. International law offers a series of means to resolve international disputes, both diplomatic (negotiations, consultation, good offices, mediation, fact-finding, inquiry, conciliation, and the use of joint bodies and institutions) and legal (arbitration and adjudication). Generally, water conflicts are settled through negotiations with an agreement as the final outcome.

Of particular relevance to the PCCP–WfP process is the way disputes are resolved within the existing legal regimes governing the international waters under consideration. Review of a number of cases where international law has been a part of resolving conflict has shown that successful achievement of cooperative solutions is facilitated by:

- The legal framework in place (series of treaties)
- The relatively good neighborly relations between the parties
- The creation of joint commissions to address the problems
- Agreement to submit the matter to arbitration
- Absence of significant adverse impact on the quantity or quality of waters flowing into the neighboring country.

Unfortunately, these enabling factors are seldom present in water conflicts between watercourse states. Quite often relations between the parties to water disputes are tense or openly hostile, and the legal basis for regulating trans-boundary waters may be either lacking or insufficient. Sometimes a
planned or existing use of a shared water resource may cause serious adverse impacts in another state, depriving it of its “equitable and reasonable use.” In such a case international law, including various mechanisms for conflict resolution, is traditionally used by states to facilitate seeking and securing a mutually acceptable solution. International law, while admittedly not a panacea for all water conflicts, provides a transparent range of rules, instruments and mechanisms capable of transforming conflicts into cooperation. Unfortunately enforcement of decisions and agreements under international law may remain problematic.

**Alternative Dispute Resolution Approaches and their Application**

1. **Prior Recourse**

Not all conflicts escalate to the level of dispute. It is more usual that efforts focus on defusing the potential for conflict that is inherent in interstate water relations. This is the primary function of the commissions and committees described in Chapter 9. Prior recourse to other measures of dispute resolution may be a requirement under customary international law. On only one occasion have two countries at odds with each other over water issues resorted to the International Court of Justice. As shown in Figure 5-2, recourse to formal legal processes should therefore be the last step in the process to obtain a cooperative agreement.

![Dispute avoidance mechanism diagram](image)

Analysis of several agreements at the global, regional, and basin level have identified key factors and patterns to be taken into consideration in negotiating international water-related agreements including:

- Initiation of negotiations: organizational setting, procedural rules and negotiation culture.
- Balancing of interests (upstream–downstream, inter-sector).
– Windows of opportunity; relationship with other, legally binding and non-binding instruments.
– Role of technology, research, and monitoring in the negotiation process.
– Negotiation on implementation and compliance.
– Role of human rights, transparency, and public participation.
– Role of management and financing issues in the negotiation process.

The level of development of water rights in the legislation and in the administrative practice of countries, and the ripeness of a dispute over such rights determines when adjudication comes into play before the courts of law, or before other institutions acting in an adjudicating capacity. Such adjudication has played, plays, and will continue to play a fundamental role to ensure security and dependability of title to water, and its enforcement against the claims of third parties. A premature judicial process may:

– Be very costly in time and money.
– Not always provide an adequate answer to the special needs of the parties.
– Not always provide an adequate answer to the special needs of society.
– Focus on procedural issues rather than the substantive issues that are the basis for the dispute.
– Damage the future relationship between the disputants. Implementation of the decision may not be enforceable.

For these reasons, in many countries when an internal water conflict erupts, the institutions, communities, and parties involved are beginning to forgo the option of the court in favor of alternative conflict resolution processes. These include negotiation, mediation, and consensus building as ways to resolve conflicts. The public, which for decades had no say in decisions that involved its interests has become active and demands to take a role in the process and have a say in the outcome with which people will have to live. This same reaction will undoubtedly be extended to international disputes.

Some conflicts may not be resolved easily, and can last many years. Sometimes these conflicts persist in spite of the fact that they cause heavy losses of resources, and even human life. According to a study at Stanford University there are three categories of barriers to resolving conflicts:

Tactical and strategic barriers, which stem from the parties’ efforts to maximize short or long-term gains.

Psychological barriers, which stem from differences in social identity, needs, fear interpretation, values, and perceptions of one another.

Organizational, institutional, and structural barriers, which can disrupt the transfer of information, and pre-vent leaders from reaching decisions that, are in the interests of the parties in dispute.
As the complexity of the means of peaceful settlement increases, the parties subject the process to less and less control and confidentiality. The costs and time also increase with the more complex means. However, states are free to select their own mechanisms for dispute settlement, and practice demonstrates a willingness to use the range of available options.

2. Negotiations
Negotiation is the means of dispute resolution most often employed by states when trying to resolve any international conflict, including those over trans-boundary water resources. Depending on the issues at stake and the number of states involved, negotiation can take various forms, from bilateral talks and diplomatic correspondence to an international conference. It can be used at all stages of the conflict. Interest-based negotiation shifts the focus of the discussion from positions to interests. Because there are many interests underlying any position, a discussion based on interests opens up a range of possibilities and creative options. The dialogue on interests should be transparent, in order for the parties to arrive at an agreement that will satisfy their needs and interests.

While interest-based negotiations have the potential of leading to the best outcomes, the parties may not adopt this method, and therefore negotiations are often “rights-based” or “power-based.” When negotiations between parties fail, the parties may then attempt to enforce what they consider to be their rights. This means appealing to the court, and will result in a legal process in which the law is the dominant feature. Alternatively resorting to threat or even violence as a way of communication for the purpose of persuasion is called power-based negotiation. Negotiations are considered merely as the first step that states usually take in resolving their dispute. If they fail or if parties are unable to enter into negotiations altogether, other means of dispute settlement are available to them, and all are based on the involvement of a neutral third party. As a mechanism of conflict prevention this creates an opportunity for project adjustment and accommodation before plans proceed.

3. Good Offices and Mediation
A third party offering good offices to the conflicting states acts as a “go-between” in order to persuade them to enter into negotiations. Neutral states, joint bodies, and international organizations, as well as individuals can offer good offices. The parties usually deem the functions of good offices to be completed once the negotiations have started. The World Bank initially offered its “good offices” to India and Pakistan in their conflict over the Indus River waters. As will be seen later, its role gradually extended to a more dynamic, and in many respects decisive, involvement in the resolution of the dispute.

**Box 5.6 Good Offices in the Indus River Dispute**
In 1951 President Black of the World Bank offered the Bank’s “good offices for discussion of the Indus water dispute and negotiation of settlement.” Both parties had to accept three preliminary conditions:

- The Indus water resources are sufficient to meet all existing uses and future needs.
- The water resources should be cooperatively developed and used to promote economic development; the basin was to be viewed as a unit.
- The problem should be solved on a functional, not political plan, independent of past negotiations, claims, and political issues.
4. Mediation

Mediation, as compared with good offices, is a step towards more active third-party participation in the negotiations. A mediator provides assistance to the disputing parties in finding a solution. The Israeli–Jordanian bilateral negotiations were combined with informal discussions where the American and Russian diplomats acted as “sponsors” and “facilitators,” or in other words mediators. The facilitators made an effort not to impose their solutions and to remain “honest brokers,” from which one or both sides from time to time sought informal help. Mediation processes are flexible, informal, confidential, and non-binding. They can be faster and less expensive than judicial procedures. They can improve the relationship between the parties. The parties and/or the mediator have the freedom to leave the process at any point.

The mediators, who are hired, appointed, or volunteer to help in managing the process, should have no direct interest in the conflict and its outcome, and no power to render a decision. The mediators have control over the process, but not over its outcome. Power is vested in the parties, who have control over the outcome: they are the architects of the solution. The mediators’ role is multiple. They should help the parties to think in new and innovative ways and avoid the pitfalls of adopting rigid positions instead of looking after their interests. They should smooth discussions when there is animosity between the parties that renders the discussions futile and, in general, steer the process away from negative outcomes and possible breakdown towards joint gains.

Example: In the Danube River dispute between Hungary and Slovakia, the Commission of the European Communities offered to mediate when the parties failed to resolve their disagreements on the future of the project through bilateral negotiations. (The boundaries between good offices, mediation, and conciliation are sometimes blurred, and one procedure can often lead to another.)

5. Fact-Finding

Many international disputes arise from disagreements over questions of fact. Inquiry and fact-finding are procedures specifically designed to produce an impartial finding of disputed facts. The UN International Law Commission (ILC) study of legal issues concerning dispute prevention and resolution established that fact-finding, as a course of action, will frequently resolve a dispute before any binding process is necessary. Fact-finding, or inquiry, allows states to refer questions to a panel of experts for impartial third-party investigation of factual or technical matters before diplomatic negotiations. Under the 1907 The Hague Convention for the Pacific Settlement of International Disputes, a commission of inquiry can be established “to facilitate a solution . . . by means of impartial and conscientious investigation.” But its role is limited to providing “a statement of facts,” which should not have the character of an award. Following box describes how this was done in the Danube River case.

Examining issues initially at the technical level, often through joint institutions (made up of the representatives of basin states), is advantageous because experts in the field are reporting and making recommendations, minimizing the potential adverse impact of political factors and considerations. The Canada–US International Joint Commission (IJC) has successfully used this approach on numerous occasions. When confronted by controversial issues of water utilization or pollution that require technical expertise, the two governments usually refer them to the IJC. The
commission’s course of action is to appoint a technical advisory board of experts to collect the necessary data, to study the problem, and to recommend solutions.

**Box 5.7 Fact-finding in the Danube River Case**

The Danube River dispute provides another example where the fact-finding procedure was extensively used to help the conflicting parties. Hungary and Slovakia agreed in 1992 to establish a fact-finding commission that included the Commission of the European Communities. The commission was asked to report on Variant C, a provisional solution proposed by Slovakia. It was to convene an independent group of experts to report on emergency measures, establish and implement a temporary water management regime for the Danube, and reach agreement on the terms to submit the dispute to the International Court of Justice.

Agreement was reached to establish a tripartite group of experts. The group included one expert from each party to the dispute and three from the Commission of European Communities. The group was requested to provide reliable and undisputed data on the most important effects of the water discharge and the remedial measures already undertaken as well as to make recommendations for appropriate measures. Although the experts designated by the Commission recommended several measures, the parties could not agree on them. Negotiations continued and eventually the parties reached an agreement “Concerning Certain Temporary Technical Measures and Discharges in the Danube and Monsoni Branch of the Danube.” Being unable to resolve their dispute finally through negotiations and mediation, they agreed to submit the case to the International Court of Justice.

