Geo-Information Infrastructure for Water Resources Management

Local and Regional Perspectives

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Abstract

Management of natural resources has become a challenging task due to rapid population growth, poverty, marginality, inaccessibility and limited understanding of environment in the mountainous region like the Hindu Kush Himalayas. Water is one of the most important natural resources which has critical impact on many aspects of development. The advances in information technology and Geographic Information Systems have provided promising tools for decision support in managing these resources. However, the potentials of these technologies are underused due to absence of a proper framework for database development and data sharing. The existing information is insufficient, dispersed and heterogeneous. The development of databases is isolated and ad hoc, resulting in duplication of efforts and data gaps. Without a proper mechanism for data sharing, the identification and access to existing data are difficult. There is a need for a developing data models based on formal modelling techniques to resolve the heterogeneity in databases and reuse them in different applications. The reengineering of different processes in data collection, database design, and data sharing mechanisms is needed for a more economical and useful development of information base. The concept of GeoInformation Infrastructure (GII) has emerged as a mechanism which facilitates access to and responsible use of geoinformation by all potential users at affordable cost. This research is carried out with an objective to develop a system architecture of GII for water resources management. ICIMOD has been taken as a case for the research to identify the problems in data collection and sharing practices for water resources management, and to set reengineering plans to support the development of GII. It is an international organization involved in various issues of mountain natural resources and environmental development, and dissemination of geoinformation technology in the region.

The activities of the organization on water resources management, and the current practices in spatial data collection and sharing are reviewed and performance issues are discussed. The external and internal environments of the organization are analysed using the SWOT analysis and advances in IT is reviewed to formulate the improvement strategies. The strategies are proposed for improved integration of multidisciplinary expertise, exploiting the potentials of available IT for better sharing of information and introducing new services, and stronger partnerships with the collaborating organizations in the field of geoinformation. The needs for reengineering of the current practices, development of GII and MLDSS are realized to implement the improvement strategies.

The management processes and information needs for water resources management at local and regional levels are studied and modeled taking the examples of irrigation and drinking water supply, soil erosion and conservation, land use/ land cover dynamics, and the estimation of regional water balance. Based on these studies, the reengineering plans are presented for data collection and sharing processes. Finally, the system architecture for GII is developed based on the operational requirements and technical possibilities in the context of the organization.

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Chapter 1

Background and objectives

1 Background and objectives

1.1 Background

One fifth of earth's land surface is covered by mountains, about 10 percent of the world's population live in mountainous regions, and a far greater proportion of the world's population depends on mountain resources. Recognizing the importance of mountains as an essential component of global life-support system, the United Nations has recently proclaimed the year 2002 as International Year of Mountains [UN, 98]. Asia contains the largest, highest and most populated mountain system. The Hindu Kush Himalayas, extending over 3500 kilometers from Afghanistan to Myanmar, has over 140 million inhabitants (figure 1-1). These mountains provide huge resources of water, energy, minerals, forest and agricultural products. Due to the rapid population growth, and development interventions to meet the needs of the growing population, these resources have been over exploited without paying much attention to their fragility [ICIMOD, 98]. Efforts are being made for the economic development of the region while protecting the environmental stability. Natural resources management for the sustainable development has been a challenging task in the area due to poverty, marginality, inaccessibility and limited understanding of the environment of the region. Water is one of the most important natural resources which has critical impact on many aspects of development. Knowledge of the socioeconomic and natural processes is important to develop strategies to address the mountain specific problems in managing these resources.

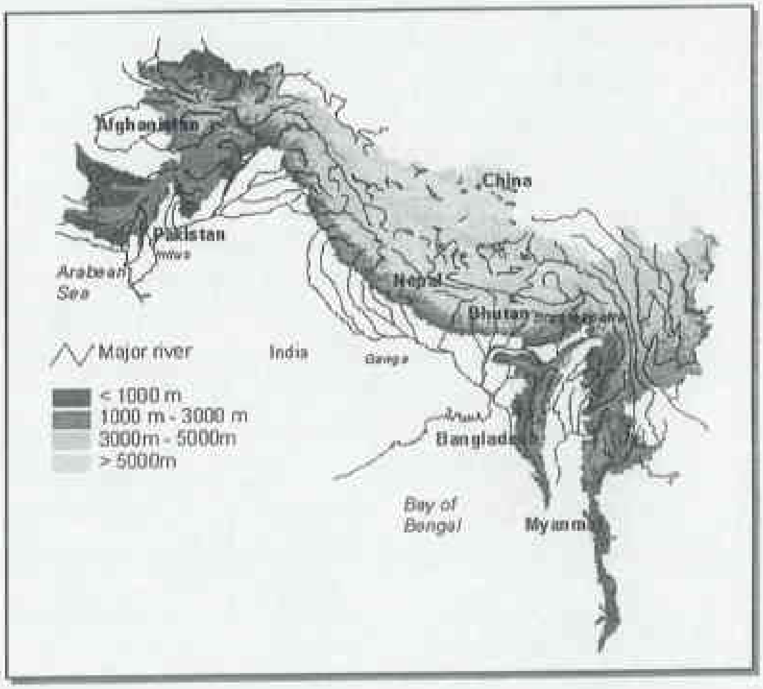


Figure 1-1 The Hindu Kush Himalayan region (source: ICIMOD/MENRIS)

With the advances in the information technology (IT), geographic information systems (GIS) have emerged as useful tools for decision making in sustainable development and natural resources management. The capability of these systems to integrate socioeconomic and biophysical data on a common and dynamic platform gives better visualization of the real world situations. However, the potential of GIS technologies are underused in the region due to isolated development of databases and absence of proper framework for information sharing. Substantial economic benefits can be achieved if greater sharing and better access to high quality spatial information can be assured. The concept of GeoInformation Infrastructure (GII) has been developed to address these issues. It is a *mechanism which facilitates access to and responsible use of geoinformation at affordable cost* [Groot, 97].

1.2 Problem definition

The Hindu Kush Himalayas are the largest storehouse of fresh water. They are the source of major river systems in the region. The extreme variability of climate and precipitation patterns, inadequate knowledge of the hydrology, and complex interrelationships with environment impose scientific and technical limitations in utilizing the potential benefits of the water resources. A thorough knowledge of water resources, of their different uses and evolution, and linkages with the surrounding environment is necessary for a better integrated and sustainable management. The information should be relevant and easy to access at the different levels. The major problems with the existing information are – the knowledge of resources and uses is insufficient, information is dispersed and heterogeneous, and the available information is not relevant enough regarding the continuity, reliability and nature of parameters [WWC, 98]. It has been realized that collecting data is relatively easy, but it is more difficult to assure data quality, integrate the data and convert information into knowledge that assists decision makers and managers [Schreier et. al, 97].

The whole economic activities of the people in the region are centered on their small mountain farms. The understanding of the processes involved in these farms at the micro level is critical for improving the living conditions of these people and the mountain environment. On the other hand, the practices of these small farmers can aggregate to pose challenges to the task of environment protection and resource management at a much larger scale. Therefore, there is a need to understand the implications and interrelationships of various processes involved in the management of water resources both at micro and macro levels. For the better understanding of these processes, they should be structured at each level. **The information requirements and the flow of information within a level and between different levels in these processes will provide a basis for data collection and data exchange framework.**

The efforts in data collection becomes inefficient and uneconomical due to differences in abstraction units, data contents, data collection methods, or lack of clear understanding between the data linkages between the different levels of hierarchy. Information as a resource needs to be managed for increased productivity. It is not only *how much*, but *what* information is necessary to support the functional processes of the business that effects the productivity. There is a need for a formal approach to provide a common ground in developing data models to resolve the heterogeneity in data and reuse them in different applications. The present practice of data collection and sharing on ad hoc basis is the main factor for inefficient use of GIS technology in the region. **The re-engineering of different processes in data collection, database design, operational processes in GIS application, and data sharing mechanisms is needed for a more economical and useful development of information base. The development of GII will facilitate the sharing, integration and use of spatial information across a broad set of potential users and the reengineering process will help in achieving the objectives of GII.** GII has become essential for the economic benefits from the past and for future investments on GIS, which are otherwise seen as a fad rather than a necessity by the decision makers.

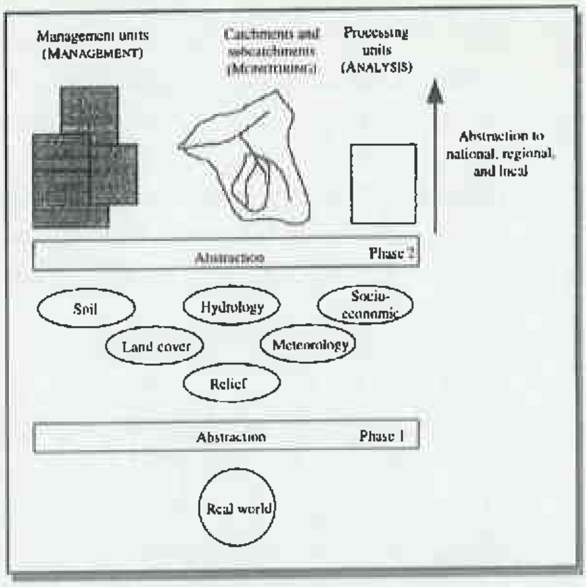


Figure 1-2 Abstraction of elementary objects at different levels of hierarchy [Bishr, 1997]

1.3 Objectives of the research

The main objective of the research is "*to develop a system architecture for geo-information infrastructure (GII) for water resources management in the Hindu Kush Himalayan region*".

The supporting objective of the research is –

- to identify the needs of reengineering in the processes of geoinformation generation and sharing to support GII

1.4 Research questions

- What are the problems in geoinformation generation and sharing in the region?
- What are the processes in water resources management and what are the needs of geoinformation for these processes?
- What are the needs for reengineering to improve the performance in use of geoinformation?
- What will be the system architecture for proposed GII and its components?

1.5 Prior Work

The need for integrated, scientific information on water resources of the mountainous areas has been realized for sustainable management strategies at local to regional scales [Bahadur, 98], [Bandhopadhyay et.al., 97], [Bandhopadhyay, 95], [WWC, 98]. The research on the dynamics of natural resources in the Nepalese watershed has identified water resources management as a critical issue for both agriculture and the people. [Schreier et.al. 97]. The research has also identified various issues in data collection and use of GIS for such applications.

Various research works on distributed database and multi level decision support systems are going on within and outside ITC. The findings of these works will be helpful as supporting tools in the design of a GII system architecture for the current research. The GeoWeb, the Delta-X and the Graz Distributed Server System (GDSS) projects have worked on different aspects of sharing geo-information in a distributed environment [Radwan et.al, 1998]. The OpenGIS Consortium is working towards the achievement of open and interoperable geoprocessing in a network environment. [Bishr, 97] defined a methodology for solving semantic heterogeneity in his Ph.D. work "Semantic aspects of interoperable GIS". [Radwan et. al., 96] worked on federated heterogeneous databases in multilevel decision support system. [Espinoza, 95] in his M.Sc. thesis worked on federated database system in a distributed environment for environmental decision making at different scales. [Nyabenge, 98] worked on developing a prototype multilevel decision support system for land use planning.

In the area of process modelling, [Weger, 98] presented an architectural approach to distributed systems development and its application to business processes in the Ph.D. thesis work "Structuring of Business Processes". [Pires, 94] provided design methods that allow to shorten the design gap between the formulation of the user requirements and the realization of the system in his Ph.D. thesis "Architectural Notes: a Framework for distributed Systems Development". [Morales, 98] worked on the M.Sc thesis "A Workflow Oriented design of "on-line" Geoinformation Services" using the architectural approach of modelling. [Sani, 98] used this approach in the M.Sc. thesis on "Dynamic Modelling in the Reengineering of Geoinformation Production Process".

1.6 Research Methodology

The International Centre for Integrated Mountain Development (ICIMOD), an international organization working for sustainable mountain development in the HKH, will be taken as a case for this study. The activities of the organization ranges from various issues on mountain natural resources and environment management to dissemination of GIS technology in the region. It is taken as a representative for the study of current practices in geoinformation generation and sharing in the region.

The research will be carried out in the following sequence.

1. Analysis of the existing situation

- Review the various activities related to water resources management and GIS technology at ICIMOD.
- Identify the performance problems in collection, sharing and use of geoinformation

2. Analyse the performance problems and improvement goals

- Carry out the strength, weakness, opportunity and threat (SWOT) of the organization to analyse the performance problems
- Identify the strategies for improvement in performance based on the SWOT analysis

3. Analyse the processes in Water Resources Management

- Define the objectives of water resources management at local and regional levels
- Define the processes in different applications of Water Resources Management
- Identify the information needs for these processes
- Develop process models using the architectural approach

4. Identify the needs for process re-engineering

- Set reengineering plans for data collection
- Set reengineering plans for sharing geoinformation

5. Design of the system architecture for GII

- Based on the findings, design a system architecture for GII and define its components. The system architecture defines the physical connections, locations and identification of key nodes and network to support the operational requirements of GII.

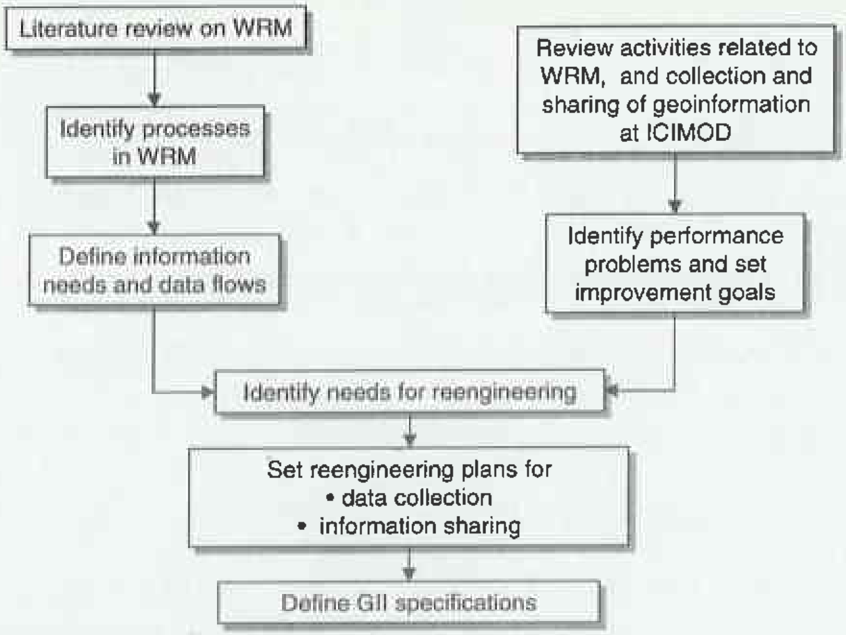


Figure 1-3. Research Methodology

1.7 Structure of the thesis

The research is presented in seven chapters. The *first chapter* presented the background of research, problem definition, objectives and research methodology. The analysis of the existing situation at ICIMOD is presented in *chapter two*. The activities related to water resources management are analysed. Similarly the ongoing activities related to geoinformation generation and the information sharing mechanism in the organization are studied and problems are discussed. *Chapter three* analyses the performance problems in detail using SWOT analysis, and the strategies for improvement are presented. Analysis and modelling of the processes in water resources management is done in *Chapter four*. The information needs in different applications of water resources management are identified taking the examples of irrigation and drinking water supply, soil erosion and conservation, land cover analysis, and estimation of regional water balance.