6. Conciliation

Conciliation “is a process of formulating proposals of settlement after an investigation of the facts and an effort to reconcile opposing contentions, the parties to the dispute being left free to accept or reject the proposals formulated.”

In conciliation, an impartial third party is requested by the conflicting states to help them to resolve the dispute by examining the facts and suggesting the terms of a settlement susceptible of being accepted by them. Thus conciliation may combine elements of mediation and inquiry. However conciliation is a more formal procedure usually performed by a commission composed of representatives of the parties to the dispute as well as independent nationals of other states. A sole conciliator may also perform conciliation. The conciliator seeks to objectively establish the facts and applicable law in a dispute through independent investigation, and this is followed by reporting of findings and recommendations to the parties.

7. Institutional Mechanisms

Trans-boundary water controversies and disputes are often resolved under the auspices of various international organizations and bodies, such as river basin commissions established by multilateral or bilateral agreements. A number of such mechanisms have been created for individual river basins or watercourses. Thus, the Canada–US International Joint Commission (IJC) includes among its responsibilities reporting on the findings of joint studies and recommending decisions on the questions of differences referred to it by the two governments. Under the 1944 Mexico–United States agreement related to the Colorado, Rio Grande, and Tijuana Rivers, the parties
established the International Boundary Waters Commission, which continues to resolve disputes over waters shared by the United States and Mexico through a series of decisions adopted as “minutes,” which are binding.

8. Arbitration
Compared with all other dispute resolution mechanisms involving impartial third parties, arbitration and adjudication are regarded as “legal” means of peaceful settlement leading to a legally binding decision. The parties must consent to arbitration – they agree to submit their dispute to an arbitrator or an arbitral tribunal, either in a prior agreement containing an arbitration clause, or after the dispute has arisen. In submitting a dispute to arbitration, parties may choose to follow the procedural rules and employ the administrative services of an arbitral institution, or they may organize the proceedings ad hoc.

While it is more formal than the alternative dispute resolution (ADR) mechanisms described in the preceding sections, arbitration offers some distinct advantages over litigation. It allows for more flexibility in that the parties can not only nominate the arbitrator(s) who will hear the dispute, but they can also determine the law governing the substance and procedure of the case, where the dispute will be heard, and the language of the arbitration. The parties can also decide whether their dispute will be heard by a single arbitrator or by a panel of arbitrators. Generally, arbitration hearings are private. The arbitral decision can also be kept confidential, but in any event, it is binding on the parties; appeals procedures are only available if established by prior agreement. Under the framework of the 1997 UN Watercourses Convention, binding settlement procedures are to be resorted to after all other means of dispute resolution has failed.

9. Permanent Court of Arbitration
The Permanent Court of Arbitration (PCA) is the longest established treaty-based international arbitration institution, and the first global mechanism for international dispute settlement. It was founded in 1899, and it now has ninety-seven Member States, signatories to either one or both of the 1899 and 1907 Conventions for the Pacific Settlement of International Disputes. Originally designed for inter-state arbitrations, the PCA has evolved its capacity to administer disputes between states and non-states, between international organizations and states, and between international organizations and private parties. The Court offers services for fact-finding and commissions of inquiry, conciliation, good offices and mediation, in addition to arbitration. The governing body of the PCA is its Administrative Council, which consists of delegates of Member States and meets twice a year. The Secretary-General and the PCA International Bureau carry out the day-to-day work of the Court.

Adjudication
Ultimately, the parties may agree to have their watercourse conflict heard by an ad hoc or permanent court. As described earlier, the most prominent standing judicial body is the International Court of Justice (ICJ), which has been used increasingly by states in their international disputes. As also noted earlier, the Gab"ikovo-Nagymaros case on the Danube River is the most important example of a judgment related to water by the ICJ.
5.5 Tutorials/Examples/Case studies

“Water governance” and “water management” appear to be used interchangeably. What is the difference between them considering river basin perspectives?

Draft river basin governance situation in Ethiopia.

What are the differences between rules, regulations and Laws?

Identify gaps between overall goals of the national water resources management policy of Ethiopia and their implementation realisms.

Explain the contribution of property right regime for sustainable water resources management.

Can you think any practical example?

State advantages and disadvantages of the three levels of institutional setup. (Decentralisation, privatisation and local institutions)

Give differences between institutions and organization.

State drivers of conflict, co-operation and their co-existing from trans-boundary river basin perspectives.

Do you think conflicts over resources are natural among humans?

What are the major causes of conflicts over water resources?

How do conflict and cooperation co-exist?

Among various approaches of dispute resolution techniques, select effective method to resolve Nile Basin conflict?

Case Study: Transboundary Dispute Resolution: the La Plata river basin

Authors: Aaron T. Wolf and Joshua T. Newton

1. Case summary

River basin: La Plata (figure 3, table 2)

Dates of negotiation: La Plata Basin Treaty signed 1969

Relevant parties: Argentina, Bolivia, Brazil, Paraguay, Uruguay

Flashpoint: None

Issues: Stated objectives: promote and coordinate joint development of the basin; “Hydrovia” proposed in 1989

Additional issues: Water-related: Joint management; Non-water: None

Excluded issues: Treaty does not provide any supra-legal authority

Criteria for water allocations: None

Incentives/linkage: Possibility of linking water projects with transportation infrastructure

Breakthroughs: None

Status: Intergovernmental Coordinating Committee functions; "Hydrovia" technical and environmental studies in February 2004 by Andean Development Corporation
Fig. 5-3: Map of La Plata River Basin (TFDD, 2007)

Table 5-2: Features of La Plata River basin

<table>
<thead>
<tr>
<th>Watershed features a</th>
<th>Basin Name</th>
<th>Riparian states (With % of national available water)</th>
<th>Riparian relations (with dates of most recent agreements)</th>
<th>Average annual flow $\text{km}^3/\text{yr.}$ c</th>
<th>Size ($\text{km}^2$)</th>
<th>Climate</th>
<th>Special features</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>La Plata</td>
<td>Argentina (3.5), Bolivia (0.7), Brazil (0.5), Paraguay (0.2), Uruguay (0.6)</td>
<td>Warm (1995 Mercosur - Southern Common Market - adds impetus to &quot;hydrovia&quot;)</td>
<td>470</td>
<td>2,954,500</td>
<td>Tropical</td>
<td>Good example of inter-sectoral, plus international, dispute</td>
</tr>
</tbody>
</table>

a Values for lakes under "Annual Flow" are for storage volumes.
b Source: Kulshreshtha (1993)
c Sources: Gleick ed. (1993); UN Register of International Rivers (1978)
The remaining data in this table is from the TFDD (2007).

2. Background
The La Plata River basin encompasses an area of 3.2 million square kilometers and is among the five largest international rivers basins in the world. It includes territory in Argentina, Bolivia, Brazil, Paraguay, and Uruguay, comprises the Parana, Paraguay and Uruguay river systems and makes up the largest wetland in the world—the Pantanal. The basin is the life sustenance for much of the agricultural and industrial sectors of the riparian states and has become a source of alternative energy and economic possibility.

The Basin’s five riparian states have a history of cooperation and joint management of the watershed, and have stressed the river's binding them to each other. Bolivia, Paraguay and Uruguay’s agriculture economies depend on the basin as crucially as the industrial sectors of Argentina and Brazil. Large amounts of grain, beef, wool, timber and some manufacturing goods are exported from this region to other parts of the world (Elhance, 1999). The 1969 La Plata River Basin Treaty, the umbrella treaty
and first to which all of the riparians are signatories, provides a framework for joint management, development and preservation of the basin. Subsequent multilateral and bilateral treaties outline the specifics of economic investment, hydro-electric development and transportation enhancement. Following the 1969 multilateral treaty, bilateral hydroelectric development opportunities were explored which gave source to the construction of dams and alternative power plants along the Parana. Today there are 130 dams along the River, two of which are widely known, the Itaipu and the Yacureta. Itaipu is the largest hydroelectric project in the world and a result of a 1973 bilateral agreement between Paraguay and Brazil. The hydroelectric dam cost the two governments and other international participants US$15 billion and 20 years to construct. The generating capacity is 26,000mW and supplies 26% of all of the electricity for Brazil and 78% for Paraguay with zero emissions.

The political and environmental dimensions of the Itaipu make for an interesting case of cooperation over a shared water resource. The land, where the Itaipu dam now sits, was once a source of great controversy between Brazil and Paraguay. Each country declared rights and legal authority over the Guaira Falls, which lies on the border of both countries and to which both claimed ownership and control. In 1957, Brazil, who believed the Falls to be within their borders and who wanted to invest in the hydroelectric power of the Falls, unilaterally took military control over the region. After five years of dispute and disagreement, Brazil and Paraguay finally negotiated the terms of the Itaipu dam. In addition to providing electricity to the two countries, the proposed project would submerge Guaira Falls (Elhance, 1999), thus, marking an end to the border dispute.

This conflict negotiation and cooperation between Brazil and Paraguay had ripple effects into areas of conservation and preservation. When the environmental concerns around the construction of the Itaipu basin came to the forefront, the two countries implemented two joint projects, the Gralha Azul and the Mymba Kuera, to minimize the effects of reservoir flooding on the regions ecology, deforestation in the region and moved the wildlife most affected by the dam to biological reserves (American University Trade and Environment database, 2004).

The Yacyreta Treaty, an agreement between Argentina and Paraguay, to construct a hydroelectric dam downstream from the Itaipu, has not been deemed as successful in its implementation. The treaty was hastily signed in December 1973, very soon after the Itaipu and was similar in content (generated power to be divided evenly between the two nations), except for the Yacyreta allowed for either country to sell power surpluses to a third party (Da Rosa, 1983). This contingency has since caused great confusion and complicated the construction. The dam, from its inception, has become a “monument to corruption.” The project has been unable to fill the reservoir to planned levels, and is operating at two-thirds of its capacity because of the environmental repercussions the system would incur if it was at 100% capacity. Already, US$1.3 billion worth of non-generated energy has been lost due to delays. In addition, the indigenous populations along the river and beside the dam do not feel like they were part of the planning process, were compensated for losses of their own land or believe they will be allocated power from the hydroelectric plant. At the moment, neither the Paraguayan nor the Argentine governments have the financial resources to allocate for improvements to the construction or to pay remittance to the 4000 families whose lives and environments have been affected by the construction of the dam.
Many bilateral treaties and hydroelectric projects have come out of the 1969 multilateral agreement, however, the first multilateral economic investment that joins all five riparian states and tests the framework of the La Plata Basin Treaty is termed “Hydrovia.” The ‘Hydrovia’ is a proposed river transportation project that will dredge and straighten major portions of the Paraná and the Paraguay, including the portions of the river that lie in the Pantanal wetlands. The initial backers of the proposal, dubbed "Hydrovia" ("waterway" in Spanish and Portuguese), were the governments of the La Plata basin states who met in 1988 to discuss the plans for the project and out of which was borne the Intergovernmental Commission on the Paraná-Paraguay Hydrovia. The project would allow year-round barge transportation (current conditions only allow for barges during the three dry months) and would open up a major transport thoroughfare for land-locked sections of the riparian states. The proposed waterway would make it possible for barge ships to take the 2000 mile trip from Argentina and Uruguay ports of the Atlantic to landlocked Bolivia and Paraguay (American University Trade and Environment database, 1999). Environmentalists and those whose livelihoods depend on traditional economies have expressed trepidation at the project.

3. The problem
A cooperative management body has been in place on the La Plata basin since 1969 and is generally considered a successful and productive organization. At the same time, ‘Hydrovia’ is the largest project for navigational river development proposed to date. Its size and possible impacts on the economies and environments of the basin states are beginning to strain the cooperative nature of basin management. The biodiversity of the world’s largest wetland, the Pantanal, could be strongly affected by the construction of the waterway. Covering over 53,760 square miles in Brazil, Paraguay and Bolivia, the Pantanal is home to 650 species of birds, 240 varieties of fish and more than 90,000 types of plants (Bascheck and Hegglin, 2004). Opponents of the project point to loss of biodiversity and significant changes in the hydrology of the Pantanal as reasons why the project should be avoided. The Pantanal currently decreases the occurrence of floods and droughts in the downstream area (Lammers et al., 1994), maintains the current ecosystem and hydrology there and is the life sustenance of the people, animals and wildlife along its banks.

4. Attempts at conflict management
The La Plata Basin Treaty of 1969 provides an umbrella framework for several bilateral treaties between the riparian states and a direction for joint development of the basin. The treaty requires open transportation and communication along the river and its tributaries, and prescribes cooperation in education, health, and management of ‘non-water’ resources (e.g., soil, forest, flora, and fauna). The foreign ministers of the riparian states provide the policy direction, and a standing Intergovernmental Coordination Committee is responsible for ongoing administration.

Basin states agree to identify and prioritize cooperative projects, and to provide the technical and legal structure to see to their implementation, illustrated best by the 130 dams along the Parana, the construction of the world’s largest hydroelectric project, Itaipu, and successive development, infrastructure and transportation projects. The treaty also has some limitations, notably the lack of a supra-legal body to manage the treaty's provisions. The necessity to go through each country's legal system for individual projects has resulted in some time lag and lack of implementation. The 1969 treaty's success has been in the areas of transportation and cooperation, so it is not altogether surprising that the ‘Hydrovia’ project has been forwarded to the planning stages and that many
multilateral and bilateral treaties came out of the 1969 La Plata Basin Treaty. The first meeting of the backers of the project was in April of 1988, out of which the Intergovernmental Commission on the Paraná-Paraguay Hydrovia was formed.

5. Outcome
As positions between supporters and opponents of the project have sharpened, these positions are based on very little information. The Inter-American Development Bank and the United Nations Development Program, in 1997, helped finance a technical and environmental feasibility study by the Intergovernmental Commission on the Paraná-Paraguay Hydrovia. The study included dredging, rock removal and structural channeling. Through motivation by independent technical critiques and environmental and social action networks the initial studies were discredited. As a result, the future of the Hydrovia is still uncertain. New studies were commissioned by Andean Development Corporation through the Intergovernmental Commission and were completed in February 2004, but the results have yet to be diffused.

6. Lessons learned
If riparian states start cooperation from the outset of a conflict, instead of letting it create stronger positions, the economic and joint management prospects are much greater. Since 1969, the quantity of joint economic ventures in the La Plata Basin has allowed for increased cooperation between the riparian nations when many times conflict could have arisen and defeated the benefits the states are receiving today.

If riparian states agree to equal access to transboundary water resources, equal and joint management, investment and distribution of that resource is feasible. In the water resources sector, neither Brazil nor Argentina has used their economic or military superiority to maintain greater control over water resources or hydroelectric potential.

7. Creative outcomes resulting from resolution process
The La Plata Basin Treaty has helped bring the five nations together and aid in not their own disputes, but assist in resolving disputes between sectors. The nations cooperate well, but the treaty has been helpful to resolve intersectorial conflicts. While the Hydrovia project was proposed in 1988, even now in 2004, there is still little movement towards implementing the project due to environmental and social action groups in defending the economic, cultural and ecological integrity of the basin. In the end, this will allow for a more sustainable project.

8. Timeline
1958 Yacyreta treaty is signed and the first joint Argentine-Paraguayan technical commission is formed to study the possibilities of obtaining hydroelectric energy from the rapids in the Paraná River.
Apr 1962 Negotiations between Paraguay and Brazil over the development of the rapids on the River Parana for hydro-electric are interrupted by Brazil, who shows military force, invades and claims control over the Guaria Falls sight.

1967 Brazilian forces withdraw and a joint Brazilian-Paraguayan commission is formed to examine the development of the region.
Apr 1969 La Plata Basin Treaty is signed by all five riparian states. The treaty provides a framework for the joint development of the basin; requires open transportation and communication along the river and its tributaries; cooperation in education and sanitation; and joint management of non-water resources (soil, forest, flora and fauna). An Intergovernmental Coordinating Committee is formed and is responsible for ongoing administration. Foreign ministers of the five riparian states are to provide policy initiatives.

Apr 1973 Itaipu treaty: Brazil and Paraguay announce plans to construct the Itaipu dam; Argentina expresses deep concern for the environmental repercussions of the dam and the effects of the dam on their own planned dam project.

Dec 1973 Yacyreta treaty: an Argentina-Paraguay organization, Yacyreta, is formed to oversee the construction of the hydroelectric dam and the contributing turbines.

1975 Itaipu dam construction begins.

Dec 1980 Joint declaration is made by the five riparian Foreign Ministers expressing a need to promote swift development of the resources on the La Plata basin.

Apr 1988 First meeting of the five riparian states on the proposed Hydrovia, a plan to develop the navigational infrastructure of the Parana, the Paraguay and the Pantanal, to make an international waterway navigable by large, ocean-going vessels. Intergovernmental Commission on the Paraná-Paraguay Hydrovia formed.

March 1991 Bilateral treaty between Brazil and Uruguay –agree to joint development of the Cuareim River and cooperation in the use of its natural resources.

1991 The Itaipu project, the world’s largest hydro-electric plant developed by Brazil and Paraguay on the Parana River, is in full operation after 20 years of construction and US$15 billion in cost.

Sept 1994 The Yacyreta turbines begin to produce electrical power for Argentina and Paraguay.

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References for the case study


6. Ethiopian Study cases of IRBM

By: Dr. Amanuel Zenebe

“Integrated River Basin Management (IRBM) is the process of coordinating conservation, management and development of water, land and related resources across sectors within a given river basin, in order to maximize the economic and social benefits derived from water resources in an equitable manner while preserving and, where necessary, restoring freshwater ecosystems.” (Source: www.panda.org. Adapted from Integrated Water Resources Management, Global Water Partnership Technical Advisory Committee Background Papers, No. 4, 2000.). IRBM can be used as a tool to improve the basin resource use for the sustainable benefits of human beings.

One of the national water policy of Ethiopia based on the principles of Dublin-Rio statements (1992) is Integrated Water Resources Management, thus the policy recognizes the hydrologic boundary or basin as the fundamental planning unit and water resources management domain. Four IRBM study cases in different contexts of water use: Awash, Abay/Blue Nile, Omo-Gibe and Ziway-Abyata in the context RV Lakes basin will be presented.

These case studies of this chapter are aimed at broadening the knowledge of students in IRBM in Ethiopian context by giving an insight on: i) river basin resources and use, ii) the impact of man on river basin resources and, iii) sustainable management of limited river basin resources for the benefit of the present and the coming generations.

To further broaden the knowledge of the students in IRBM, students will be given a group assignment (a group of 2-4) to review literature on IRBM and write a term-paper, which will be shared to other groups in the classroom in the form of presentations and discussions.

6.1. Abay Basin

6.1.1 General basin characteristics

Population

The Abay River basin is home to 18.4 million of Ethiopia’s 81 million people as projected by Central Statistical Agency (CSA, 2005) for 2010 (Awulachew et al., 2007) based on 1994 population census. Abay river basin, which contributes 86 % runoff to the Nile and it is the most populous basin in Ethiopia and is the 5th densely populated of basin of Ethiopia. All population projections show continuous growth, which in turn will increase demand for natural resources among the Amhara, Oromia and Benishangul Gumuz regional states of Ethiopia (Table 6.1).

Table 6-1: Population by region as projected in the 1994 Population Census for Abay basin, (Awulachew et al., 2005; CSA(2005).

<table>
<thead>
<tr>
<th>Region name of Abay basin</th>
<th>Unit</th>
<th>Amhara</th>
<th>Oromia</th>
<th>Benishangul Gumuz</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Region name of Abay basin</td>
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203
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<td>31.46</td>
<td>22.23</td>
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<td>5134964</td>
<td>568572</td>
<td>17096320</td>
<td></td>
</tr>
<tr>
<td></td>
<td>123</td>
<td>82</td>
<td>13</td>
<td>85</td>
<td></td>
</tr>
<tr>
<td>Projected for 2010 Population Density (persons/km²)</td>
<td>12310897</td>
<td>5494788</td>
<td>617841</td>
<td>18423525</td>
<td></td>
</tr>
<tr>
<td></td>
<td>133</td>
<td>87</td>
<td>14</td>
<td>92</td>
<td></td>
</tr>
<tr>
<td>Projected for 2015 Population Density (persons/km²)</td>
<td>13874675</td>
<td>6201139</td>
<td>695360</td>
<td>20771174</td>
<td></td>
</tr>
<tr>
<td></td>
<td>150</td>
<td>99</td>
<td>16</td>
<td>104</td>
<td></td>
</tr>
</tbody>
</table>

**Geography**

The Nile, the longest river of the world, flows some 6700 km through ten countries before reaching the Mediterranean Sea. Its headwaters are in Lake Victoria at about 4° S latitude, and it flows mostly northward to its mouth at 32° N latitude (Conway, 2000).