Chapter five presents the reengineering plans for improved information generation and sharing. *Chapter six* discusses the different components of GII. A system architecture for GII is presented based on architectural framework. *Chapter seven* concludes with findings and recommendations for further research.

2 Analysis of Existing Situation

2.1 Introduction

The context and need for the present research were presented in the previous chapter. This chapter studies the present activities in water resources management and use of geoinformation in the HKH region. The analysis of existing practices in acquisition and sharing of spatial data for water resources management is carried out taking the activities at the International Centre for Integrated Mountain Development (ICIMOD) as a case study. The role of ICIMOD in the endeavours of sustainable management of mountain natural resources and its efforts in the dissemination of GIS technology in region justifies its selection for this study. Section 2.2 begins with a brief introduction of the organization, its working environment and the organizational themes. Sections 2.3 and 2.4 deal with the ongoing activities related to water resources and GIS technology in the organization. Section 2.5 discusses the current practices in generating geoinformation and 2.6 shows the existing situation in the flow of geoinformation. The performance issues are dealt in section 2.7 with the concluding remarks in section 2.8.

2.2 The Organization

Mandate

ICIMOD is an international organization committed to promoting the development of an economically and environmentally sound mountain ecosystem and improving the quality of life of mountain people in the Hindu-Kush Himalayan (HKH) region. It was established in 1981 through the formal agreement between UNESCO and the government of Nepal, and subsequently joined by the seven countries of the HKH region, namely Afghanistan, Bangladesh, Bhutan, China, India, Myanmar and Pakistan, as the regional member countries. ICIMOD works mainly at the interface between research and development and acts as a *'knowledge bank'* on the HKH and a *facilitator for generating new mountain-specific knowledge*. It also attempts to ensure that new knowledge is shared among all relevant institutions, organizations, and individuals in the region [ICIMOD, 98].

Organizational structure

The organization is headed by the directorate consisting of the Director General, Director of Programmes and the Head of Administration and Finance. The organizational structure (figure 2-1) consists of three thematic divisions and three support divisions. The thematic divisions are - Mountain Farming Systems (MFS), Mountain Natural Resources (MNR) and Mountain Enterprises and Infrastructure (MEI) to look after the mountain specific problems in these related themes. MNR is working on natural resources such as forests, water, ranges, wildlife, and biodiversity, which are common property resources. MFS has a major component on technologies and management practices such as soil fertility and water management, and integrating indigenous knowledge in mountain agriculture. MEI is working on promotion of economically viable and sustainable infrastructure and services, and integrated area planning. The support divisions are - Mountain Environment and Natural Resources' Information Systems (MENRIS), Information Communications and Outreach (ICOD), and Administration Finance and Logistics (AFLS). MENRIS works as a resource centre for application and dissemination of GIS to integrated development and environmental management in the region. ICOD concentrates on outreach, information analysis and networking activities.

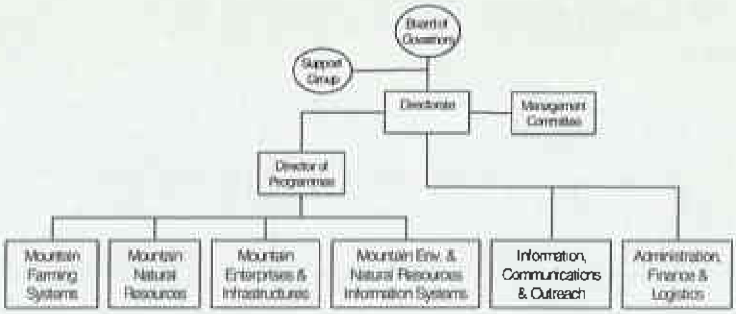


Figure 2-1 Organizational structure of ICIMOD [ICIMOD, 98]

The external environment

The ultimate beneficiaries of ICIMOD activities are the mountain households of the HKH. However, as an institution not directly involved in implementing development projects, it works through a network of appropriate local bodies. The local community based organizations (CBOs), non governmental organizations (NGOs), international non governmental organizations (INGOs), government agencies and academic institutions are its partners collaborating in its various activities. ICIMOD's programs are supported by donor agencies and governments. It also works in cooperation with multi lateral international organizations to achieve the common goals.

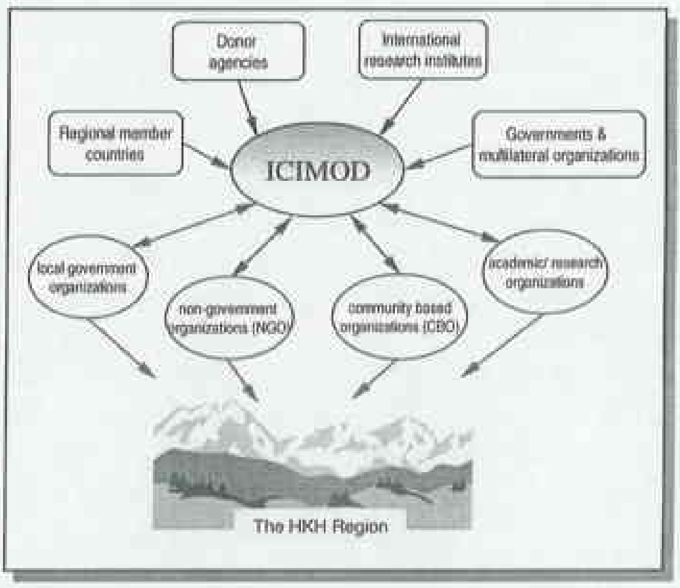


Figure 2-2 The external environment

Organizational themes

The activities of the organization are focused on five major themes on sustainable mountain development. They are:

- Promoting Sustainable Livelihoods for Mountain Households
- Gender Balanced Mountain Development
- Sustainable Management of the Mountain Commons
- Capacity Building of Mountain Development Organizations
- Information and Outreach

2.3 Activities related to Water Resources Management

With a long term goal to contribute to poverty alleviation and environmental stability in the HKH region, ICIMOD faces diverse challenges of mountain development. Water is one of the most important natural resources in the region which has close links with other development issues like agriculture, energy and women empowerment. ICIMOD's programme on water resources has been guided by the recommendations of 1992 Dublin Conference on Water and Environment [ICIMOD, 98] which state "*fresh water is a finite and vulnerable resource, water development and management should be based on a participatory approach, women play a central part in water management, and water should be recognized as an economic good.*"

ICIMOD's activities on water resources are focused on better understanding of the key factors influencing flow regimes, and potential for improvement in prevailing water harvesting systems. The activities related to water resources are discussed below.

Sustainable management of mountain commons

The activity on water resources under *sustainable management of mountain commons* emphasizes on better understanding the hydrology of the region. The main objectives of the programme are to provide comprehensive assessments of river flow regimes and local water harvesting and management systems in different climatological areas [ICIMOD, 98]. The programme includes major components on:

- Analysis of hydrological data to identify commonalities and differences in flow regimes of HKH rivers and streams
- Studies of upstream and downstream use of water resources and their implications for the future
- Linkages with various regional and international activities in harnessing mountain water resources
- Comprehensive reviews of local water-harvesting systems and conflict management

The HKH-FRIEND project

In collaboration with the United Nations Educational Scientific and Cultural Organization (UNESCO), the regional countries and the World Meteorological Organization (WMO), ICIMOD has launched a HKH Flow Regimes from International Experimental and Network Data (FRIEND) project to develop a regional research program. It is the secretariat and the regional database centre of HKH-FRIEND. It is expected to provide an active forum and institutional base for intensifying hydrological research through exchange and sharing of knowledge, experience and data among researchers in the region.

People and resource dynamics in mountain watersheds

ICIMOD's another activity on *people and resource dynamics in mountain watersheds* (PARDYP) is working on developing a comprehensive monitoring system in selected watersheds of the HKH for biophysical, geo-environmental, and socioeconomic processes. Mountain watersheds are being subjected to a variety of changes ranging from rapid extraction of resources to environmental impacts of different development interventions. Increasing siltation, runoff, flooding, acute water scarcity in dry seasons and degradation of forests and farmlands have become serious problems in most mountain watersheds. The major outputs of the activity are expected to be a comprehensive database and analysis of critical watershed variables and processes, assessment of the impact of human interactions over time in different ecological zones, and a better understanding of watershed dynamics, particularly upstream and downstream interactions.

2.4 Activities related to GIS technology

The rapid technological advancements in information technology have resulted in wide use of GIS as a major tool for decision support in the management of environment and natural resources. ICIMOD's activities on GIS and remote sensing (RS) are focussed on the following themes:

- Strengthening capacities of the national institutions of the regional countries for application of GIS and RS in natural resources management
- Development of HKH database and networking
- Promoting the sharing of geoinformation

Realizing the problems with ad hoc and isolated development of geographic databases in the past, ICIMOD has included the "*development of essential elements of a regional geographic information infrastructure (GII)* " as one of the activities in its second regional collaborative programme (RCP2) to work for more structured databases and facilitating their access and use. The main objective of this programme is to work towards a sound regional geographic information infrastructure with particular consideration to standardized regional datasets, and facilitation of exchange and development of mountain-specific application methodologies.

2.5 Current practices of GeoInformation generation

Establishment of a baseline information of the natural resources is the first requirement for the analysis of the key environmental processes. The various activities of ICIMOD include the generation of socioeconomic and natural resources databases. The activities of MNR division on *people and resource dynamics* involve detailed field data collection on land use, hydrology and meteorology in six mountain watersheds. MENRIS is working on the development of GIS databases on various scales [ICIMOD, 96]. It is developing and compiling the foundation databases which form a basis for various analyses in different disciplines. The databases at the regional level are compiled from various global data sources such as digital chart of the world (DCW), United Nations Environment Programme (UNEP) and Food and Agriculture Organization (FAO). The national level databases are created from topographic maps and other national sources. The district level databases are developed during the case studies conducted in collaboration with various national line agencies. Remote sensing data from different sources are used for its various case studies and project works. The databases being developed at MENRIS are based on different themes and application scales (Table 2-1). The methods adopted for creating databases are through field data collection, digitization of existing paper maps, and compiling spatial and non spatial digital data produced by other agencies.

Table 2-1 Databases in MENRIS (source: ICIMOD,96)

Topography	Settlements, contours, roads, drainage, geology, administrative boundaries
Thematic data	land use, land capability, land systems
Ecology	Vegetation, soil, climate, biodiversity
Socioeconomic data	Population, health, agriculture, education, inputs, products, resource stores

Applications	*Scale*
Regional levél analysis	1:1,000,000
Country level analysis	1:250,000
Provincial / district level analysis	1:50,000/25,000

Further reference to these will be made in chapter 6 to relate the proposed GII system to the current activities.

2.6 Flow of GeoInformation

The activities on water resources and geoinformation are focussed on creating a better understanding of the hydrology and the natural processes at the local and regional levels, and the development of necessary databases. These activities involve data collection from the field and other data sources for use in different applications. Besides its own case studies on application of GIS and RS, and the database development programme, MENRIS provides support to the thematic divisions for their needs in generation and analysis of geoinformation.

The flow of data between different divisions inside the organization and with the external users is shown in figure 2-3. Each division is involved in data collection activities for their specific applications. Requests are made to the MENRIS division for preparation or analysis of the spatial data. Some of the projects within the thematic divisions (e.g. PARDYP) have their own GIS setup.

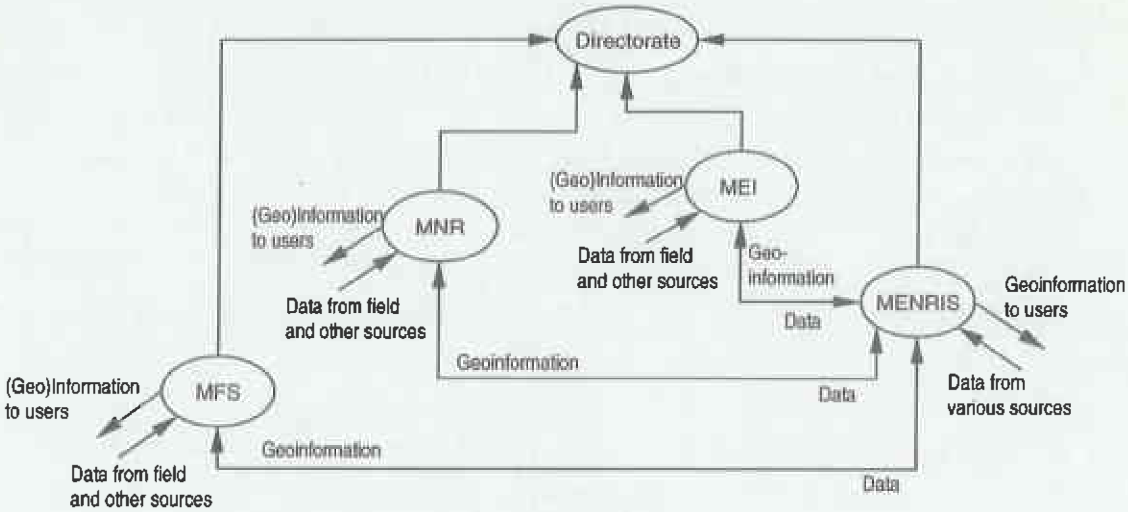


Figure 2-3 Existing data flow within and outside the organization

The dissemination of the data to the external users is done as per their request to each division and approval from the directorate. The user makes a request to the respective division directly or through the directorate and the data is released on a case by case basis.

The discussions in this section and the previous section show that there are a lot of activities focussed on creating spatial databases. The different divisions are involved in the data collection activities, on different themes and at different scale. However, a common framework for coordinating these activities is missing. Also, the sharing of geoinformation is done on an ad hoc basis, without a formal data sharing mechanism. As mentioned earlier, **the problems due to ad hoc and isolated database development and need for GII has been clearly stated in the second regional collaborative programme of the organization [ICIMOD, 98]. In this context, the present research will identify the necessary improvements in data collection and sharing practices in the organization for implementing GII. It will provide a framework to develop a system for GII.**

2.7 Performance issues

The above discussions show that the region is data scarce and most of the activities on water resources management are focussed on the development of databases to support the management process. It is evident that database development is a major component in most of the activities of the organization. Hence, the efficiency and economy in data collection, and reusability of the databases will enhance the performance of its activities. The availability of relevant data, accessibility to the available data, timeliness in data acquisition, and the quality of the data can be seen as performance indicators in these activities.