Abay basin is geographically located between 34°16’31” and 39°049’38” East longitudes and between 7°42’9” and 12°45’19” North longitudes (Fig. 6.1). The basin is bounded west by the Sudan and North by Tekeze basin; East by Awash and south by Baro-Akobo and Omo-Ghibe basins.

![Fig. 6-1: The elevation map of Abay Basin](image-url)
The Abay River is one of the major tributaries of Nile River. It originates at the highlands of Amhara in northern Ethiopia and flows about 800 km (UNESCO-WWAP, 2007) in west direction. The Abay River Basin covers about 200,000 sq. kms of three regional states of Amhara, Oromia and Benishangul-Gumuz, and a very small proportion of Addis Ababa, which is not shown in the map (Fig. 1-1). Fig. 1-1 presents the location and altitudinal variation over the Blue Nile Basin in Ethiopia.

**Climate**

Precipitation in Ethiopia is to a large extent governed by the movement of the Inter-Tropical Convergence Zone (ITCZ) and its interaction with topography (Avery, 2010). The Abay basin has the mean annual rainfall 1451 mm based on the data of Bahr Dar station for the period between 1960 and 1992 (Kebede et al., 2006 in Melesse, et al., 2011) and with minimum 794 mm and maximum in 2049 mm (Abtew et al., 2006 in Melesse, et al., 2011). The average annual evapotranspiration 1300 mm. Annual rainfall over the basin decreases from the south-west (>2000 mm) to the north-east (around 1000 mm), with about 70 per cent occurring between June and September (Conway, 2000). The basin annual air temperature ranges between 11.5 and 25.5 °C (UNESCO-WWAP, 2007). There is a considerable spatial and temporal variation in the basin, for instance, precipitation increases from north to south, and with elevation (Beyene, et al., 2007). There are various agro-ecological zones in the area and the most dominant ones are Hot to warm moist low land (M1) and Tepid to cool moist mid high land (M2), which cover 23% and 30% respectively in the area.

**Geomorphology, Geology and soils**

Abay basin has an extremely varied topography and its landscape is characterized by highland complex of mountains and bisected plateau. A digital elevation model (DEM) of 90m by 90m (3 arc-seconds) from the Shuttle Radar Topographic Mission (SRTM) showed that the basin lies between 472 and 4261 m a.s.l and has an average elevation of 2358 m (+/- 1084 m). This large standard deviation in the elevation and the cross-sectional profile in Fig. 6-1 show how the basin is rugged. The basin is formed on a wide range of geologic formations. The type of geological formation dominates the basin are early tertiary volcanos which covers above 50%, and Precambrian rock is the second dominant rock in the basin. There are also intrusive rocks, late tertiary and Mesozoic volcanos, and alluvial sediments in small proportions. Based on the soil map of Ethiopia (based on the soil map by woody biomass study), 16 major soil units were identified. Nitisols are the most dominant soils in the area and mainly found in basalt plateaux of Ethiopian highlands covering 34.04 % and these soils are excellent for furrow-irrigation. The next most dominant major soil units are Cambisols and Vertisols with coverage of 23.63 % and 16.51% respectively. The Abay basin has a varied land use /land cover with a proportion of 37.2% for agriculture, 30.3 % for grassland and bushland and 1.96 for water bodies (Melesse, et al., 2011).

**Wildlife**

The Semien mountains in the Abay basin are home of larger endemic mammals and birds. The 179 sq-km park of Semien Mountains lies within the afro-alpine zone between 1900m and 4543m elevation (Phillips and Carillet, 2005).

**Water Resources**

Available river flow records, which are sparse and of limited duration, are presented for the Blue Nile and its tributaries upstream of the border with Sudan. Runoff over the basin amounts to 45.9 km³ a⁻¹.
(equivalent to 1472 m³s⁻¹) discharge. Between 1900 and 1997 annual river flow has ranged from 20.6 km³ (1913) to 79.0 km³ (1909), and the lowest decade-mean flow was 37.9 km³ from 1978 to 1987 (Conway, 2000). The average annual discharge at the Sudanese-Ethiopian border (Roseires until 1965 and Diem afterward) is 47.44 km³. Therefore, the runoff/rainfall ratio over this basin is about 25%, which is the highest among all the sub-basins (Karyabwite, 2000) and contributes about 44% of the total discharge of Ethiopia (UNESCO-WWAP, 2007). The main tributaries of Abay River basin are the Gilgel Abbay, Megech, Ribb, Gumera, Beshlo, Woleka, Jemma, Muger, Guder, Chemoga, Fincha, Dedessa, Angar, Dura and Beles (Melesse et al., 2011). According to Frenken 2005, the Lake Tana, with a surface area of 3,673 km² is the largest lake of Ethiopia, in a depression of the northwest plateau, 1,800 m above the sea level and forms the main reservoir for the Blue Nile. The lake has a drainage area of 11,650 km²; its maximum depth is 14 m. The estimated ground water potential of the basin is 1.8 Bm³ (Awulachew et al., 2007), which is the highest potential of all basins in Ethiopia (Fig. 1.1). Yet, less than 5 % of irrigable land in Blue Nile basin has been developed for food production (Deresa et al., 2009).

### 6.1.2 Current Developments and their impacts in the basin

#### Irrigated Agriculture

The National Irrigation Development Strategy of Ethiopia aimed at utilising natural resources to achieve food self-sufficiency, generate export earnings, and provide raw materials for industry on a sustainable basis (MoWR 2001 in Kamara1and McCornick (unpub)). According to MoWR data, it is identified that the Abay river basin has a potential of 211 irrigation projects, of which 90 are small-scale, 69 are medium-scale and 52 are large-scale. A total of 815,581 hectares of potential irrigable land is estimated, out of which 45,856 ha are for small-scale, 130,395 hectares for medium-scale and 639,330 hectares for large-scale development (Awulachew et al. 2005). However, there are no standard agreed criteria for estimating the irrigation potential in Ethiopia results in variation of estimating irrigation potential (Table 6.2). According to WAPCOS, 1995 in Awulachew et al. 2007, the basin has 27% of irrigable area of the country.

#### Hydropower development

Abay basin has a gross hydro-electric potential of 78820 Gwh a⁻¹ (Awulachew et al., 2007), which makes the basin the first largest hydropower development potential of all sub-basins, and it accounts for about 51% of the country. Therefore, the Ethiopian Renaissance dam, which is under construction, is expected to generate 5250MW power and to store 63 B m³ water. The dam will be the 10th largest hydro-power development in the world (ETV-news). Like many dams in northern Ethiopia, this dam is also expected to be exposed to reservoir sedimentation.

Table 6-2: Irrigation potential in the River Basins of Ethiopia (Awulachew et al., 2007).

<table>
<thead>
<tr>
<th>Basin</th>
<th>Catchment area (km²)</th>
<th>Irrigation potentials (Ha) (Respective recent master plan studies)</th>
<th>Irrigation Potential (WAPCOS, 1995)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Small</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

206
<table>
<thead>
<tr>
<th></th>
<th>scale area (km²)</th>
<th>drainage area (km²)</th>
<th>irrigable area of Ethiopia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abbay</td>
<td>198,891</td>
<td>45856</td>
<td>201346</td>
</tr>
<tr>
<td>Awash</td>
<td>110439</td>
<td>30556</td>
<td>112,697</td>
</tr>
<tr>
<td>Rift Valley</td>
<td>52,739</td>
<td>N/A</td>
<td>52,739</td>
</tr>
<tr>
<td>Omo-Ghibe</td>
<td>79,000</td>
<td>10,028</td>
<td>78,213</td>
</tr>
</tbody>
</table>

*Note: The national water resources master plan (WAPCOS 1995) was a desk study without significant*

**Fishery, Navigation and tourism**

Lake Tana is also used for fishing, navigation and tourism. Tis Abay, water that smokes, or The Blue Nile waterfall and the Semien Mountains are also tourist attraction places in the basin.

**Positive and negative aspects of development**

Water harvesting in dams and ponds has crucial role in supplementing irrigation and generate hydro-power. In response to this, the Ethiopian government has been involved in the construction of small to large-scale surface water harvesting infrastructures as a means of increasing water supply for various purposes. But, these infrastructures have limitations due to lack of reliable hydrological data during the design stage that is the reservoirs are filled with sediments before they complete their life cycle. The Grand Renaissance Dam of Ethiopia is expected to generate cheap and clean hydro power; it will also serve as sediment trap to the downstream country, like Sudan, and will have longer life cycle as large dead storage can be provided. Moreover, agronomic and health hazards in some cases leads to abandonment of dams and associated land (Haile et al., unpub.).

**Stakeholders and groups affected by the development**

Large-to medium scale dams are being under construction in the Abay basin, and such projects will affect the cultivated and grazing lands, which are accepted to be inundated due to dam construction. Farmers that own plots on the reservoirs will be highly affected by the project, and these farmers need compensation of their land, and job guarantee in after completion of the project.

**Institutional and organizational setting**

Institutions at federal level and international organizations act as a donors, and the regional bureaux, local government institutions and NGOs as implementing agencies in the time of project implementation (Awulachew et al., 2005). Awulachew et al., 2005 also explained that some of the regional bureau mandates involve planning, design and construction of small scale irrigation schemes and handover to another bureau for management, operation and maintenance. Small –scale irrigation is carried out by the regional Water Resources Bureau and the schemes are then handed over to the Agricultural bureau for further implementation. These arrangements are also applied to The Awash, Rift Valley and Omo-Ghibe basins.
The government organ working in water aspects are the Bureau of water resources in Amhara, Oromia and Benishangul-Gumuz regions, and other organizations involved in the irrigation development in the region are: Organization for Rehabilitation and Development in Amhara (ORDA), Ethiopian Social Rehabilitation and Development Fund (ESRDF), International Fund for Agricultural Development (IFAD), African Development Fund (ADF), and African Development Bank (AfDB) (Awulachew et al. 2005). Moreover, the Ethiopia is the member of The Nile basin Initiative (NBI), created in 1999 on initiative of the council of Ministries of water resources of the countries of the Nile basin for managing the water resources of the Nile River (Frenken, 2005). The water in the Nile River is shared among ten countries.