However, the data collection activities are carried out on individual project basis and there is a lack of sufficient integration and coordination in these activities. Due to the lack of data quality standards and data content specifications, there are problems in use of the data in different applications. Since a formal data sharing policy is missing, the information exchange process is rather ad hoc. Each division is involved in the dissemination of its own databases. There is a need for a mechanism to share the geoinformation among all the potential users in the region. The current activities on geoinformation show that there is an awareness for the need of coordination in database development and promotion of data exchange. However, clear programs to address these issues seems to be missing.

2.8 Conclusions

An introduction to ICIMOD and its various activities related to water resources and geoinformation are presented. From the review of the current practices on data collection and sharing, it is realized that there are performance problems. There is a need for reengineering in these activities for enhancing the performances. The development of GII will facilitate these activities with better flow and interoperability of the information. A detailed analysis of the performance problems and the strategies for improvement will be presented in the next chapter.

3 Performance problems and improvement goals

3.1 Introduction

The previous chapter came up with general performance problems through the analysis of existing practices in geoinformation generation and sharing. A detailed performance analysis is done in section 3.2 using the five forces model to identify the strengths, weaknesses, opportunities and threats of the organization. Section 3.3 discusses the major performance problems. The SWOT matrix is presented in section 3.4 and section 3.5 discusses the strategies identified. Sections 3.6 and 3.7 discuss why there are needs for reengineering and development of geoinformation infrastructure.

3.2 Performance analysis

The performance of any organization is dependent on the available resources, capacities and competence. There are external as well as internal factors that affect its competence. The external environment offers opportunities or threats to the organization whereas the strengths and weaknesses within the organization determine its ability to benefit from the opportunities and avoid the threats. Although the nature of ICIMOD, as a non profiting international organization, is quite different from business organizations, the analysis of its strengths, weaknesses, opportunities and threats (SWOT) will give an insight into the areas where it can exploit the opportunities and improve its performance. The analysis is done at three levels [Almeida, 96], the industry, location and the organization.

a. The industry

The industry is a group of organizations producing similar products or services. According to the five forces model by Michael Porter, the opportunities and threats from the industry in which the organization is included depend mainly on the following five forces,

- *Competition among the organizations in the same industry*

  In the present context, the existing international and national organizations working for the sustainable development in the region form this force.

- *Threat of new entrants*

  This force consists of the newly formed international or national organizations in the region, or the existing organizations which are extending their activities in the region.

Table 3-1. Five forces analysis

Five Forces	Constituents of the force	Status of the organization [*]	Opportunity/ Threat
Competition among the organizations in the same industry	▪ Existing international and national organizations working for the sustainable mountain development	1. A unique international institution with mandate in diverse issues of mountain development in the HKH	(O)
Threat from new entrants	▪ New international and national organizations working for the sustainable mountain development ▪ New organizations which provide consulting services in similar themes	2. There is a willingness among other international organizations to work in partnership to achieve common goals 3. The organization has a strategy to build the capacity of national institutes and work in collaboration	(O) (O)
Threat from substitute products/ services	▪ Research findings by research and development agencies ▪ Value added Geo-Information products by NMAs and private organizations ▪ Training programmes by different organizations on related themes ▪ Consultation services by other organizations	4. Value added products, knowledge – the organization has a strategy of repackaging the knowledge and information generated by others to come up with a mountain specific solutions in the HKH 5. The organization provides specialized trainings related to various sustainable development issues 6. The organization provides consultation services on specific topics, but there are possibilities of other organizations providing similar services	(O) (O) (T)
Suppliers	▪ International and regional funding agencies ▪ Colleges, universities, and various research and development organizations in a number of countries ▪ National mapping agencies and line agencies producing thematic databases	7. The organization's activities are dependent on donor support 8. The sources of knowledge/ data are limited 9. The sources are not well coordinated	(T) (T) (T)
Buyers /Clientele	▪ Multi lateral and regional development organizations, government, non-government, community-based organizations, and the private sector	10.The clients are many and diverse 11.Expectation of high quality services from the donors agencies, governments, and the clients	(O) (T)

[*] The numbers in this column are used for reference in discussions on performance problems.

- *Threat of substitute products or services*

  The substitute products and services include the research and development activities, value added geoinformation products, training and consultation services by other organizations on similar themes.

- *Bargaining power of the suppliers*

  The major suppliers are academic and research institutes, national mapping agencies (NMA) and line agencies producing the basic and thematic databases.

- *Bargaining power of the buyers*

  The buyers or the clientele include the government and non-government organizations, community based organizations, and multi lateral organizations which use the products and services from ICIMOD.

A strong force indicates threat whereas weak force indicates opportunities for the organization. The five forces against the status of the organization is given in table 3-1.

b. The location

The environment of the geographic location where the organization operates also determines the opportunities and threats to the organization. The four determinants are –

- Firm strategy, structure and rivalry
- Related and supporting industries
- Factor condition
- Demand condition

The more demanding and the higher the quality of the above determinants, the bigger is the contribution to the competitive advantage of the organization's location in that area. The status of the organization regarding these determinants is given in table 3-2. Each issue presents an opportunity or a threat to the organization.

Table 3-2 Location analysis

Factor	Status of the organization*	Opportunity/ threat
Firm strategy, structure and rivalry	12. Numerous issues on mountain development in HKH where it can use its expertise	(O)
	13. Difficult working environment in the mandate area (mountainous region)	(T)
Related and supporting industries	14. Lack of sufficient coordination among the institutions in the region	(T)
	15. Lack of sufficient infrastructure in the region to support the information technology	(T)
	16. Unavailability of sufficient and reliable databases	(T)
	17. There are no data sharing policies in the region	(T)
	18. Data standards are lacking	(T)
Factor condition	19. The workforce is hired from among international and national experts	(O)
	20. The major funding agencies are the multi lateral agencies and governments outside the region	(O)
Demand condition	21. Increasing awareness for the use of GIS and remote sensing technology in environment and natural resources management projects	(O)
	22. Increasing use of information technology in the region	(O)

c. Resources, capacities and strategies

The analysis of the organization takes into account the strong and weak points in its resources, capacities and strategies. The resources include the human resources, information technology and information resources. The strategies of the organization at corporate, business and functional levels determine the strengths and weaknesses of the organization. The status of the organization related to these factors is given in table 3-3. Each issue is taken as a strength or a weakness of the organization.

* The numbers in this column are used for reference in discussions on performance problems.

Table 3-3 Resources, capacities and strategies

Factor	Status of the organization*	Strength/ Weakness
Resources	23. Highly experienced multi disciplinary technical staff	(S)
	24. Extensive network of partner institutions	(S)
	25. Latest technical facilities in Information Technology	(S)
	26. Good support from the donors	(S)
	27. Lack of databases	(W)
Capacities	28. Influential in policy matters	(S)
	29. Lack of sufficient integration in activities	(W)
Strategies	30. Application oriented research programs	(S)
	31. Function oriented divisional activities	(W)
	32. Difficulty in measurement of success in its activities	(W)
	33. Difficulty in continuity for support to the programs initiated in collaboration with other organizations	(W)
	34. Lack of cost recovery mechanism in the programs	(W)
	35. Lack of a structured data sharing mechanism	(W)

3.3 Performance problems

The above tables listed the strengths and weaknesses within the organization and the opportunities and threats in the environment. They indicate several issues which cause problems in the performance of the organization. They are discussed below.

3.3.1 Lack of sufficient integration in activities

The organization aims at addressing diverse issues related to mountain development (refer to 1 in SWOT tables). These issues on natural resources management cut across a wide range of disciplines. Proper understanding of the processes involved in the management of different resources is needed for an integrated and coordinated approach in dealing with these issues. The activities on database development are being carried out on project basis with low focus on generic uses of data which have often necessitated duplication of efforts (ref 9, 13, 16, 31). There is a need for a focus on user/ discipline requirements so that the use of data can optimized. The field level data collection and the regional database development programmes need to be designed such that the information can be generated at different levels of aggregation for its use in decision making at the desired level.

Again due to lack of data and clear understanding of the processes in the region (ref 13, 16), there are difficulties for linkages in activities at micro and macro levels. There is a need for multi level decision support system (MLDSS) to support the needs for decision making at different levels and provide integrity in these activities.

* The numbers in this column are used for reference in discussions on performance problems.

3.3.2 Lack of data

The data on HKH region is scarce due to its difficult topography and backwardness in overall development. The lack of consistent and reliable foundation database has been the major hindrance in the development of spatial database on different themes (ref 13, 14, 16, 17). The Mapping Science Committee (MSC) has defined the foundation spatial data as *the minimal directly observable or recordable data from which other spatial data are referenced and compiled* [NRC, 95]. It has recommended the geodetic control, ortho-rectified imagery and the digital terrain (DTM) as the critical foundation data. The complexity of the mountainous areas is due to high spatial variability of altitude resulting into high differences in climate, vegetation and other natural features within short distances. The unavailability DTM has been a major drawback in the application of GIS in the mountainous region. As the spatial data available in the region are in analogue form, application of GIS in most cases has to start from digitization of paper maps (ref 15). Although there is a tendency for gradual shift to digital technology by the national mapping agencies, the data are not yet available in the digital format in the region [Survey Dept., 98]. In the context of water resources data, due to difficult access, sparse settlements with limited services and harsh environment, the density of hydrological observation network in the area is low where there is higher spatial variation and more stations are needed for better understanding of hydrology [Kundzewicz et. al, 96].

3.3.3 Lack of quality standards

Quality of the data is important in GIS applications for the validity of inferences from different analyses (ref 11). However, quality assurance has been a difficult task as the data are compiled from different paper maps, often in different scales, projection systems, and produced in different years (ref 9, 14, 16). The present attitude of *making best use of what is available* may not work in the long run as the use of spatial data grows and the applications are targeted to solve the real problems rather than to demonstrate the capabilities of GIS technology.

3.3.4 Lack of coordination in data generation and sharing

There is a growing awareness and use of GIS in the region. There has been a rapid adoption of computers and GIS technology by many organizations without proper and sufficient capacity building (ref 21, 22). However, the transfer of technology should be seen as a multidimensional process which involves selection, acquisition and appropriate adoption in the context of political, cultural, social and economical conditions of the receiving society [Groot et.al., 94]. The investments in the technology have not returned the expected outputs due to lack of the necessary data and favorable environment for data exchange.

The development of spatial databases in the region have been isolated and on ad hoc basis. The knowledge about existing databases such as what data exists, who has those data, and whether and how they are available, is necessary for widespread sharing of the data. The existing data are not being used due to the lack of information on their availability and contents (ref 16). A *metadata* of the existing geoinformation has been realized as an urgent need to facilitate the information sharing.

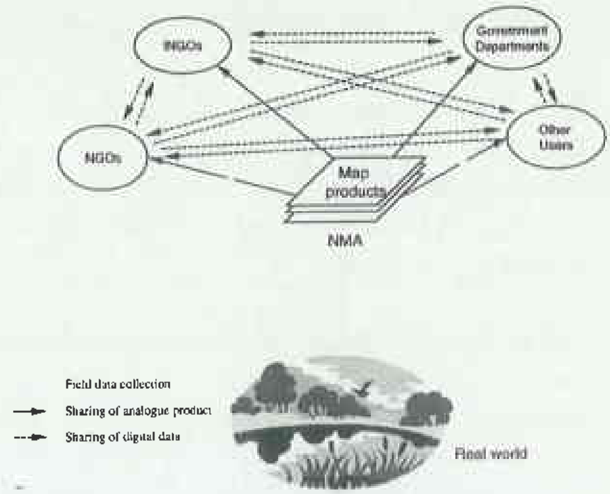


Figure 3-1 Present scenario of data sharing

Lack of data sharing policy

The policy on exchange or sale of digital data is yet to be formulated in the region (ref 17). The information on geodetic references and topographic information are often restricted. Awareness on the benefits of data sharing and formulation of policies to facilitate such information exchange is needed among the policy makers, users and producers of data.

Lack of standards

Different biophysical and socioeconomic data are collected according to a logical classification system. Creating databases which are useful to a large user group is possible only if certain standards exist which are accepted by the users. *The relevant standards are those that govern the processes and procedures and also standard datasets that provide a definitive description of particular phenomena* [Nanson et. al., 95]. The standards include methods of referring to objects, describing data content and quality, data models and data transfer formats. No standards have yet been developed in the region for classification systems of themes like land cover, land use, soil and biodiversity, or on the matters of data quality, contents and transfer (ref 18).

Lack of data sharing mechanism

There are no formal networks for the national or regional data sharing. The data is provided by a particular organization which holds the data to the user as per the request. The process often requires a lot of administrative procedures which are different in different organizations and for different users (ref 17, 35).

3.3.5 Lack of cost recovery mechanism

The activities of the organization do not have cost recovery mechanisms which are important for the sustainability of the programmes (ref 7, 34). There are difficulties in continuing the activities when long term donor support is not available. The same is true in the activities concerning the dissemination of GIS technology, and geoinformation generation and sharing.

The pricing of digital data is complicated as there are no guiding policies in the region. The national mapping agencies have been financed by the government funds and the present prices of products are heavily subsidized [Survey Dept., 98]. ICIMOD has been charging data handling and material costs for the digital data on a case by case basis. Data is provided free to government institutions and academic purposes. A reasonable pricing policy suitable to the socioeconomic and political conditions of the region is needed to facilitate the use of data by the potential users as well as to sustain the data sharing activities.

3.4 The SWOT Analysis

The SWOT analysis is used to analyse the current business situation and delineate areas for improvement and changes. Threats and Opportunities are the results imposed on the organization by the external environment whereas Strengths and Weaknesses are internal to the organization. Based on parallel analysis of Opportunities and Threats on one hand and Strengths and Weaknesses on the other, a SWOT matrix provides a breakdown of possible initiatives or actions that will allow the organization to achieve its stated strategic goals.

Constraints		**External environment**	
		Opportunities (O)	**Threats (T)**
Internal environment	**Strengths (S)**	Set of actions to make use of the strengths and take advantages of opportunities	Set of actions to use the strengths to counter the threats
	Weaknesses (W)	Set of actions to minimise weaknesses and make use of opportunities	Set of actions to remove weaknesses in front of threats

Table 3-4 SWOT Analysis

		Opportunities	Threats
		▪ A unique international institution with mandate in diverse issues of mountain development in the HKH ▪ There is a willingness among other international organizations to work in partnership to achieve common goals ▪ The organization has a strategy to build the capacity of national institutes ▪ The organization has a strategy of repackaging the knowledge and information generated by others to come up with a mountain specific solutions in the HKH (value added) ▪ The organization provides specialized trainings related to various sustainable development issues ▪ The clients are many and diverse ▪ Numerous issues on mountain development where it can use its expertise ▪ The workforce is hired from among international and national experts ▪ The major funding agencies are the multi lateral agencies and governments outside the region ▪ Increasing awareness for the use of GIS/ RS technology in environment and natural resources management ▪ Increasing use of information technology in the region	▪ Possibilities of other organizations providing similar consultation services ▪ Organization's activities are dependent on donor support ▪ The sources of knowledge/ data are limited ▪ The sources are not well coordinated ▪ Expectation of high quality services from the donors agencies and the governments ▪ Difficult working conditions in the mandate area (mountainous region) ▪ Lack of sufficient coordination among the institutions in the region ▪ Lack of infrastructure in the region to support the information technology ▪ Unavailability of sufficient and reliable databases There are no data sharing policies in the region ▪ Data standards are lacking
Strength	▪ Highly experienced multi disciplinary technical staff ▪ Extensive network of partner institutions ▪ Latest technical facilities in Information Technology ▪ Good support from the donors ▪ Influential in policy matters ▪ Application oriented research programs	▪ Exploit the multidisciplinary expertise for integrated approach to sustainable development ▪ Exploit the available IT facilities for value added products, capacity building and specialized training	▪ Formulate policies for data sharing ▪ Develop mechanisms for data integration ▪ Incorporate quality issues ▪ Use the potentials of IT in communications, coordination and data sharing
Weakness	▪ Lack of databases ▪ Lack of sufficient integration in activities ▪ Function oriented divisional activities ▪ Difficulty in measurement of success in its activities ▪ Difficulty in continuity of programs ▪ Lack of cost recovery mechanism in the programs ▪ Lack of a structured data sharing mechanism	▪ Utilize partnerships with collaborating organizations for data generation and sharing ▪ Work on better understanding of processes for integration of different activities ▪ Include quantifiable indicators in its activities ▪ Include cost recovery mechanisms for sustainability of activities	▪ Work in collaboration with NMAs for creation of foundation database ▪ Develop data sharing policies in collaboration with national line agencies

3.5 Improvement strategies

From the SWOT analysis (table 3-4), various strategies have been identified to improve the performance.

To make use of the strengths and take advantages of opportunities (Strength/ Opportunities)

- Exploit the multidisciplinary expertise within the organization for integrated approach to diverse issues on sustainable development
- Exploit the potentials of IT facilities for generating value added products, capacity building of the partner institutions and conduct specialized training

Minimise weaknesses and make use of opportunities (Weakness/ Opportunities)

- Utilize the partnerships with collaborating organizations for generation and sharing of geoinformation
- Work on better understanding of processes for integration of different activities
- Include quantifiable indicators in the programme activities for monitoring the performance
- Include cost recovery mechanisms for sustainability of activities

Use the strengths to counter the threats (Strength/ Threats)

- Use the potentials of available IT in communications, coordination and data sharing
- Work with NMAs and national line agencies to formulate policies for data sharing
- Develop mechanisms such as data quality, transfer standards for data integration from different sources
- Incorporate quality components in its activities of geoinformation generation

Remove weaknesses in front of threats (Weakness/ Threats)

- Work in collaboration with NMAs for creation of foundation database
- Develop data sharing policies in collaboration with national line agencies

3.6 Strategies for improvement

The list of strategies in section 3.5 provides a framework for setting the improvement goals. The strategies are interrelated and some of them deal with long term processes which need interactions with the external environment. The strategies which are more urgent and are related more to the internal activities are discussed here.

a) Integration of multidisciplinary expertise

The organization has a strong position of having international experts in different disciplines. There is a need for integrating its multidisciplinary expertise to deal with these interrelated problems. There should be a shift from function oriented approach to process oriented approach in its activities so that better horizontal linkages are possible among the different divisions. A thorough analysis of different processes is needed to identify the redundant processes and reengineer them for performance improvement.

The activities of the organization involve studies both at the local and regional scales. There are difficulties in the vertical linkages of these studies. The issues involve multiple disciplines, different interest groups and many decision alternatives which are spatially variable. Decision making in natural resources and environmental management involves different processes at multiple scales. There are set of objectives, resources and constraints at each level. Each level has its own set of priorities and scope of decision making. The interrelation between decision making at different levels in watershed management is shown in figure 3-2 from a study conducted by [Radwan et.al. 96]. At the *national level*, decisions concerning the guidelines and constraints for an environmental project are defined for the whole country. Decisions are taken based on the information from the regional level information. Political factors play a strong role at this level of decision making. The *regional level* decisions mostly deal with identifying the proper combination of management scenarios. At the *local level*, scenarios with highest priority are implemented. The results and impacts are used to provide feedback to the regional level. There is an extensive flow of information and decision between these different levels of hierarchy.

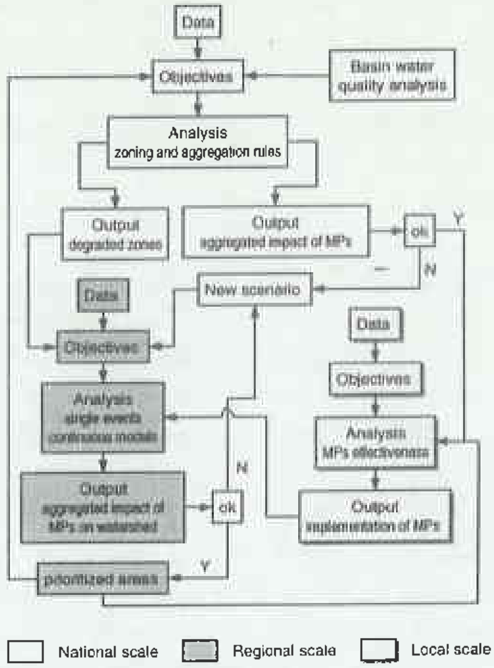


Figure 3-2 Interrelations between different levels [Radwan et. al. 96]

With the growing use of GIS in the organization, it should take advantage of the developments in the field of multi level spatial decision support systems (MLSDSS). Spatial decision support systems (SDSS) are interactive, computer based systems designed to support users in achieving higher effectiveness of decision making while solving semi structured spatial decision problems [Malczewski, 97]. The SDSS has three components – dialogue, data and modeling (figure 3-3). The database management system (DBMS) contains the functions to manage spatial and non spatial database, whereas the model base management system (MBMS) provides the decision models. The dialogue generation management system (DGMS) manages the interface with the user and rest of the system.

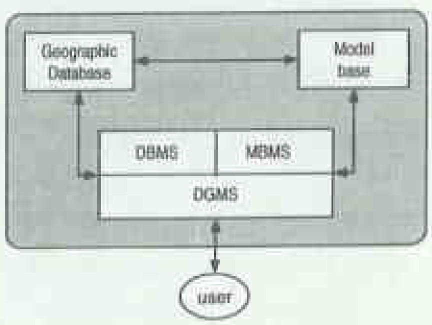


Figure 3-3 Components of SDSS (Malczewski, 97)

With the existing expertise on the thematic disciplines and information science, there should be efforts to develop such MLSDSS for mountain specific applications such as water resources management to deal with decision problems at different levels. The development of MLSDSS will demand for development of data models and model bases.

b) Exploit the available facilities on Information Technology

The organization is well equipped with the latest IT facilities and has been working in capacity building of its partner institutions through training programmes and provision of hardware and software for GIS. There is a growing user group of geoinformation technology in the region. The organization should exploit its existing hardware/ software and Internet facilities for the production of value added products and facilitating efficient exchange of geoinformation.

The development of new technologies in data acquisition such as *digital photogrammetry*, *automatic feature extraction* techniques, *laser scanning* should be explored for faster data acquisition since the scarcity of foundation data is a major problem in the region. Due to difficult access to the mountainous area, *high resolution and multispectral remote sensing techniques* can prove very useful in the region for assessing and monitoring the natural resources.

The developments in *client server* technology, *distributed computing* and *networking* have opened new opportunities for the organization of this nature where the collaborating institutes are geographically distributed. The historic development of the *Internet* technology has offered better opportunities for communication and networking. Internet provides a big potential for efficient and effective ways in obtaining, using and sharing geographic information [Plewe, 97]. The organization has already started using the Internet in its efforts of networking and facilitating information sharing, such as the formation of the NepalNet and the Mountain Forum, the electronic networks which offer a venue for global linkage of individuals and organizations concerned with mountain cultures, environment and sustainable development. These networks are used for conducting electronic conferences, sharing the views, and exchange of information on various issues. However, the use of the Internet for sharing of spatial data has not been started yet. With the new developments in *Internet GIS*, there are possibilities of disseminating data as well as GIS functionality to the users. The organization should initiate automation of the geoinformation sharing process through the use of these enabling technologies.

The development of dispersed and heterogeneous databases is one of the limiting factor for use of GIS in the region. The organization can benefit well from the developments by the *Open GIS* Consortium which is working on interoperability issues to enable sharing of data and resources between different users or applications. Details on related technologies are given in Annex 1.

c) Partnerships with collaborating organizations

Most of the activities of the organization are carried out in collaboration with different national institutions. These institutions are working on different themes of environment and natural resources management in the different countries of the region. The good relationships with these institutions, which are working in different political and organizational setups, should be utilized on building a framework for developing standards for data collection and sharing. The institutions can contribute in collection of data in their respective themes and locations which can be aggregated into a seamless regional database if the standards are agreed upon and the activities are well coordinated.

3.7 Need for reengineering

The above discussions identified different strategies for improving the performance. The strategy for integrating multidisciplinary activities demands more focus on processes. The need for coordination in data collection activities and sharing of the data by different applications requires agreement on data models and processes for better interoperability and reuse of the data. Involvement of expertise from different disciplines is necessary for the development of data base and model base for developing MLSDSS. Reengineering in the current practices will be needed to achieve the desired integration.

Another strategy of exploiting the potentials of IT will introduce new processes in data acquisition and new services for disseminating information. This will demand for new quality standards and pricing strategies. The adoption of new technology and automation requires reengineering in the processes.

Collaboration with the partner institutes in the region has been the main strategy of the organization in implementing its various programmes. The present relationships with these organizations can be extended in the field of data collection, developing standards, and networking for data sharing with the development of local clearinghouses. This will demand more active involvement by these institutes and a greater sharing of responsibilities. The reengineering needed for this will be more at the strategic level.

3.8 Need of GeoInformation Infrastructure (GII)

Lack of databases, and insufficient coordination and integration in geoinformation generation and sharing are identified as the major hindrances in the performance of the organization. The discussion in section 2.4 show that the need for GII has been realized by the organization for the benefit from different activities on database development for various disciplines within and outside the organization. GII is defined as "the system of sources, network linkages of computer systems, standards and protocols, as well as legal and regulatory elements aimed at facilitating access and use of spatially related data from many different sources to the widest possible group of potential users at affordable costs/ prices" [Groot, 98]. GII is needed to improve access, sharing, integration and use of geoinformation, to support decision making at different levels [Paresi, 98]. GII provides a platform to develop information policies, and institutional, technical and economical arrangements to enhance the availability for correct, up to date and integrated geoinformation.

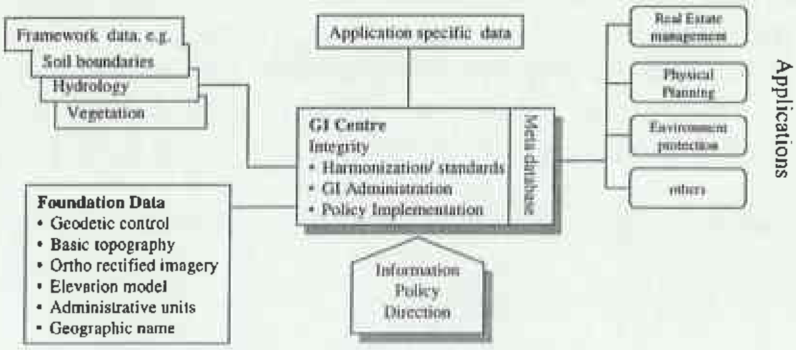


Figure 3-4 Structure of GII (Groot, 97)

With *"information and outreach"* as one of its basic themes, GII is essential for the organization to support the information flows between different thematic divisions within the organization and with diverse institutions within and outside the region. GII is important for the development and successful implementation of MLSDSS as it facilitates the resource discovery and sharing of knowledge and information at different levels.

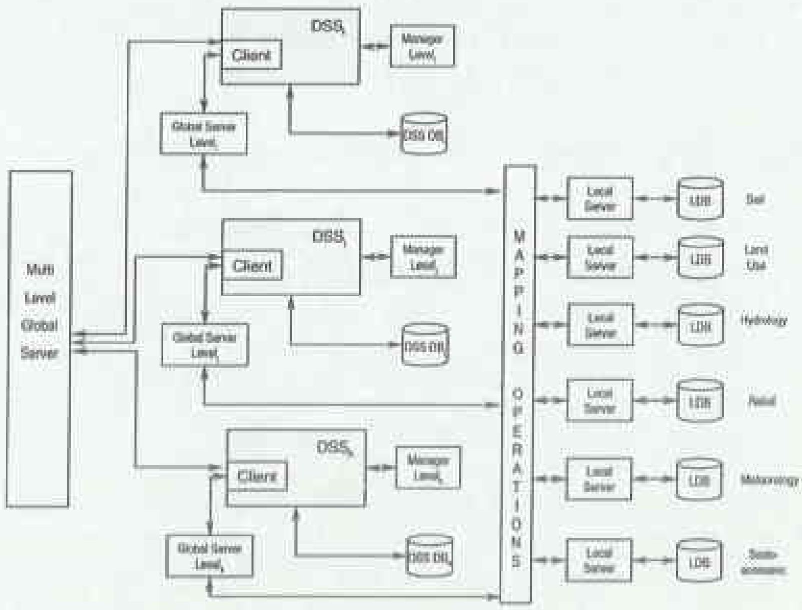


Figure 3-5 Architecture of a MLDSS (Radwan et.al., 96)

Figure 3-5 presents an architecture of MLSDSS developed by [Radwan et. al. 96] showing the information sharing between different levels of decision making. The architecture is based on the assumption that each decision level has its own SDSS. The two types of databases are distinguished. The basic database forms the lowest level of aggregation hierarchies for each decision level and is required by all levels of decision making. A dedicated server is provided for transferring these basic data. The second type of database, called SDSS database supports the underlying decision support system at each level. A multi level global server is provided in order to resolve the heterogeneity between the different SDSS databases.

The *local server* contains sharable data of each participating basic database. The sharable data is supported by a metadata. The role of the local server is to put at the disposal of clients a common object oriented interface on top of the local DBMS. It is responsible for accessing and retrieving data as requested by the client through the global server. These databases contain the core information needed by various applications in the organization. However, the sources of these databases can be resident in other institutions and shared by the organization.

The global server has a global external schema which provides a mechanism for resolving the different aspects of heterogeneity. Each level of decision making is provided with a global server which supports all users at their underlying level. At each level, the global server links its client with the local server. The global server controls the transactions with clients and data sources, maintains a global directory and execute data conversions. The *multi level server* links the different decision making hierarchies to establish the corresponding feedback between the three decision levels in terms of data, knowledge, and decision necessary for their activities. It controls the communication between clients and access and retrieval from the corresponding DSS database in a specific level. Such databases contain mission specific data collected specially for the applications under consideration. The concept of this architecture will be used later in this study for the design of MLDSS.