Problems and constraints to be addressed

Constraints of Water Resources Development in Ethiopia are numerous and fall in one of the general categories of legal, political, social, institutional or technical (Awulachew et al., 2007).

a) Land degradation and reservoir sedimentation

The Abay basin is the most degraded basin due to rapid population growth, poverty, poor watershed management, poor or absence of effective water use policy and frequent natural disasters (Melesse et al., 2011). Land is not used according to suitability due to the absence of land use plan in the basin. For instance, the Semien National Park in the basin is threatened due to land use conflict between cultivated (grazing) versus wildlife. Soil loss in areas cultivated through traditional practices amount to 122–128 tons per hectare per year in the highlands of Abay Basin (The World Bank, 2006). According to Woodward et al., (2007), 72% of the total suspended sediment load of the Nile (120 * 10^6 t a^-1) is contributed by Abay basin; whereas, Atbara and White Nile contributes 25% and 3% respectively. Sediment load of Abay is estimated to 40 10^6 m^3 a^-1 (UNESCO-WWAP, 2004). The basin has second highest sediment load next to Omo-Ghibe. In Ethiopia, due to lack of reliable hydrological data many dams and reservoirs have been over-dimensioned because of overestimation of runoff coefficients using standard empirical formulas. Likewise, many reservoirs fill up with sediments at an alarming rate because of underestimation of sediment yield (Zenebe, 2009).

b) Hydrological variability

The extreme hydrological variability and seasonality of the Abay River usually results in devastating droughts and floods. Ethiopia faced droughts and floods during El Niño and La Niña years respectively (Grey and Saddoff, 2005).

Ethiopia has experienced at least five major national droughts since 1980 (World Bank, 2008), and Abay basin is one of the most affected basins in Ethiopia. Harvesting and storing runoff water in reservoirs, so this water can be used for supplementing the rain-fed agriculture and providing water for irrigated agriculture, is crucial for ensuring food security in drought-prone areas of the Abay Basin and elsewhere in Ethiopia.

Moreover, it is evident that, the problem of river flooding in Ethiopia is getting more and more acute due to human intervention in the fragile highland areas at an ever-increasing scale (Gashaw and Legesse, 2011). Areas around Lake Tana are prone to flooding (UNESCO-WWAP, 2004) and South Gondar (mainly Fogera woreda) Zone of Abay Basin was a typical manifestation of river floods (Gashaw and Legesse, 2011). Building storage infrastructures and catchment treatment by soil and water conservation measures is very crucial to regulate and minimize flooding in flood-prone areas.
c) Trans-boundary nature of the river

The international nature of the Abay basin is one of the challenges in managing the surface water resources of the basin. UNESCO-WWAP (2004) mentioned that it is paradoxical that Nile is one of very few river basins that show great disparity among the riparian states, between those that contribute almost all the waters but use almost none and those that contribute nothing but use most of its waters. For sustainable use and management of the Nile basin resources, there must be a comprehensive and fair agreement among the Nile riparian countries. According Swain (2008), the Nile basin Initiative (NBI) has brought together all riparian countries of the Nile River, and the countries are expected to work for a joint initiative over equitable utilization of Nile River Water Resources, and this initiative is expected to promote cooperation and contribute to the socio-economic development by use of the Nile basin resources sustainably.

d) Lack of institutionalized research and institutional capacity

Although several water sector institutions have been established at federal and regional levels, according to Awulachew et al (2007), the institutionalized water research does not exist in Ethiopia unlike the agricultural and health sectors. Although human, land and water resources for irrigation development may be available; constraints are lack of institutional capacity, private sector involvement, and markets, as well as food insecurity which affects the dilemma of cost recovery because of targeting food security first by growing food crops instead of cash crops (Frenken, 2005).

6.1.3 Conclusions

Soil erosion, fertility loss, sedimentation and loss of biodiversity due to deforestation and land degradation are common in the Abay basin. As a consequence, water shortage, water quality deterioration and flood impacts occur. Therefore, integrated river basin management is an important tool to optimize the use of water for various purposes, so as to minimize land degradation and sedimentation, to protect loss of biodiversity, and to sustain environmental services and socio-economic benefits of the River basin. Moreover, special attention should also be given to coordinated planning with downstream riparian countries for the success of the hydropower and irrigation development projects in Abay basin.
6.2. Awash Basin

6.2.1 General Basin characteristics

Population
Awash basin covers parts of Afar, Amhara, Oromia, Somali, Addis Ababa, and Dire Dawa regional states, and it is the fourth populous basin in Ethiopia and ranked the 3rd of all basins of Ethiopia in terms of population density (Table 6.3).

Table 6-3: Population by region as projected in the 1994 Population Census for Awash basin, (Awulachew et al., 2005; CSA (2005).

<table>
<thead>
<tr>
<th>Region name of Awash basin</th>
<th>Unit</th>
<th>Afar</th>
<th>Amhara</th>
<th>Oromia</th>
<th>Somali</th>
<th>Addis Ababa</th>
<th>Dire Dawa</th>
<th>Total</th>
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<tbody>
<tr>
<td>Area</td>
<td>km²</td>
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<td>15480</td>
<td>26474</td>
<td>29020</td>
<td>334</td>
<td>784</td>
<td>110691</td>
</tr>
<tr>
<td>%</td>
<td></td>
<td>34.87</td>
<td>13.99</td>
<td>23.92</td>
<td>26.22</td>
<td>0.30</td>
<td>0.71</td>
<td>100</td>
</tr>
<tr>
<td>Counted in 2006</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Population Density (persons /km²)</td>
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<td>2160111</td>
<td>398228</td>
<td>2973000</td>
<td>398000</td>
<td>8388250</td>
</tr>
<tr>
<td>Density</td>
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<td>123</td>
<td>82</td>
<td>14</td>
<td>8910</td>
<td>508</td>
<td>76</td>
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<tr>
<td>Projected for 2010</td>
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<td></td>
<td></td>
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<td></td>
</tr>
<tr>
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<td>3622798</td>
<td>443475</td>
<td>9483684</td>
</tr>
<tr>
<td>Density</td>
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<td>15</td>
<td>10857</td>
<td>566</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Population Density (persons /km²)</td>
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<td>2318535</td>
<td>2608616</td>
<td>491993</td>
<td>4365468</td>
<td>524577</td>
<td>10999869</td>
</tr>
<tr>
<td>Density</td>
<td></td>
<td>18</td>
<td>150</td>
<td>99</td>
<td>17</td>
<td>13083</td>
<td>669</td>
<td>99</td>
</tr>
</tbody>
</table>

Geography
Awash basin is geographically located between 34°16'31" and 39°49'38" East longitudes and between 7°42'9" and 12°45'19" North longitudes. The basin is bounded by Denakil basin in the north, Abay and Omo-Ghibe in the west, Wabi-Shebele and Ogaden in the South, and Ayesh, Somalia and Djibouti in the East. The basin has a drainage area of 110,000 sq. kms. Fig. 6.2 presents the altitudinal variation over Awash Basin in Ethiopia.
Fig. 6-2: The elevation map of Awash basin in Ethiopia

Climate
The mean annual rainfall of the basin is 557mm and reaches 1500 mm at the eastern highlands of Addis Ababa. The catchment receives its maximum rainfall during June-September and constitutes 70 to 75 % of the annual rainfall. The second rainy period covers the period from February to May (Tarekegn Unpub, Fig. 6.3.). The mean annual evapotranspiration is 1800mm, and the basin annual air temperature ranges between 20.8 and 29 °C (UNESCO-WWAP, 2007). The climate of the basin varies from humid subtropical to arid. Hot to warm arid lowland plains (A1) covers about 55% of the basin, and Tepid to cool moist mid highlands (M2) and Hot to warm moist lowlands (M1) cover 10.85 and 13.21 respectively.
Fig. 6-3: Monthly Rainfall, Evaporation and Flow of Upper Awash River  
(Tarekegn, unpublished)

**Geomorphology, Geology and soils**

The Awash Basin rises at an elevation of 4195 masl over the central highland of Ethiopia. The river flows generally north eastwards along the Rift Valley and terminates in The salt lake, Lake Abe at an elevation of 210 masl on the Ethiopia-Djibouti border (Phillips and Carillet, 2005). The Awash basin has an average elevation of 2194m (+/- 1143m) (Fig. 2.1). This large standard deviation in the elevation shows ruggedness of the basin.

The types of geological formation of the basin are volcanic rocks (75%) and tertiary and younger sediments (25%). There are 16 types of soils in the Awash basin (based on the soil map by woody biomass study). The dominant soils in the basin are Cambisols, Regosols, and Solonchaks. Cambisols cover 16.54%, and they are moderately developed soils characterized by slight or moderate weathering of the parent material and by absence of appreciable quantities of illuviated clay, organic matter, aluminium or iron compounds. Regosols are soils from unconsolidated materials, exclusive of materials that are coarse textured or show fluvic properties. These soils are very young soils almost without soil development, and are shallow soils, covering 19.31%. Solonchaks are salt soils covering 13.79%. The major land uses in the Awash basin are croplands (22%), bare lands (18%), grasslands and woodlands (25%) and other types of land cover.

**Wildlife**

More than 400 bird species have been recorded in the Awash National Park, among them six endemics. The beautiful beisa oryx is easily seen in the park (Phillips and Carillet, 2005). The wild ass lives in open desert country and in lava-strewn hills among the rocks and cliffs, across the plains of the Danakil region and the Awash Valley. The Somali wild ass (*Equus asinus somalicus*) is of global significance as it is the only existing representative of the African wild ass with only a few hundred individuals left ([www.stlzoo.org](http://www.stlzoo.org)).
Water Resources
The flow of the river is highly seasonal and 85% of the flow occurs during the months of June-September. The monthly rainfall, evaporation, and flow depths are plotted and shown in Fig. 2.2. The estimated ground water potential of Awash basin is 0.14Bm³ (Awulachew et al., 2007).

6.2.2 Current developments and their impacts in the basin

Irrigated Agriculture
The Koka reservoir is located in the upper reaches of the Awash basin approximately 75 km southeast of Addis Ababa, and has been in operation for the last 45 years eventually it becomes a multipurpose reservoir and serves as a source of water for the 30,000 ha irrigation farms downstream and for flood control (Tarekegn, unpub). According to WAPCOS, 1995, the Awash river basin has 5.5% irrigable area of the country, which accounts 205,000 ha (Table 2-1). Most of the irrigation schemes in Awash Basin have good reputation in irrigation efficiency which varies from 30 to 55% (Taddese, et al. (unpub.)). Large-scale irrigated farming is common on the floodplain. State farms control some 80% of the irrigated area and smallholder farmers farm the remaining 20% (Taddese, et al. (unpub.)). Of the state farm area 92% is grown with cotton, 3% with bananas and 5% with cereals and vegetables (UNESCO-WWAP, 2004). According to WAPCOS, 1995 in Awulachew et al. 2007, the basin has 5.5% of irrigable area of the country.