3.9 Conclusion

This chapter presented the analysis of the organization in the context of external and internal environments and came up with strategies for improving the performance. The strategies indicated the requirements of reengineering to improve performance and exploit the potentials of emerging technology. The need for GII and MLDSS was discussed to support the information needs in decision making. However, the reengineering task needs the understanding of different processes and their relationships. Chapter 4 will be dedicated in studying the different processes involved in a multidisciplinary activity like water resources management, followed by reengineering plans in chapter 5. Chapter 6 will discuss the specifications of GII for the performance improvement of the organization.

4 Processes in Water Resources Management

4.1 Introduction

The previous chapter identified the need of reengineering for the integration of multidisciplinary activities. Water resources management is such an activity which demands the integration of different disciplines and at different scales. This requires the understanding of the processes involved. This chapter presents the general principles of water resources management and the various processes involved. Section 4.2 gives general introduction to water resources management and section 4.3 discusses the management objectives in the context of the HKH region. The management processes are explained in section 4.4 taking the examples of irrigation and drinking water supply, soil erosion and conservation, land use and land cover dynamics, and the estimation of regional water balance. The process models are presented in section 4.5.

4.2 Water Resources Management

Water plays an important role in the economic growth and improved quality of life. Although the Hindu Kush Himalayas are the largest storehouse of fresh water, availability of sufficient amount of water where and when needed is a major problem in the region. The problem is due to the natural phenomenon that 80 percent of the annual supply appears in 20 percent of time during the summer monsoon. Water resources management represents attempts to control water as it passes through its natural cycle for the social, economic and environmental benefits. *Water resources management is the application of structural and non-structural measures to control natural and man made water resources systems for beneficial human and environmental purposes* [Grigg, '96]. It is a complex system which needs intensive participation and integration of various disciplines in the decision making process. It requires combined efforts of professionals from large range of disciplines such as economists,

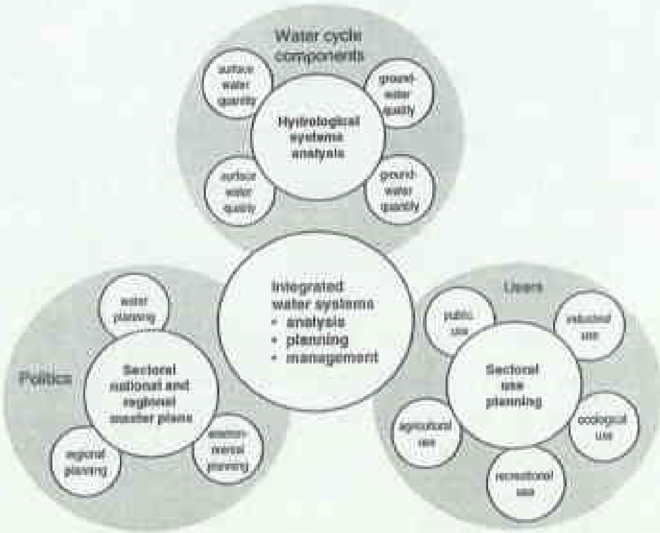


Figure 4-1 Integrated approach in the analysis, planning and management of water systems [Engelen et.al., 96]

engineers, hydrologist and ecologists as well as a cross sectoral integration in the planning and management process [Refsgaard et. al, '96].

The components of water resources management can be distinguished as the user component, water cycle component and the political component [Engelen et.al., 96]. The user component represents the use of water for various purposes such as domestic use, agriculture, aquaculture, industry, nature and landscape conservation, recreation and flood control. They describe the management requirements. The water cycle component represents the various natural water supplies with their physical, chemical and biological characteristics. They provide the potential sources to meet the user demands. The policy component represents the technical and management measures. They form the measures to balance the demands and supplies. The selection of the measures and handling of these selected measures form the basis for decision making in the management process. These measures try to affect either the demands through information, permits, regulations and price policies or the supplies by construction of technical works or operation rules. Water resources planning and management is needed at different levels and for different objectives. The user requirements, the political priorities and the natural hydrological systems all have different characteristics depending upon their level of hierarchy.

4.2.1 Hierarchy in water resources management

A large scale water resources management system can be seen as a hierarchical multilevel system. The overall system can be considered to be built up from a number of subsystems and there is mutual dependence between the levels. However, water resources management as a complex system has many viewpoints [Grigg, '96]. The different viewpoints have different meanings of hierarchy.

The *political viewpoint* can be seen as the organizational setup for water resources management. There are local, federal and state government agencies which form hierarchical layers in the process of planning and decision making.

The *sectoral viewpoint* is focussed on purpose or function of water management such as drinking water supply, irrigation or waste water management. There are hierarchies in the management of each sector. However, the integrated water resources management cut across these sectors at each level of hierarchy. For example, the same stream in a village provides water for irrigation and drinking purposes, which are looked after by different agencies.

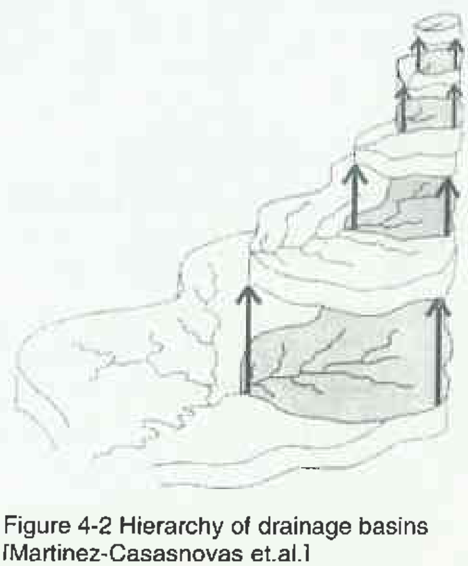


Figure 4-2 Hierarchy of drainage basins [Martinez-Casasnovas et.al.]

The *geographical viewpoint* refers to scale and accounting units such as river basins and watersheds. A watershed can be viewed as a natural unit of the landscape in which nested sub-watersheds form a hierarchy of biophysical units that can be separated and analysed as unique input-output systems [EFC, 98]. A watershed approach is being adopted to provide the coordination and integration needed to address the overlapping functions in water resources programs. Watersheds can be scaled to different sizes to address different magnitude scenarios. Although the watershed boundaries seldom coincide with administrative boundaries, watersheds as the natural units provide a better framework for data collection and analysis, and compel the managers to focus on the system as a whole.

4.3 Water resources management objectives

The objectives of water resources management is to fulfil the water needs for variety of activities which are essential for the existence and development of the human society (Figure 4-3) [after Singh, '95]. However, the water needs for all the activities can not be met due to various natural and socio-economic constraints. The management policy has to be developed for prioritizing the water use. The economy, environmental impact, ecological and health considerations and socio-cultural aspects form the basis for formulating the objectives and management policies.

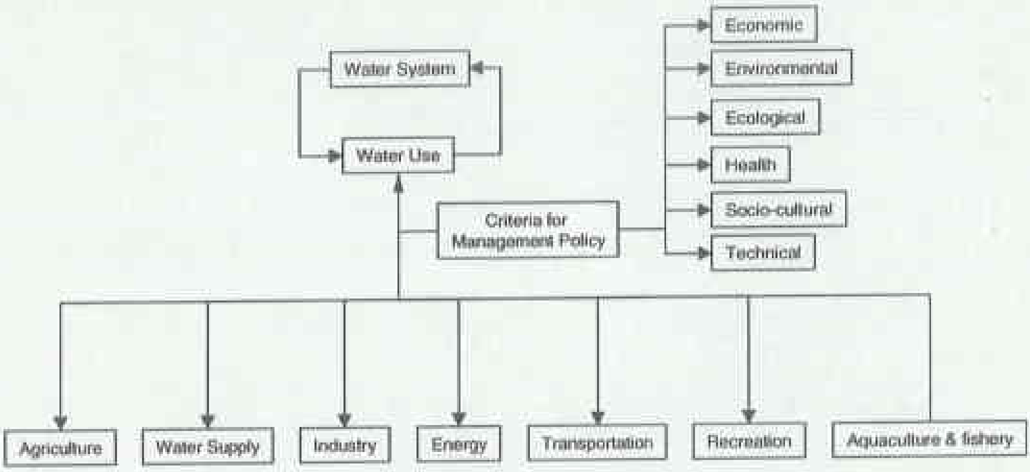


Figure 4-3 Water use and criteria for management policy [adapted from Singh, '95]

4.3.1 Water resources management at the local level

The objectives of water resources management are influenced by the needs of the people, and the economic, environmental and technical factors. In the HKH region, and particularly in the context of Nepal, the natural resources and the social, cultural and economic activities of the people are dependent on the physiographic conditions of the area. Nepal is divided into five physiographic regions (figure 4-4) - the *Terai* with flat and fertile lands below 300m, *Siwalik* with low river valleys and dense forest between 300 and 700m, *Middle mountains* with green forests and steep slopes leading to fertile valleys between 700 and 2000m, the *High mountains* with bush type green forests and steep slopes within 2000 and 2500m, and the *High Himalayas* with altitude greater than 2500m [ICIMOD, 96]. All the areas except the southern Terai belt are characterized by steep slopes and terrace farms.

The mountain communities have been adopting diverse strategies and systems for water management to meet their year round needs. Their economy is largely dependent on agriculture. The major priority of water management in these areas is to get sufficient amount of water during the time of cultivation. Hill irrigation systems form an important basis for the economic development of these areas. Traditionally, farmer communities have been involved in the development, operation and maintenance of irrigation systems [Pradhan et.al.,90]. These indigenous systems are constructed using local technologies and managed to a large extent by the beneficiaries.

Another priority in the mountain areas is drinking water where people have to walk for hours to fetch water for household needs. Community water supply systems to reduce this hardship are being constructed with the involvement of government agencies and INGOs. Apart from the social benefits, these systems have economic benefits as the people can utilize the time and labour saved to other economic activities.

Due to high slope and thin soil cover in the mountains, soil erosion during the rainy season is a major problem for sustainable mountain farming. Erosion control is another important objective of water management at the local level.

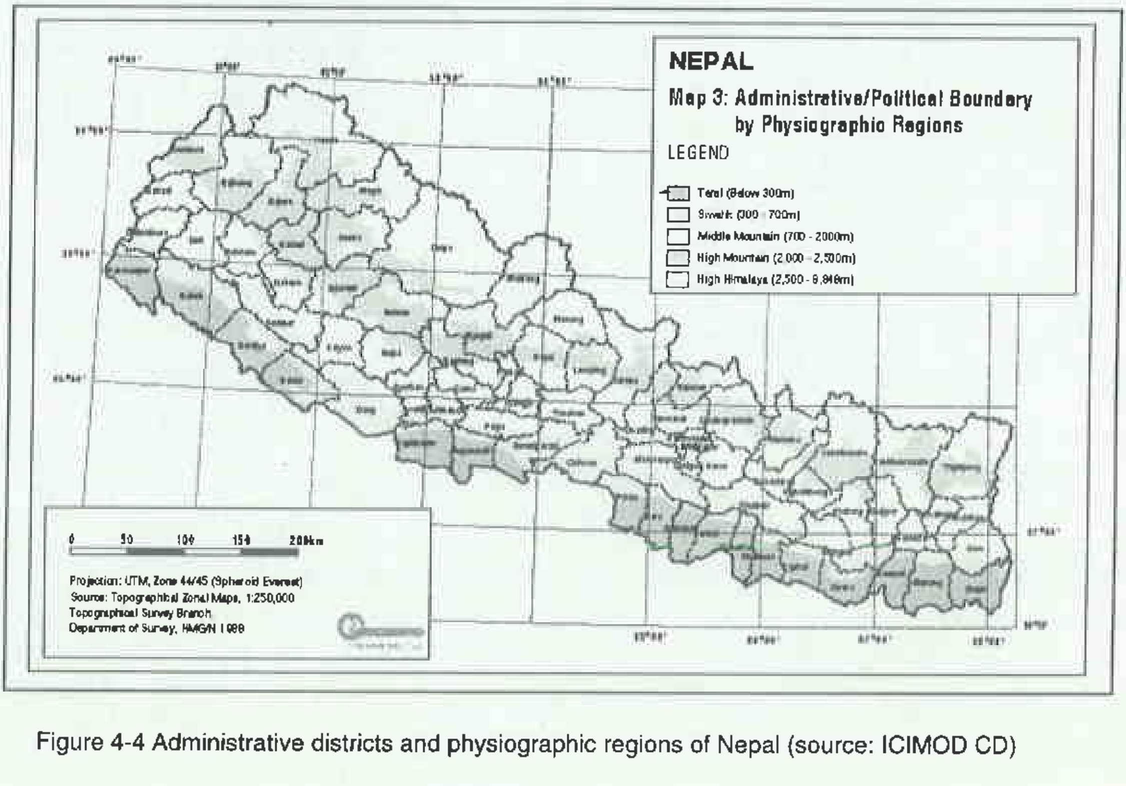


Figure 4-4 Administrative districts and physiographic regions of Nepal (source: ICIMOD CD)

4.3.2 Water resources management at the regional level

The Himalayan rivers offer a vast potential for power generation, and harnessing this potential of hydro power has been major efforts of the countries of the HKH region [ICIMOD, 98]. These multipurpose mega projects for power, and irrigation and flood control in the downstream plains play very important role in the national economy of these countries. Another objective of water resources management in the regional context is to solve the problems in water sharing of international rivers. River basins are natural accounting units for water management at the regional level. However, as the political boundaries do not coincide with the river basins and there are often more than one political unit within a river basin, there are difficulties in coordination and conflicts in decision making. The lack of political unity is due to the fact that the river basins are often non-economic or social units. The theory of regionalization is being advocated for improving the problems in water management at regional level. *Regionalization in water management is integration or cooperation on a regional basis, or any plan that integrates management actions in a river basin, metropolitan area, or other geographical region* [Grigg, 96].

Water induced disasters are another problems in the development of infrastructure in the mountain areas. The combination of weak geology and the intense precipitation make these areas vulnerable to hazards even in normal conditions [Chalise, 97]. The swelling glacier lakes in the Nepalese Himalayas and Tibet and the potential hazard downstream from the outburst of these lakes have generated great concern in recent years. The preparedness for such hazards needs a regional perspective.

The problems in integrated management of the water resources in the HKH region are aggravated by the lack of data needed for the decision making. The available data at present is discrete and has yet to be synthesized to yield an aggregate body of knowledge on water management. Improving the collection and analysis of water resources data has itself been an important objective in water resources management.