Hydropower Development
There are three functional dams in Awash River Basin, Aba Samuel (1.5 GWh/year) commissioned in 1939, Koka (110 GWh/year) commissioned in 1960, Awash II (165 GWh/year) commissioned in 1966, and Awash III (165 GWh/year) commissioned in 1971. Koka was built on the upper Awash for hydropower generation and irrigation development downstream (UNESCO-WWAP, 2004). Koka dam was the first major hydroelectric development in the country. The 24 m high dam originally impounded some 1750 million m³ of water. The dam provides a gross head of 42 m for the power plant, which has three units with total installed capacity of 43 MW. The Awash II and III plants lie in-series, down-stream from Koka, both have installed capacities of 32 MW each, with rated heads of 59.8m. Although, the dam was initially constructed for hydropower production, it is also used for downstream flood regulation. The gross hydro-electric potential of Awash basin is 4470 Gwh a⁻¹ (Awulachew et al., 2007). The dam is also being affected by reservoir sedimentation. According to UNESCO-WWAP (2004), the estimated sediment load of Awash basin is 19 \times 10^6 m³ a⁻¹. In the coming years five additional dams are proposed to be built for hydropower generation and irrigation development in the basin (UNESCO-WWAP, 2004).

Tourism
Tourism is also one of the economic activities in the Awash basin. For instance, Awash National Park is the oldest and the most visited Ethiopia’s park, and one of eastern Ethiopia’s star attractions. It also contains an interesting range of volcanic landscape (Phillips and Carillet, 2005).

Domestic water supply and sanitation
Ethiopia has a very low level of water supply coverage, with only 17 and 35% of the rural and urban population having access to safe drinking water, and similarly low levels of sanitation coverage. The sanitation coverage in the capital Addis Ababa, which is believed to have better service, was estimated at 12.5 percent (MoH and World Development Report 1997). The welfare monitoring survey (CSA
1998) pointed out that, out of this, 11 percent of the households have flush toilet, 73.3 percent of the households have pit latrine, 3.1 percent of the households use household containers, 10.5 percent of households use open defecation (field and forest) and 2.2 percent of the households use other means. Thus, the conditions of sanitation are even worse in other parts of Ethiopia.

Positive and negative aspects of development

Irrigated agriculture is one of an important component in the development of Ethiopia and has positive and negative impacts.

The human interference in the Awash basin has positive effects. It opens job opportunities to large number of job seekers go to lower Awash River basin where they could get jobs in factories and temporary cotton picking contracts (Gabeto, 2010). Another large-scale irrigation scheme is Finchaa. Finchaa Irrigation Farm is a mechanized farm located in Eastern Wellega Zone in Oromia Regional State; North-west of Addis Ababa. This scheme covers an area of 8,060 hectares of irrigated area. This farm mainly produces sugar cane, which is a raw material in the Finchaa Sugar Factory. Wonji is also one of the large-scale irrigation schemes with an estimated irrigated area of 5,925 hectares (Kamara and McCormick, unpub). Moreover, the Koka dam generates hydropower for the country as well.

The negative effects of the human interventions in the basin are soil erosion and reservoir sedimentation, salinization, weed infestation, flooding, water pollution and water related diseases.

a) Soil erosion and reservoir sedimentation

The single overriding factor in the ecology of the Awash Basin is the rapid and continuous increase in population and the adverse effects on the resources of the basin, in particular, on the rapid erosion and degradation of the upland soils. Soil erosion is caused by removal of vegetation cover through deforestation and overgrazing, repeated tilling of the soil to prepare fine seedbed, improper land use and lack of adequate soil and water conservation in the Awash basin. The average annual soil loss by erosion in catchments of Awash basin is in the order of 200-300 t ha$^{-1}$ or 20,000-30,000 t km$^{-2}$ (PDRE, 1989 in UNESCO-WWAP, 2004). The reservoir sedimentation due to erosion has lowered the water volume from the designed live storage capacity of 1,667 Mm$^3$ to 1,186 Mm$^3$ at present (i.e., loss of 481 Mm$^3$), which is a loss of 30% of the total storage volume of the reservoir (EEPC, 2002 in UNESCO-WWAP, 2004), and diminishes the power generation capabilities and amount of water for irrigation. Minimizing sedimentation through integrated river basin management will contribute to Ethiopia’s power generation export to neighbouring countries and earn foreign exchange.

b) Salinization

Irrigation consumes between 70 and 90 % in developing countries (Kamara and McCormick, unpub.), thus irrigation should be coupled with drainage facilities in order to minimize the adverse effects of irrigation. Inadequate natural drainage causes water logging, salinisation and, in some cases, deterioration of soil quality through erosion, leaching, destruction of soil structure or even soil losses (Mintesinot and Mitiku; Paulos; McCormick et al. 2003). In the Middle and Lower Awash Valley, development of large irrigation projects without a functional drainage system and appropriate water management practices has led to a gradual rise of the saline groundwater table (Taddese, 2001). In effect, development of shallow saline groundwater, with high evapotranspiration contributed to
secondary salinization (Girma and Endale 1996 in Taddese, 2001). The low salinity of the River Awash water from August to November is associated with the high rainfall in the central highlands. During the last decades most of the agricultural land has been abandoned as a result of inherent soil salinity and saline shallow ground water in The Middle and Lower Awash. In most of the irrigation project development drainage system were not built, and irrigated land did not change over time and expanded, as salinity became a major threat for development of agricultural land (Awulachew et al., 2007). Over 2,000 ha of the Melka Sedi Amibara State Farm that was cultivated for bananas for about 16 years (1971-1986), and other areas that were cultivated for cotton recently (1982-1992), have gone out of cultivation due to these problems (Girma and Awulachew, 2007). The construction of subsurface drainage for large scale irrigation schemes was started in the Awash Valley for salinity control but discontinued (Frenken, 2005). Solonchack (saline soils) can be managed by leaching and draining, applying soil ameliorants, and selecting suitable salt resistant crops.

c) Weed infestation
A thorny shrub or weed named Prospopis julifora was introduced in the Middle Awash Valley and invaded most of the area near the enterprise, which was once barren land during dry seasons and possibly used for grazing purposes during wet seasons (Awulachew et al., 2007). Even if it has some benefits in reducing wind erosion and increasing the organic matter content of the soil, it created problems both to the enterprise and the surrounding inhabitants as it affects the canal network of the farms and cannot be used as animal feed (Awulachew et al., 2007).

d) Pollution loads of industrial effluents
With Addis Ababa in the headwaters of the Awash valley, discharge of untreated wastewater and pollutants into the river by the high water consuming industries, is a serious issue. For instance, Akaki area draw water for production purposes from water supply sources and discharge their by-product wastes in to streams and rivers without any kind of treatment (UNESCO-WWAP, 2004). There are no regulations and effective control regarding industrial effluent discharges by concerned parties (UNESCO-WWAP, 2004). Downstream uses in the most developed river in the country include domestic water supply and irrigation. Elevated levels of fluoride, which exist naturally in the groundwater in the Awash basin, however, make these sources unsuitable for domestic water supply (WWDSE 2001 in UNESCO-WWAP, 2004).

e) Flooding
The Awash River basin frequently floods in August/September following heavy rains in the eastern highland and escarpment areas. A number of tributary rivers draining the highlands eastwards can increase the water level of the Awash River in a short period of time and cause flooding in the lowlying alluvial plains along the river course. Certain areas which frequently, almost seasonally, get inundated are marshlands such as the area between the towns of Debel and Gewane in the vicinity of Lake Yardi and the lower plains around Dubti down to Lake Abe. The third area which often floods is, about 30 kilometres north of Awash town in the vicinity of Melka Werer. Flooding along Awash River was mainly caused by heavy rainfall in the eastern highlands and escarpment areas of North Shewa and Welo and not because of heavy rain in the upper watershed areas (i.e. upstream of the Koka Reservoir). Over the years soil and water runoff in the escarpment areas have steadily increased as a result of deforestation, the most serious environmental degradation in the escarpment areas being caused by overpopulation in the highlands. Tributaries to Awash river such as Kessem, Kebena, Hawadi, Ataye Jara, Mille and Loqiya rivers contributed most to the lowland flooding in Afar
Flooding particularly along the Awash River causes damage to standing crops and infrastructures. The construction of dykes mitigated the problem but has not provided a long-lasting solution (Frenken, 2005).

f) Health
The increased incidence of water related diseases such as malaria, schistosomiasis and diarrhoea have been associated with the development of irrigated agriculture in the Awash Valley, small dams in Tigray and elsewhere in Ethiopia (Mintesinot and Mitiku; Mitiku et al. 2001). Diarrhoea accounts for over 46% of infant mortality in Ethiopia.

Stakeholders and groups affected by the development
Pastoralists in the lowland of Awash basin are mainly affected due to the conversion of grazing lands to irrigated agriculture. Moreover the introduction of the weed (Prosopis julifora) to the area also affected the pastoralists by reducing the land for grazings, and the water pollution in upstream (such as Addis Ababa) will also affect the health of people downstream.

Institutional and organizational setting
The institutional and organizational setting is similar throughout the country (section 1.2.3). Land use was based on traditional ownership, although all land officially belonged to the governments. The social organization in the Afar region is governed by a customary law and social structure that unites several tribes. Land use is specifically adapted to the size and kind of livestock such as cattle, goats, sheep, and camels; the delineation and non utilization of lands, usually reserved for livestock grazing, for regeneration purposes. Conflict is ongoing in the Awash River Basin, much of which is inter-ethnic and inter-clan in nature. Changes to land use had many unwanted impacts, and most of the pastoralists were evicted from the wet grazing lands for dam construction and irrigation development for sugar cane, horticultural crops and cotton (Fiona Flintan and Imeru Tamrat 2002; François Piguet, 2001 in Taddese et al., unpub).