4.3.3 Stakeholders in water resources management

Stakeholders are all agencies, organizations and individuals that are involved in or affected by the water resource management decisions. A watershed approach creates opportunities for a broad range of stakeholders to play meaningful roles in basin plan development and implementation [EPA, 95]. The management policies and water allocation decisions are influenced by the interests of the stakeholders. The roles and responsibilities of the stakeholders include:

- Data and research sharing
- Joint monitoring
- Identification of waterbody stressors

- Priority setting
- Reviewing management plans
- Shared commitment of resources for plan implementation

There had been sectoral approach to water resources management in Nepal with different government line agencies working for different uses of water. The government agencies which are related with water resources are the Department of Irrigation, Department of Water Supply and Sewerage, Ministry of Local Development, Department of Agriculture, Agricultural Development Bank, and Water and Energy Commission Secretariate. Most of these agencies have local offices in all the 75 districts of the country. They look after irrigation, drinking water supply and sanitation and small hydropower schemes. There is often overlap of mandates of these agencies in the same administrative areas. The Department of Hydrology and Meteorology is responsible for maintaining the hydrological and climatic data in the country. A number of integrated watershed management projects in different parts of the country are being carried out under the Ministry of Forest and Soil Conservation.

Besides these government agencies, there are a number of national and international non-governmental organizations (NGOs and INGOs) who are working independently or in collaboration with one or several of these government agencies. Some of the major INGOs and donor agencies involved are United Nations International Children's Emergency Fund (UNICEF), United Nations Development Program (UNDP), European Union, development agencies from European countries, Asian Development Bank, World Bank and FAO. ICIMOD is working in collaboration with the government agencies, INGOs and NGOs in watershed management programmes.

The real stakeholders in water resources management are the local people whose livelihood is directly linked with the management activities. With the present practice of forming users committee and its involvement in all local planning and implementation activities, the community based organizations have gained a separate identity in the management process.

It shows that water resources management involves diverse interest groups with their own priority objectives. The area of interest differs in water use and scale in terms of geographical coverage and resources allocation. Hence, the information requirements by these groups are also diverse in nature.

4.4 Processes in water resources management

As discussed in 4.3.1, the major priorities of water management at the local level are irrigation and drinking water supply, and soil conservation. Similarly, the study of land use/land cover dynamics is another important area which has direct influence in water resources management. The processes involved and data requirements for these activities are studied in the following sections. The process for estimation of regional water balance is taken as an example of regional level application.

4.4.1 Irrigation and drinking water supply

The most common and traditional use of water is for irrigation and drinking purposes. As the population of the region is dependent on agriculture as the main source of livelihood, irrigation is the first priority of the people at the local level. There are different approaches to irrigation management practices such as farmer managed systems and agency managed systems [Pradhan et.al. 90]. Similarly, there are agency managed water supply systems or community water supply systems for drinking water supply. Although these two sectors are often dealt by separate line agencies, a general approach of planning and management is considered for the current study which is applicable to both disciplines.

The processes involved in the management of drinking water supply and irrigation are:

- *Definition of management area* – a watershed boundary in case of the watershed approach
- *Identification of stakeholders* – identifying the concerned households, communities, community based organizations within the watershed, and the government line agencies and non government organizations which have activities related to water in the area.
- *Assess current and future demands* – estimate the demand based on the present and projected population, agricultural land, crop type, livestock, industries, existing irrigation and drinking water infrastructure
- *Assess water sources* – assess location of and discharges from streams and springs, and water quality
- *Analysis of resource and demand* - identify the water deficit area and prioritize
- *Define alternatives* – develop alternative plans to meet the demands
- *Evaluate alternatives* – evaluate the alternatives based on natural characteristics of watershed, technical and financial aspects
- *Project selection*
- *Implementation*
- *Operation and maintenance of the system*

The process is shown in figure 4-5 and the information need and output of each activity in the process is given in table 4-1.

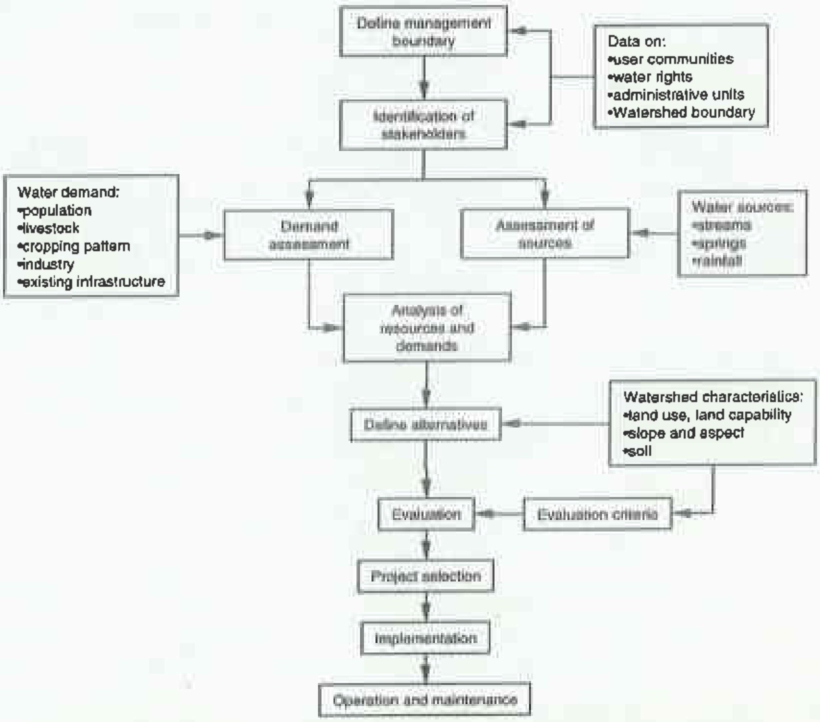


Figure 4-5 Management process for Irrigation and drinking water supply

Table 4-1 Processes and information needs for irrigation and drinking water supply management

ID[*]	Process	Information need	Source/ resolution	Data extraction method	Output
A	Definition of management boundary	Flow direction	Topographic map (1:25000 – 1: 50000) (DEM) Aerial photo (1:5000 - 1:20000) Satellite image (20m/ 30m)	Manual digitization/ Automatic delineation	Watershed area
B	Identification of stakeholders	Administrative boundaries Communities Line agencies NGOs CBOs Water rights	Census data Sectoral plan documents Local administrative units Field survey		List of stakeholders and their interests
C	Assess current and future demands	Population Livestock Cropping pattern (land use) Industries Existing infrastructure	Field survey Census data Land use maps (1: 25000 – 1:50000)	Norms for demand estimation	Quality and quantity demands, seasonal variations, future demands
D	Assessment of water sources	Hydrology (streams, springs, lakes, groundwater) Water quality Precipitation	Hydrological data on stream discharges and water quality (monthly data) Meteorological data (monthly data)	Manual digitization Field measurements	Location, quality and quantity of available sources
E	Analysis of resources and demand	Demand and supply data (C and D) Precipitation Stream flows Potential Evapo-transpiration Soil	Hydrological Meteorological data Soil data (1: 25000 – 1:50000)	Water balance models	Surplus/ deficit
F	Define alternatives	Watershed conditions (location of settlements, topography, land use, soil) Local needs (socioeconomic and environmental)	(from steps C, D, E)	Design norms	Preliminary design of systems
G	Evaluate alternatives	Socioeconomic, Environmental factors		Decision rules	Best alternative
H	Project selection	Best alternative		Management decision	
I	Implementation	Detailed design and implementation plan		Community participation Consultants Contractors	Water supply/ irrigation system
J	Operation and maintenance	Operation/ management committee		Users committee Operation rules	Operation and monitoring

[*] ID is used for reference in process diagrams.

4.4.2 Soil Erosion and Conservation

Soil erosion is a matter of concern in the mountainous area due to steep topography, thin soil cover and the natural factors such as heavy seasonal precipitation. In the integrated watershed approach, soil management and water management have been realized as interdependent, interactive and inseparable activities.

There are many approaches to the estimation of soil erosion and conservation practices. The methodology considered in this study is based on [Shrestha et.al., 99] and [Morgan, 95]. The processes involved in the study of soil erosion and conservation are:

- *Delineation of management area* – the watershed boundary
- *Identification of erosion features* – e.g. rill erosion, gully erosion, sheet erosion, debris sliding, slumping
- *Soil loss assessment* – involves the analysis of causal factors such as, Topography (slope aspect, gradient), Rainfall (annual rain, rainfall energy, mean daily rain), Soils (moisture content, bulk density, soil detachability index), Land use and land cover (vegetation parameters -% rainfall contributing to permanent interception, ratio of actual to potential ET, crop management factor); and the estimation of Soil loss using some model (e.g., Morgan's model, USLE method)
- *Hazard assessment* – by applying the decision rules (e.g. based on slope, aspect, bed rock type, land cover, proximity to stream etc.)
- *Conservation planning* - agronomic measures, soil management, mechanical methods

The process is shown in figure 4-6 and the information need and output of each activity in the process is given in table 4-2.

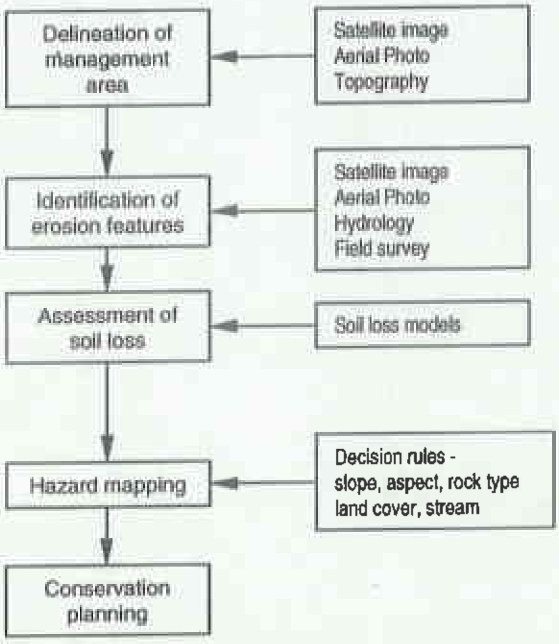


Figure 4-6 Process for soil erosion conservation [Shrestha et.al., 99]

Table 4-2 Processes and information for soil erosion conservation

IDS	Process	Information need	Source	Data extraction method	Output
A	Delineation of watershed boundary	Flow directions	Topographic map (1:25000 – 1:50000) (DEM) Aerial photo (1:5000 - 1:20000) Satellite image (20m/ 30m)	Visual interpretation/ Automatic delineation using DEM	Watershed area
B	Identification of erosion features	Shape, size, location of erosion features	Aerial photo (1:5000 - 1:20000) Satellite image (20m/ 30m) Field survey	Visual interpretation	Erosion features
C	Soil loss assessment	Slope Aspect Rainfall Soil Geology Land use/ land cover	DEM Meteorological data (monthly/ daily) Soil data (1:25000 – 1:50000) Geological data (1:25000 – 1:50000) Land use/ land cover data (1:25000 – 1:50000)	Map calculation Soil loss models	Soil loss rates
D	Hazard assessment	Slope Aspect Parent rock type (Geology) Soil Land cover Proximity to streams (Hydrology)	DEM Geological data Soil data Land cover data Hydrological data (same as above)	Decision rules	Area susceptible to erosion
E	Define conservation needs	Needs of stakeholders Demography Socioeconomic factors Land use policies Hazard information	Census data Household survey Policy documents Hazard map	Decision rules	Priority areas
F	Conservation planning	Information from D and E		Management decision	Plans for conservation measures (Agronomic, afforestation, Soil management, Mechanical methods)

4.4.3 Land use/ land cover dynamics

Land use and land cover are major factors that influence water demand. The study of the changes in land use/ land cover is an important component in all watershed management programmes and the information on trend of such changes is needed for water resources planning. The processes involved in the study of land use dynamics has been taken from the current methodologies adopted in the case studies and watershed management project of ICIMOD [Trapp et.al., 96], [Shrestha et.al.,95].

The processes involved are:

- *Assess current (recent) land use/ land cover* – (image classification, interpretation of satellite images, aerial photographs)
- *Assess past land use/ land cover* – (past land use/ land cover maps, data, image classification/ interpretation of satellite images, aerial photographs of earlier dates)
- *Change detection* – (comparison of land use/ land covers of different dates using ovelay operations)
- *Trend analysis* – (study the pattern of changes, causes and effects of changes)

The process is shown in figure 4-7 and the information need and output of each activity in the process is given in table 4-3.

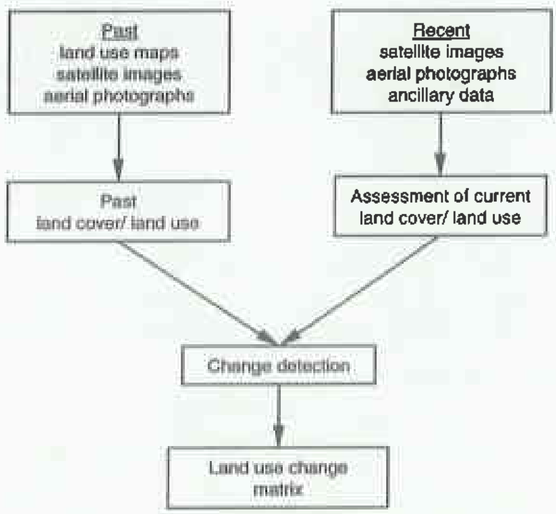


Figure 4-7 land use/ land cover change detection

Table 4-3 Process and Information need for Land use / land cover study

ID L	Process	Information need	Source/ resolution	Data extraction method	Output
a1 a2 a3	Assessment of current land use/ land cover	Topographic data (DEM) Land use/ land cover data (field/ reference)	Topographic map (DEM) (1:25000 – 1:50000) Aerial photo (recent) (1:5000 – 1:20000) Satellite image (recent) (20m/ 30m)	Visual interpretation Manual digitization Image classification Field verification	Recent land use/ land cover map
a1 a2	Inventory of past land use/ land cover	Topographic data (DEM) Land use/ land cover data (field/ reference)	Topographic map (DEM) Aerial photo (past) Satellite image (past) Existing land use maps (same as above)	Visual interpretation Manual digitization Image classification Field verification	Past land use/ land cover of the area
a4	Change detection	Past and present land use/ land cover data	Past and present land use/ land cover data	Overlay operations/ Map calculations	Land use/ land cover change map
a5	Trend analysis	Land use/ land cover data at different dates	Land use/ land cover data at different dates	Graphical/ statistical methods	Trend in the change

4.4.4 Regional Water balance

Estimation of water balance at regional levels is needed for assessing the state of land and water resources. The information is important for water resources planning and predicting the potential for agricultural production. The processes in estimation of regional water balance in this study. is based on the methodology developed and Land and Water Information Systems (LWIS) programme of the Food and Agriculture Organization of the United Nations (FAO) [Hoogeveen, 97].