Problems and constraints to be addressed
The main ecological problems of the basin are deforestation, soil erosion, fertility loss, salinization, flooding, sedimentation and loss of biodiversity. For instance, floods Dire Dawa City experienced flash flood in summer 2006 (Gashaw and Legesse, 2011). According to MCE 2004, large tracts of irrigated lands have been left fallow (abandoned) for a number of years. Many of these lands have now been invaded with bushes and trees requiring huge rehabilitation and construction works. The reasons for the underutilization of the irrigated land in the Awash basin are lack of capacity and readiness of the local community to takeover and manage the abandoned irrigation farms; land claim conflicts among communities; and lack of institutional power of the regional government to develop a policy on use and management of the irrigation farms.

6.2.3 Conclusions
The Awash River basin is the most used basins as compared to the other river basins in terms of irrigation and hydro-power generation. Irrigation development in the area creates job opportunities. However, due to mismanagement of agricultural areas, some farm lands are affected by salinization. Other problems such as ecosystem deterioration, weed infestation, water pollution and water related
diseases are also common in the basin. Therefore, IRBM is very important to use and manage the basin resources for the benefit of present and future generations.
6.3 Omo-Ghibe Basin

6.3.1 General basin characteristics

Population
Omo-Ghibe basin covers parts of Oromia, and SNNP regional states, and it is the second populous basin in Ethiopia and the most densely populated basin of all Ethiopian basins (Table 6.4).

Table 6-4: Population by region as projected in the 1994 Population Census for Omo-Ghibe basin, (Awulachew et al., 2005; CSA 2005).

<table>
<thead>
<tr>
<th>Region name of Omo-Ghibe basin</th>
<th>Oromia</th>
<th>SNNP</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (km²)</td>
<td>19533</td>
<td>60744</td>
<td>80277</td>
</tr>
<tr>
<td>%</td>
<td>24.33</td>
<td>75.67</td>
<td>100.00</td>
</tr>
<tr>
<td>Counted in 2006</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Population number</td>
<td>1593794</td>
<td>8080807</td>
<td>9674601</td>
</tr>
<tr>
<td>Density (persons/km²)</td>
<td>82</td>
<td>133</td>
<td>121</td>
</tr>
<tr>
<td>Projected for 2010</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Popn. number</td>
<td>1705476</td>
<td>8567688</td>
<td>10273164</td>
</tr>
<tr>
<td>Density (persons/km²)</td>
<td>87</td>
<td>141</td>
<td>128</td>
</tr>
<tr>
<td>Projected for 2015</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Popn. number</td>
<td>1924714</td>
<td>9633244</td>
<td>11557958</td>
</tr>
<tr>
<td>Density (persons/km²)</td>
<td>99</td>
<td>159</td>
<td>144</td>
</tr>
</tbody>
</table>

Geography
Omo-Ghibe basin is geographically located between 34°55’50” and 38°25’42” East longitudes and between 4°25’40” and 9°2’48” North longitudes (Fig. 6.4). The basin is bounded by Abay and Awash basins in North, Baro-Akobo in the west, Kenya in South, Rift Valley basin in the East. The total area of the basin is about 80,000 sq. kms.
Climate

The mean annual rainfall and evapotranspiration of the basin are 1140 mm and 1600 mm respectively, and the basin annual air temperature ranges between 17 and 29 °C (UNESCO-WWAP, 2007). Most of the precipitation is received in summer season (June-September) (Fig. 6.5). There are various agro-ecological zones in the area and the most dominant ones are Tepid to cool sub-humid mid highlands (24.25%), Hot to warm sub-humid lowlands (20.99%), Hot to warm moist lowlands (13.76%).
**Geomorphology, Geology and soils**

The Omo-Ghibe basin has altitude ranging between 318 and 3594 and with an average elevation of 1962 m (+/- 940m) (Fig. 6.4). This large standard deviation in the elevation shows the basin has rugged topography.

The basin is formed on a wide range of geologic formations. The type of geological formation dominates the basin are early and late tertiary volcanos, which cover above 70%, and Tertiary and younger sediment also cover about 24%. The Precambrian rock is very limited in this basin. There are 15 types of soils in the Omo-Ghibe basin. The dominant soils in the basin are: Nitisol (26%), Vertisol (18%), Cambisols (16%), and Fluvisol (16%). The Omo-Ghibe basin has a varied land use/land cover including agriculture, grassland, forest, bare land and water bodies. the basin has a dominant land cover including about 28 % (Mosaic Forest / Croplands), and 40 % (shrubland and woodland).

**Wildlife**

The basin is endowed with a variety of wildlife.

**Water Resources**

The total mean annual flow from the Omo-Ghibe river basin is estimated at about 16.6 B m$^3$ (UNESCO-WWAP, 2004), accounting for 14% of Ethiopia’s annual runoff (Woodrofe et al, 1996). The estimated ground water potential of the basin is 0.42Bm$^3$ (Awulachew et al., 2007), which is the largest potential of all basins of Ethiopia. Only the Blue Nile carries larger flows. Hence the Omo-
Ghibe Basin is a very significant resource within Ethiopia (Avery, 2010). Moreover, Lake Turkana is found in Kenya and Ethiopia is sustained by the inflows of Ethiopia’s Omo River, which alone provides 90% of the lake inflow (Avery, 2010). Fig. 3.1 presents the altitudinal variation over the Omo-Ghibe basin of Ethiopia.

6.3.2 Current developments and their impact in the basin

**Irrigated Agriculture**

Large-scale and medium-scale irrigation potential are identified in the basin, with an estimated irrigable area of 57,900 and 10,028 hectares respectively, and a total irrigable area of 67,928 hectares (Awulachew et al., 2007). However, this figure could be much higher given the vast land area of lower Omo-Ghibe basin. The basin has 12% irrigable area of the country (WAPCOS 1995 in Awulachew et al., 2007).

**Hydropower development**

The gross hydro-electric potential of Omo-Ghibe basin is 36,560 Gwh a⁻¹ (Awulachew et al., 2007, which is second largest potential next to Abay basin, accounting for 24% of the gross hydro-electric potential of the country. Currently, a cascade of five hydro-electric power projects (Gibe I-V) along the Omo-Ghibe River (Fig. 6.4) is either planned or (being) developed (Avery, 2010). The construction of Gibe I and II is completed, Gibe III is under construction and IV and V are planned. The basin has the highest potential of sedimentation of all basins of Ethiopia with the total suspended sediment load of 120 * 10⁶ t a⁻¹ (UNESCO-WWAP, 2004).

**Fishery and Tourism**

Lake Turkana was inhabited by 48 species of fish, 18 of which are either endemic or Nilotic. Twelve species are riverine and specific to the Omo River and thirty species are Soudanian (Hopson et al., 1982 in Avery, 2010). The basin has Omo and Mago parks and its tourism potential is high.

**Positive and negative aspects of development**

The cascading dams in Omo-Ghibe will have positive effects on generating hydro-electric power and regulating the flow there by reducing downstream flooding, and for cultivating downstream potential vast plains by irrigation.

There are also some adverse affects in the basin. Lake Turkana is almost entirely dependent on the Omo-Ghibe River for almost 90% of its inflow and its flow pattern modification in the upstream reduces the lake level and associated biomass in the lake (Avery, 2010). According to Avery 2010, the Gibe III hydropower project (200 km² reservoir with gross storage 15 km³) is under construction and this project alone will need an equivalent of over two metres on Lake Turkana in order to fill its large reservoir. Thereafter, the scheme will “process” 67% of the water that reaches Lake Turkana, constantly releasing water in order to generate the power for which it is designed. If irrigation development proceeds as planned in the Omo Basin, the lake will diminish, as will biomass and fisheries (Avery 2010).

Due to the interference of human beings in the basin, forests and vegetation have been cleared and as a consequence, runoff has become more variable, with much more rapid response to rainfall in the last
20 years (Avery, 2010), resulting in increased flooding, which are accompanied by accelerated sediment transport in downstream areas.

**Stakeholders and groups affected by the development**
The stakeholders and groups affected by the development are farmers of the basin and pastoralists and fishermen in the Lake Turkana.

**Institutional and organizational setting**
The government organs currently involved with irrigation development in SNNPR region include: Southern Irrigation Development Authority (SIDA), Bureau of Agriculture (BoA), the Cooperative Promotion Bureau (CPB), Bureau of Co-operatives and Rural Development Coordination Office (RDCO). The NGOs and donors are many and some of them include: World Vision, Lutheran World Federation (LWF), ADB, ADF, AFD, Action Aid, Greek Aid, IFAD, Food and Agricultural Organization (FAO), United Nations Children’s Fund (UNICEF), the Ethiopian Social Rehabilitation and Development Fund (ESRDF) and the Government.

**Problems and constraints to be addressed**
Flood disasters in Ethiopia are attributed to rivers that overflow or burst their banks and inundate downstream plain lands, for instance the flood that has recently assaulted Southern Omo Zone (Gashaw and Legesse, 2011). The Gibe III Project under construction and the other four constructed and planned projects (Giba I, II, IV and V) are able to regulate the floods, and generate hydro-power and provide water for irrigation. However, the adverse effect of these reservoirs on the water level of Lake Turkana and its resources is an important IRBM issue that should be addressed by Ethiopian and Kenyan Governments and stakeholders.

**6.3.3 Conclusions**
Modification of Omo-Ghibe river flow patterns has impacts in the flow regime in lower part of the basin as well as in the Lake Turkana ecology. The lake is mostly situated within Kenya, whereas the Omo-Ghibe River is entirely within Ethiopia. Therefore, Integrated River Basin Management of the Omo-Ghibe Basin is crucial to address the sustainable use of water resources of the basin and Lake Turkana.
6.4 Rift Valley Basin

6.4.1 General basin characteristics

Population
Rift Valley basin covers parts of Oromia, and SNNP regional states, and it is the seventh populous basin in Ethiopia and ranked the 2nd of all basins of Ethiopia in terms of population density (Table 6.5).

Table 6-5: Population by region as projected in the 1994 Population Census for Rift Valley basin, (Awulachew et al., 2005; CSA 2005).

<table>
<thead>
<tr>
<th>Region name of Rift-valley basin</th>
<th>Area (km²)</th>
<th>Oromia</th>
<th>SNNP</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Counted in 2006</td>
<td>%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Population number</td>
<td>41.69</td>
<td>58.31</td>
<td>100.00</td>
<td></td>
</tr>
<tr>
<td>Density (persons/km²)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Projected for 2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Population number</td>
<td>1838541</td>
<td>4193411</td>
<td>6031952</td>
<td></td>
</tr>
<tr>
<td>Density (persons/km²)</td>
<td>82</td>
<td>133</td>
<td>112</td>
<td></td>
</tr>
<tr>
<td>Projected for 2015</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Population number</td>
<td>1967374</td>
<td>4446070</td>
<td>6413444</td>
<td></td>
</tr>
<tr>
<td>Density (persons/km²)</td>
<td>87</td>
<td>141</td>
<td>119</td>
<td></td>
</tr>
</tbody>
</table>

Geography
Rift Valley basin is geographically located between 36° 34' 53" and 39° 40' East longitudes and between 4° 21' 53" and 8° 28' 37" North longitudes. The basin is bounded by Awash basin in the north, Kenya in South, Genale-Dawa and Wabe-Shebele basins in the east. The total area of the basin is about 54,600 sq. kms.
Fig. 6.6: The elevation map of Rift-Valley Basin in Ethiopia

**Climate**

The mean annual rainfall and the mean annual evapotranspiration are 1150 mm and 1607mm respectively. The basin’s annual air temperature ranges between <10 and 27°C (UNESCO-WWAP, 2007). The basin is mainly dominated by Tepid to cool sub-humid mid highlands (21%), Hot to warm semi-arid lowlands (13%), and Hot to warm humid lowlands (12%). Moreover, there are also various agro-ecological zones in relatively small proportion.

**Geomorphology, Geology and soils**

The Rift Valley basin has elevation ranging between 461 and 4182 and with an average elevation of 2316m (+/- 1066m) (Fig. 6.6). This large standard deviation in the elevation and the cross-sectional profile in Fig. 4.1 show the basin has relatively less rugged topography. Fig. 6.6 presents the altitudinal variation over the Rift Valley basin in Ethiopia.

The type of geological formation dominates the basin are late tertiary volcanos which covers about (44%), and early tertiary volcanos is the second dominant rock in the basin 21%. Precambrian and tertiary and younger sediments are also found in the basin. There are 16 types of soils in the Rift Valley basin. The dominant soils in the basin are Vertisols (18%), Fluvisol (16%), Cambisol (13%) and Luvisols (10%). Vertisols are generally chemically fertile and productive if they are well managed. The dominant land use and land cover in the area are shrublands, which accounts for 21%. Cropland, woodland and grassland are common in the rift valley basin.
**Wildlife**

91 mammal species are found in the park, e.g., bushpigs, warthogs, Anubis baboons, thumbless, colobus monkeys, genets, bushbacks, and vervet monkeys are found in the forests. Burchell’s Zebra are found in the Savannah plains. Antelopes and Gazelle. A massive crocodile population is found in Lake Chamo.

**Water Resources**

The total mean annual flow from the Rift Valley basin is estimated at about 5.64 B m$^3$ (UNESCO-WWAP, 2004) and estimated ground water potential of the basin is 0.1 Bm$^3$ (Awulachew et al., 2007). This basin is endowed with seven of the eight major natural lakes in Ethiopia (The World Bank, 2006) and the lakes are of varying size with environmental significance (Awulachew, 2007, Table 6.6). Lakes Shala and Abayata have concentrations of chemicals used in production of soda ash (The World Bank, 2006).

The total surface area of these natural and artificial lakes in Rift Valley Lake basin is presented in Table 6.6. Lakes Shala and Abayata have high concentrations of chemicals and Abayata is currently exploited for production of soda ash. Large wetlands in the river basin serve as source of water for large rivers, flood retention and groundwater discharge (Frenken, 2005). Moreover, the wetlands are areas of high biodiversity and are often vital to the livelihood strategies of local communities through the provision of environmental services and socio-economic benefits (Frenken, 2005).

Table 6-6: Basic hydrological data of lakes and reservoirs in the Rift Valley Lake basin.

<table>
<thead>
<tr>
<th>Name</th>
<th>Location</th>
<th>Elevation (m.a.s.l)</th>
<th>Drainage area (km$^2$)</th>
<th>Surface Area (km$^2$)</th>
<th>Maximum depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ziway</td>
<td>38°23' 07°54'</td>
<td>1636</td>
<td>7380</td>
<td>440</td>
<td>8.9</td>
</tr>
<tr>
<td>Langano</td>
<td>38°31' 07°32'</td>
<td>1585</td>
<td>2000</td>
<td>230</td>
<td>47.9</td>
</tr>
<tr>
<td>Abiyata</td>
<td>38°35' 07°33'</td>
<td>1580</td>
<td>10740</td>
<td>180</td>
<td>14.2</td>
</tr>
<tr>
<td>Shala</td>
<td>38°35' 07°03'</td>
<td>1550</td>
<td>2300</td>
<td>370</td>
<td>266</td>
</tr>
<tr>
<td>Awassa</td>
<td>38°27' 07°07'</td>
<td>1680</td>
<td>1300</td>
<td>92</td>
<td>22</td>
</tr>
<tr>
<td>Abaya$^1$</td>
<td>37°50' 06°15'</td>
<td>1169</td>
<td>16342</td>
<td>1140</td>
<td>24.2</td>
</tr>
<tr>
<td>Chamo$^1$</td>
<td>37°38' 05°50'</td>
<td>1110</td>
<td>18575</td>
<td>317</td>
<td>14.2</td>
</tr>
<tr>
<td>Koka$^2$</td>
<td>36°10' 08°28'</td>
<td>1590</td>
<td>11250</td>
<td>236</td>
<td>13</td>
</tr>
</tbody>
</table>

Source: MCE (2001), $^1$Awulachew (2001), and $^2$reservoirs (Awulachew, 2007)

6.4.2 Current developments and their impacts in the basin

**Irrigated Agriculture**

In this river basin 37 irrigation potential sites are identified out of which 5 are small-scale, 18 are medium-scale, and 14 are large-scale. The estimated irrigation potential is 134,121 hectares. Out of these, a potential, 30,556 hectares are for small-scale, 24,500 hectares for medium-scale and 79,065 hectares for large-scale development (Awulachew, 2005). The Hare Irrigation System is one of the
irrigation system in the rift valley basin found in the western part of the Abaya-Chamo Lake Basin and has total catchment area of 169 km², out of which 22.24 km² is irrigable plains in lower portion of the basin near the shoreline of Lake Abaya (Girma and Awulachew, 2007).

**Hydropower development**
Rift Valley basin has a gross hydro-electric potential of 800 Gwh a⁻¹, which accounts for 0.5% of the country potential (Solomon, 1998). However, according to the Reconnaissance Master Plan for Development of Natural Resources of the Rift Valley Lakes basin made by Sir William Harcow Partners Ltd (NBCBN, 2005), due to shortage of water, sedimentation problems and unavailability of suitable dam sites development hydropower in these basins seems unlikely. Sediment load of the basin is 8 x 10⁶ m³ a⁻¹ (UNESCO-WWAP, 2004). Lake sedimentation will be a threat to the natural lakes if deforestation and overgrazing continues in the basin.

**Fishery, Navigation and Geo-tourism**
The rift valley Lakes are used for fishing, navigation and tourism. The Nechisar National Park covers 514km² and contains diverse habitats ranging from wide open savannah and acacia woodlands to thick bush and section of riparian forest.

**Positive and negative aspects of development**
Irrigation practice in the rift valley basin contributed to high yield of crops, e.g., yields ranges between 144 and 219 qt ha⁻¹ for banana, between 7 and 22 qt ha⁻¹ for cotton and 22 and 29 qt ha⁻¹ for maize in the irrigation schemes (Girma and Awulachew, 2007).

The major environmental concerns in the area are:

a) Decrease in ground water depth
The decline in groundwater depth in the scheme, especially near Lake Abaya, which is mainly caused by poor management of irrigation water and lack of working drainage facilities (Girma and Awulachew, 2007).

b) Soil erosion and sedimentation
The other environmental problem is the increasing removal of vegetation cover in the watershed and the resulting high soil erosion and transported sediment. This has also created significant problems in the scheme’s irrigation canal network. Siltation of canals is severe, especially at the modern schemes of Chano Mile and Chano Chalba (Girma and Awulachew, 2007).

c) Salinization
Soils of the Rift Valley are high in pH. In these areas precipitation is low, while evapo-transpiration is considerably higher (Dubale, 2001). In the Lake Ziway basin, salt incrustation is observed where irrigation is practiced by pumping water from the lake (Fisseha, 1999 in Dubale, 2001).

**Stakeholders and groups affected by the development**
The stakeholders and groups affected by the development are farmers and pastoralists of the basin.

**Institutional and organizational setting**
The Hare Irrigation Scheme is managed by the farming community itself. Water Committees (WCs), which are elected from the irrigators themselves, are responsible for the operation and management of the scheme. The duties of these WCs include scheduling and allocation of irrigation water, assessing and identifying maintenance needs, settling disputes that may arise during the distribution of irrigation water and fining illegal water users according to their bylaws (Girma and Awulachew, 2007). The number of members in the WCs varies between five and nine. The WCs usually consist of a chairman, secretary and members, and it is accountable to its District Council. The products are sold by negotiations between producers and traders. Farmers sell their products either in local market (Arba Minch town) or Addis Ababa through their representative (Girma and Awulachew, 2007). Some farmers even started to get involved in the other sectors such as transport, by owning vehicles like minibuses and trucks, from the benefits they gained from their irrigated farms (Girma and Awulachew, 2007).

**Problems and constraints to be addressed**

**Flooding**

Flooding in Rift Valley Basin areas is a phenomenon that is happening every year except that the magnitude is changing from year to year. In the lower arid areas where the inhabitants are nomadic pastoralists flood brings moisture to their dry season grazing land to grow enough grass that could last for most of the dry months as such it is not a threat. In some areas where farmers practice flood recede agriculture flood is considered as a beneficial positive impact. The people have developed tradition of living with it. However, flush floods in many areas have resulted in damages to property and human life (UNESCO-WWAP, 2004).

**Commercial land-use activities**

Soda ash mining which started on Lake Abijata National park in 1990 has resulted in polluting the lake water affecting the loss of algae that supported the fish. As the fish died out due to lack of food, the pelicans that feed on the fish left the place. Lake Abijata used to supply food for the pelican nesters on the neighboring islands of Lake Shalla, which is one of the seven nesting sites of the great white pelican in the whole of Africa. (UNESCO-WWAP, 2004)

6.4.3 Conclusions

Population density is highest in Rift Valley Lakes Basin indicating the immense pressure on the resource base. The growing pressure on the fresh water resources is enforced by population growth that leads to conflicts among demands for various purposes (e.g., irrigation, industrial purposes and lake ecology conservation). This problem can be mitigated by the Integrated River Basin Management.

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