The processes involved are:

- *Delineation of sub basins* – using DEM with further verification from existing maps
- *Calculation of precipitation* – using global precipitation data sets e.g. Leegates-Willmot dataset, Leemans-Cramer dataset
- *Estimation of runoff* - using soil water balance (monthly precipitation, actual evaporation, soil water storage capacity, seepage from/to ground water, land use) or using the runoff coefficient
- *Estimation of open water evaporation* – needed only for water bodies
- *Assessment of Irrigation* – natural and artificial water outlet, (e.g. aquastat database for area under irrigation)
- *Calculation of water balance* – using water balance equation

The process is shown in figure 4-8 and the information need and output of each activity in the process is given in table 4-4.

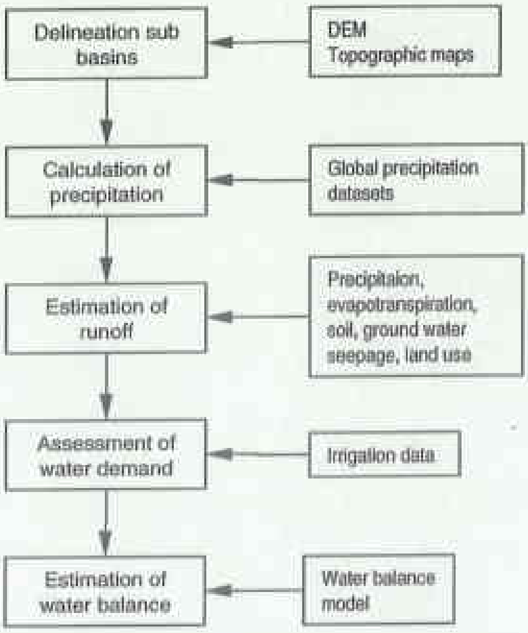


Figure 4-8 Estimation of regional water balance

Table 4-4 Process and Information need for regional water balance estimation

ID	Process	Information need	Source	Data extraction method	Output
A	Delineation of sub basins	Flow direction	Global DEM (1Km), topographic maps (1:1000000)	Interpolation, manual verification	Boundaries of sub-watersheds
B	Calculation of precipitation	Precipitation data	Global datasets e.g. Leegates-Willmot dataset, Leemans-Cramer dataset	interpolation	Mean precipitation per watershed
C	Estimation of runoff	(Precipitation data, evapotranspiration, soil water storage capacity, ground water seepage, land use) or runoff coefficients	Global datasets	interpolation	Mean runoff per watershed
D	Assessment of Irrigation	Water consumption by irrigation	Global datasets e.g. aquastat		Consumptive water use
E	Calculation of water balance	Water Input and output per watershed	The above calculations	Map calculation	Water balance per watershed

4.5 Process models

Modelling is the abstraction of features from the real world which are important to understand the interaction with the environment in some context. A model is defined as a simplified representation of a system where a system refers to any collection of objects or processes that interact in some way. Systems vary in size and complexity and they can be modeled at various levels of abstractions, depending upon the objectives of the study. The purpose of the modeling process is to produce an instance of the system, its objects or processes of interest and their interactions.

Systematic representation and analysis is necessary in studying the processes and seeking ways to improve, upgrade or redesign them. Process modeling can be seen as the creation of diagrams, their documentation and supporting mathematical concepts to show the relevant processes, their outputs and the input needs. It is done using a specification language, a particular method based on existing modeling tool with well defined set of rules for the structuring of the model to meet the particular development objectives. Process modelling helps to understand the processes, to analyse, compare and evaluate different processes, to design new processes, and to work out the requirements for IT support for the processes. It helps implementation of the processes in work flow management systems and simulation tools. Process modelling is necessary for reengineering as it gives a better insight to the processes, allowing performance analysis at various abstraction levels [Radwan et. al. 98a].

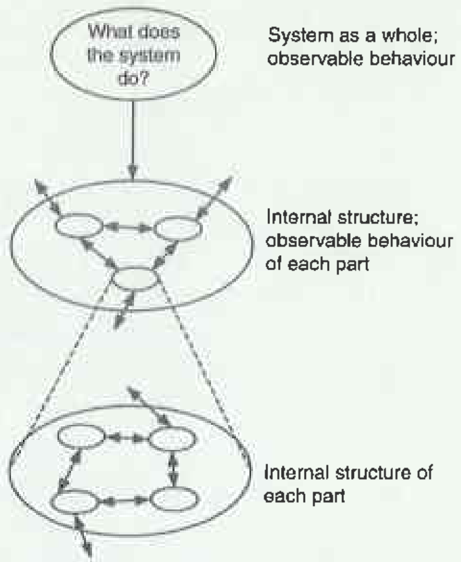
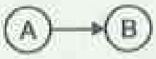
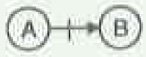
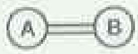
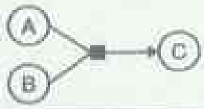
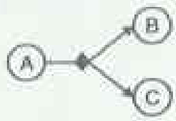
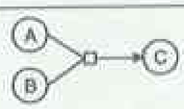
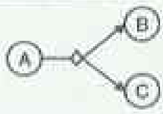


Figure 4-9 Modelling at different abstraction levels.

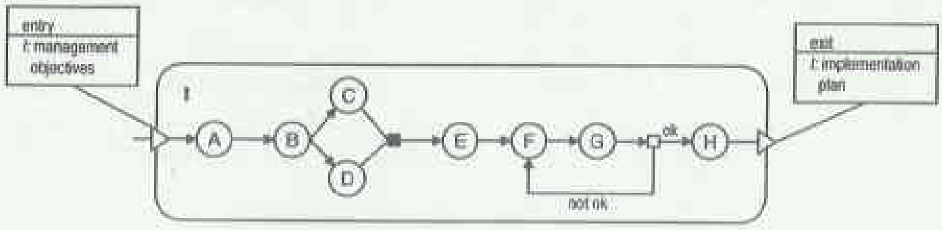
The architectural approach of process modeling developed by the Centre of Telematic and Information Technology (CTIT) of University of Twente is used for defining the process models in this study. These process models will be useful to identify the possibilities of reengineering the processes which will be studied in the next chapter.

Description of architectural model is given in Annex 2. Graphical notations used to represent the actions and their behaviour pattern are given in table 4-5.

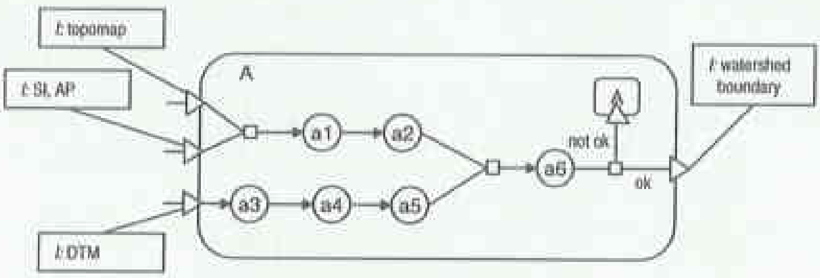
Table 4-5 Causality conditions and their graphical representation

Causality relation	Graphical representation	Action description/ Behaviour pattern
Enabling: B allowed to occur only if A has occurred		A is an *enabling action* because occurrence of A enables occurrence of B
Disabling: B is allowed to occur only if A has not occurred, and does not occur simultaneously		A is an *disabling action* because occurrence of A would exclude occurrence of B, if B has not already occurred
Synchronization: B is allowed to occur if A occurs at the same time		A and B are *synchronized actions* because their occurrences must be synchronized
A enables occurrence of B, and B enables occurrence of C		*Sequential ordering* – activity B depends on the result of A, and C requires the result of B
And-join: Occurrence of both A and B enables C		Activity C requires the results established by both A and B
And-split: A enables occurrence of both B and C		*Independence* – activities B and C are independent of each other and can be performed simultaneously, following completion of A
Or-join: Occurrence of either A or B can enable C		Activity C is performed following the completion of either A or B
Or-split: A enables occurrence of either B or C		*Choice* – the results established by activity A may be used to perform activity B or C, but not both.
A and B both occur but not at the same time		*Interleaving* – Activities A and B need to use single resource

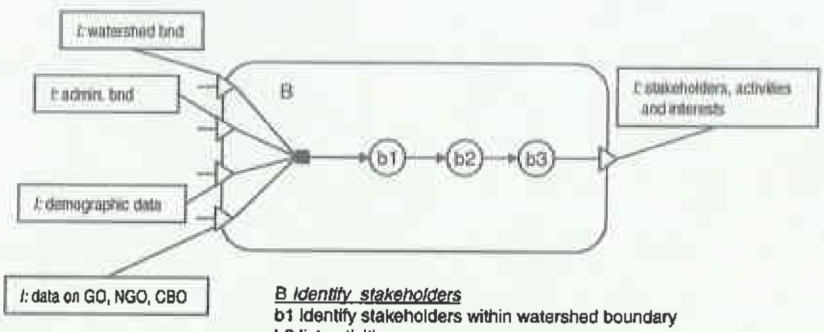
4.5.1 Process model for Irrigation and drinking water supply



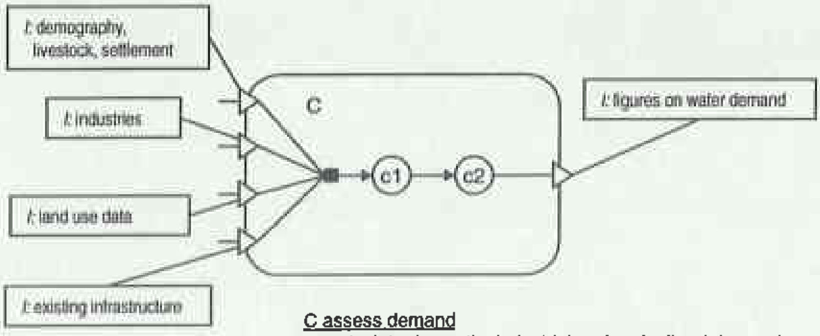
I Irrigation and drinking water supply
A define management boundary
B identify stakeholders
C assess demands
D assess sources
E analyse resources and demands
F define alternatives
G evaluate alternatives
H select project



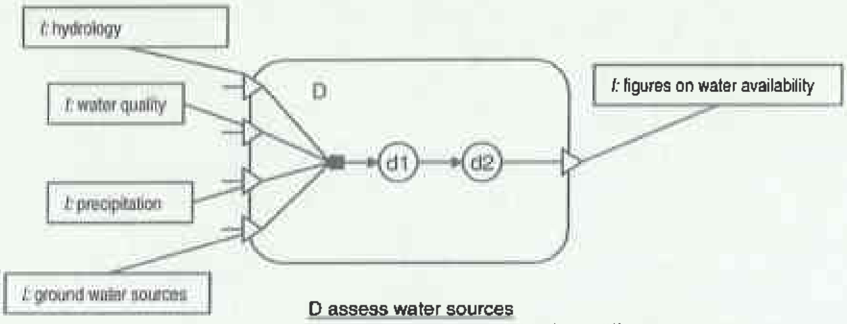
A define management boundary
a1 manual tracing of watershed boundary
a2 digitize boundary
a3 calculate flow direction
a4 calculate flow accumulation
a5 delineate watershed boundary
a6 verify



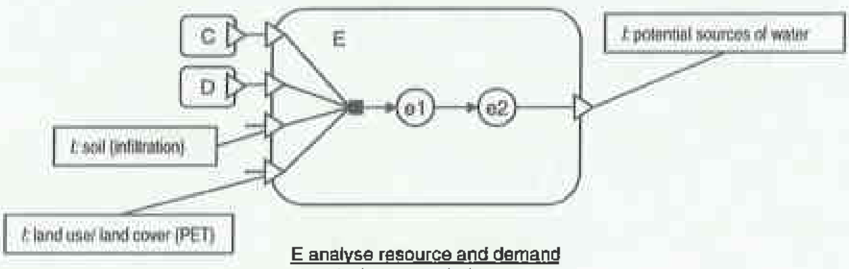
B identify stakeholders
b1 identify stakeholders within watershed boundary
b2 list activities
b3 identify stakeholder interests



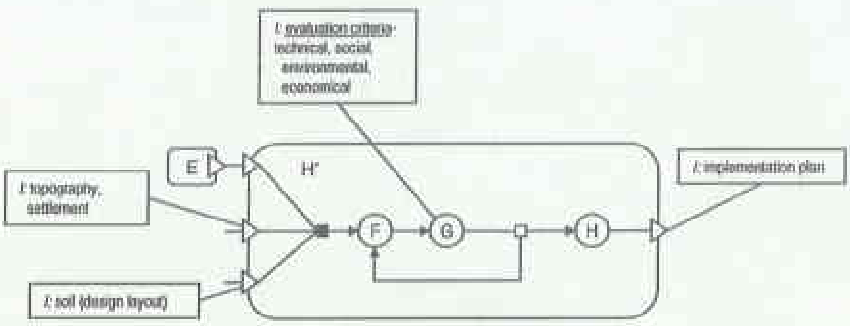
C assess demand
c1 calculate domestic, industrial and agricultural demand
c2 project future demand



D assess water sources
d1 calculate water available from different sources
d2 calculate safe yield

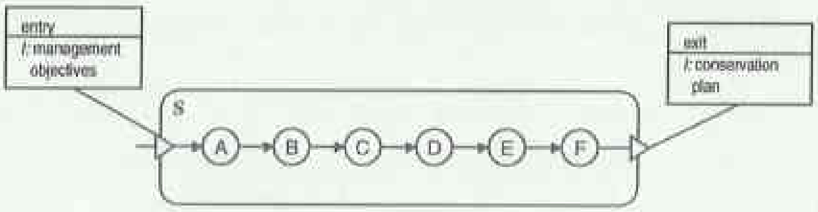


E analyse resource and demand
e1 calculate water balance
e2 identify potential sources

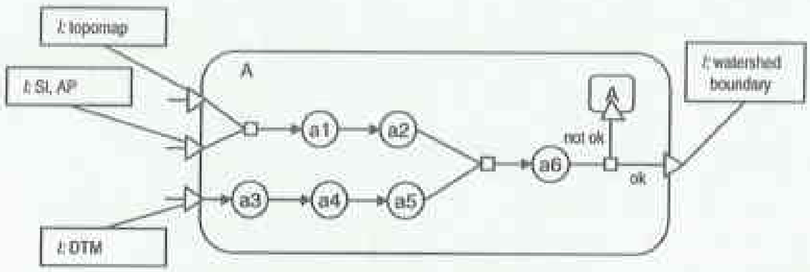


H' design, evaluate and select project
F define alternatives
G evaluate alternatives
H select project

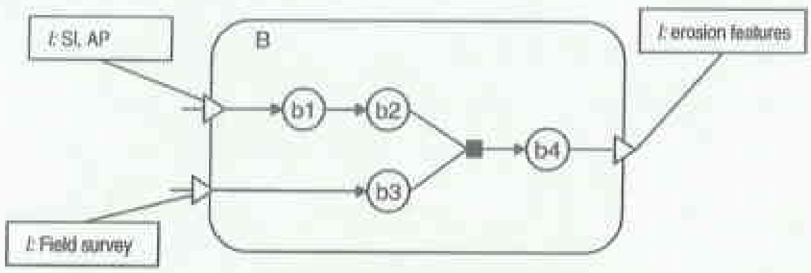
4.5.2 Process model for soil erosion and conservation



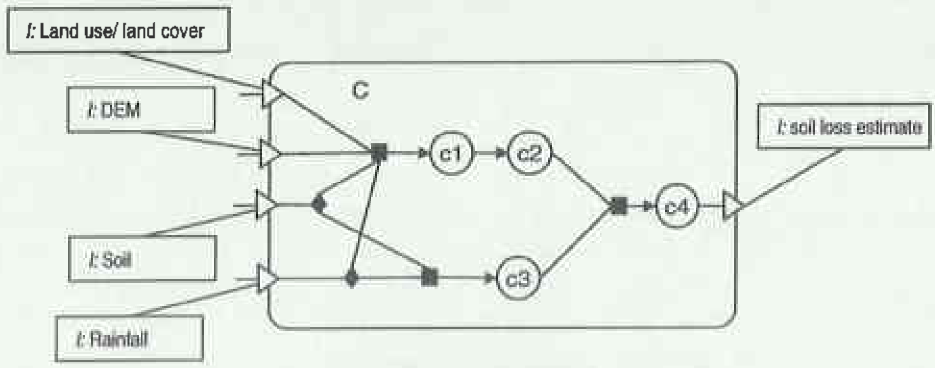
S *Soil erosion and conservation*
A define watershed boundary
B identify erosion features
C assess soil loss
D hazard assessment
E define conservation needs
F conservation planning



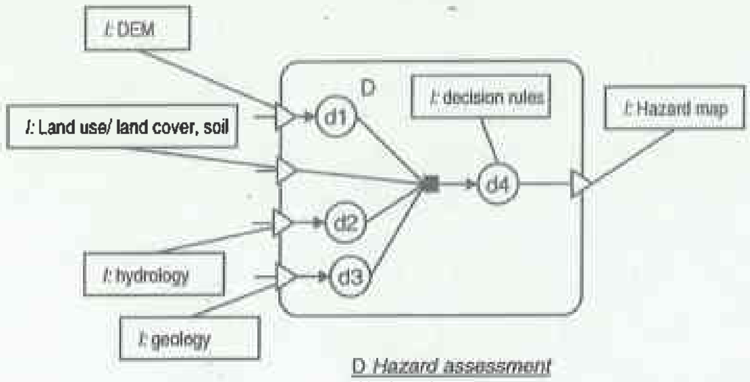
A *define management boundary*
a1 manual tracing of watershed boundary
a2 digitize boundary
a3 calculate flow direction
a4 calculate flow accumulation
a5 delineate watershed boundary
a6 verify



B *Identification of erosion features*
b1 visual interpretation of erosion features
b2 verification
b3 identification of erosion features
b4 digitization

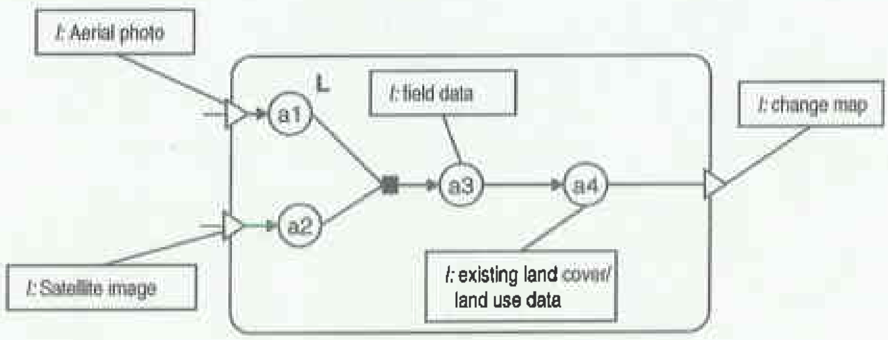


C *Soil loss assessment*
c1 calculate overland flow
c2 calculate transport capacity
c3 splash detachment rate
c4 soil loss rate



D *Hazard assessment*
d1 slope/ aspect
d2 proximity to hydrological features
d3 parent rock type
d4 identify hazard zones

4.5.3 Process model for land cover analysis



L *Land use dynamics*
a1 aerial photo interpretation
a2 Image classification
a3 field verification
a4 change detection

4.6 Conclusion

The general principles of water resources management, the management objectives and the activities involved in the management processes are reviewed taking the examples of irrigation and drinking water supply, soil erosion, land use/ land cover analysis and regional water balance estimation. Understanding of the processes helps to analyse the commonality in the different activities and facilitates the integration and optimization. The common information needs for different processes in these examples will be analysed and the possibility for reengineering the processes will studied in the next chapter.

5 Reengineering plan

5.1 Introduction

The previous chapter studied the processes and information needs in water resources management. The common processes and information needs in these activities are identified in this chapter to come up with reengineering plan. Section 5.2 defines reengineering plans and section 5.3 discusses the reengineering in data acquisition process. Reengineering for information sharing will be presented in section 5.4.

5.2 Reengineering process

In the present context, the business process can be considered as a set of activities involved from data capture to information distribution for water resources management. Business process reengineering (BPR) is defined as "*the fundamental rethinking and radical redesign of business processes to achieve dramatic improvements in critical, contemporary measures of performance, such as cost, quality, capital, service and speed*" [Hammer et. al. 1993]. It is a methodology to improve the effectiveness, efficiency and adaptability in the way the organizations operate. BPR seeks solutions to fragmented processes by taking a fresh look at their objectives. The need for BPR was realized in this study for a coordinated and integrated approach in various activities in natural resources management. The coordination is needed in data collection and sharing practices to achieve economy, quality and efficiency in the activities. From the discussions in chapters 3 and 4, the reengineering needs are identified for developing a spatial framework for data collection and database development, and the use of IT for information dissemination. The proposed reengineering plans are listed below:

Reengineering plans for data collection:

- Develop a spatial reference system at a regional scale, with specifications for georeferencing the local data to the regional data and vice versa. This will facilitate the aggregation databases at different scales.
- Develop a spatial framework for data collection. This will involve agreement on data collection units, e.g. Terrain mapping Units (TMU) and specifications for aggregation hierarchies.
- Develop core databases at regional and local levels as a foundation for core geoinformation applications.
- Develop data models based on common concepts and formal modelling techniques to support data acquisition, creation of databases, and their use in applications. This will facilitate the use of data by different users for their specific purposes.

Reengineering plans for information sharing:

- Establish a formal data sharing mechanism with well defined responsibilities among various actors.
- Exploit the potentials of IT to develop a network for data sharing.
- Introduce new geoinformation services based on IT potentials.

5.3 Reengineering in data acquisition process

5.3.1 Spatial reference system

The difficulties in integrating the existing data from different sources can be solved to some extent by developing a spatial reference system covering the whole region. Since the different countries have adopted their own coordinate systems, specifications for transforming the national coordinates into a regional framework is important for compiling the regional databases from the local databases. One of the options will be to develop specifications for transformation of local reference systems into World Geodetic System (WGS). WGS was introduced to tie different regional datums together for military and other purposes and to answer the need for a global geodetic reference with the advent of the satellite based positioning systems. The use of WGS84 reference system will also facilitate to integrate field data as it is used for GPS measurements.

5.3.2 Spatial framework for data collection

Watersheds for data collection units

Administrative units such as districts and villages have been the basis for data collection in creating most of the databases. As the census data are based on these administrative units, it is a convenient way for compiling socioeconomic data. However, integrated area planning demands for better understanding of natural processes and the resource based approach like watersheds are suitable for such applications. Watersheds are the natural demarcation for geohydrological processes and provide a spatial framework for aggregation hierarchy in a nested approach (see figure 4-2). The watershed management units can be used to integrate activities from the smaller hydrologic units to large river basins and ecoregions. The collection of data based on watersheds will ensure that the data is complete for a natural system, which may not be true if data is based on administrative units. However, watershed approach may have problems in dealing with demographic data which has no spatial reference other than the administrative unit. Field data and re-aggregation of the census data from a lower level may be necessary in such cases. For example, the census data are published at district level whereas data at ward or village level may be needed to match the boundaries of these databases with the watershed boundaries.

5.3.3 Common databases (foundation data)

As discussed in chapter 3, the problems in the application of GIS are mainly due to unavailability of basic data. This has led to duplication of effort in data collection as well as inconsistencies in the databases. Development of core databases, which can be used by different applications at various scales, is an important activity in the reengineering plan. For this, the management processes in irrigation and drinking water supply, and soil erosion and conservation (from chapter 4) are analyzed to identify the common data needs. The activity on land use/ land cover study is taken as one of the data sources for these applications and not considered in the comparison. The matrix is presented in table 5-1.

The table shows that topographic data or digital elevation model (DEM) is the basic data requirement which appear repeatedly in a number of activities in both the processes, and the aerial photographs and satellite images are the important data sources. Another basic data need for water resources management is the hydrological data. Therefore, the DEM and the hydrological data are needed as the core datasets for the water resources applications.

The other thematic data requirements are soil, geology, meteorology and land use/ land cover which are needed at different stages in the management process. The TMU approach is considered as an alternative solution as it contains the inherited data related to soil, geological and lithological aspects of the terrain. The TMU approach is discussed in the following section based on [Meijerink, 88] and [Suryana, 96].

Table 5-1. Common data needs in irrigation and drinking water supply/ soil erosion and conservation

Management process		Soil erosion and conservation				
		Define boundary	Identify erosion features	Assess soil loss	Hazard assessment	Conservation plan
Irrigation and drinking water supply	Define boundary	DEM, AP, SI	AP, SI	DEM	DEM	
	Identify stake holders					Socio-economy, policies
	Assess demands			Soil, LU/LC	Soil, LC	Socio-economy, policies
	Assess sources	AP, SI	AP, SI, Hydrology		Hydrology	
	Water balance (demand/ supply)	AP, SI	AP, SI, Hydrology	Soil, LU/LC	Soil, LC, hydrology	Socio-economy, policies
	Develop alternative plans	DEM, AP, SI	AP, SI, Hydrology	DEM, precipitation, soil, geology, LU/LC	DEM, soil, geology, LC, hydrology	Socio-economy, policies

Terrain mapping units (TMU)

The concept of TMU was proposed for providing an alternative solution to problems associated with data acquisition and data capture for GIS [Meijrink, 1988]. TMUs are defined as unique associations of geology, geomorphology, morphometry, and soil distribution. They are usually obtained by interpretation of aerial photos or satellite images and verified in the field. The delineated TMUs represent less variable natural divisions of a terrain often with distinct boundaries. Each TMU can be defined with a unique set of properties and can have subunits. The concept of TMU is closely related with the terrain mapping systems including the graphical representation of terrain objects. The terrain objects are described by a set of geometric and thematic attributes. These attributes are used as criteria or determinants for selecting and classifying TMU in a natural terrain. The resulting descriptive class hierarchy for TMUs leads to disaggregation of the terrain system into consecutively main units, sub units and catenas, and catena elements.

The hierarchical structuring of TMUs is done by applying object-oriented abstraction concepts including classification, aggregation, generalization/ specialization, and association [Suryana et.al., 94]. Considering the aggregation hierarchies, TMUs can be considered as composite objects with specific geometric and thematic attribute structures. The general attributes associated with TMUs are very complex, but the individual attributes such as morphometry can be ordered in a generalization/ specialization hierarchy according to the level of observation or mapping.

Hierarchical structure: class and aggregation hierarchies of TMUs

The hierarchical structuring of TMUs is related to techniques of managing the complexity and multi scaled dependency of hierchically structured attributes. This can be augmented through proper data modeling including selection of the most appropriate criteria (attributes) for classification, scale, hierarchical structure and functional units in describing a particular system of interest. TMU can be divided into three different level of hierarchy levels, + 1, 0, and -1. The TMUs at +1 level can be classified into sub units and catenas (at level 0) and catena elements (at level -1). The class hierarchy of TMU is based on three different determinants – primary, secondary and tertiary determinants (table 5-3) which are of partly descriptive nature and partly are composed of general attribute structure.

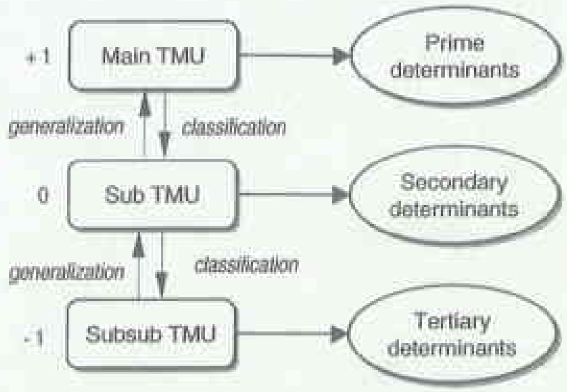


Figure 5-1 Different aggregation levels of TMU [Suryana, 96]

Superclass TMU or main unit TMU are determined at the highest aggregation level according to their general attributes (primary determinants). The main geomorphological units are differentiated according to their origin and used further as main functional units. Further differentiation into geomorphologic units is done on the basis of specific landforms. Each geomorphic or main unit is accompanied by a physiographic description to satisfy general needs and has a specific morphometric characteristic.

Many main units will consist of an association of different sub units or catenas. These sub units are determined from the descriptive secondary determinants of the sub TMU. The subsub TMU is defined at the lowest aggregation level. These units comprise the elementary objects or instances of class hierarchy. The derived catena elements are non mappable units and inherit specific information on slope class, slope length, soil texture, erosional processes from the higher level attributes.

Table 5-2 Terrain Mapping Unit (TMU) classification criteria [Meijerink, 88]

Determinant	General sequence	Description
Prime determinants	Lithology or origin (interchangeable), specific orign. Morphometry	▪ Origin: of landforms or complexes (fluvial, volcanic, strucutural etc) ▪ Specific origin: Differentiation of landforms or associations of landforms within the main origin: physiographic criteria may be used in conjuction with analytical geomorphologic criteria, such as age, tectonic or climatic history, proceses ▪ Lithology: Lithologic or lithostratigraphic units or complexes, usually grouped in formations; mixtures of unconformable beds (overburden) and underlying lithology ▪ Morphometry:Internal relief, valley density, slopes
Secondary determinants	No general sequence	▪ Sub units: Differentiation of important/ relevant or large landform or association of landform elements; related to specific origin ▪ Soil units: Soil units may in some cases form the basis of differentiation of sub units; in exceptional cases even for main units (as combination of lithology and specific origin). Soil units are generally associated with geomorphologic or physiographic main units, sub units or catena elements ▪ Catenas and slope properties: Characteristic sets of crests, slopes and valleys and their properties (cliffs, screes etc.)
Tertiary determinants	No sequence	▪ Process related aspects: Landforms dominated by specific denudative or erosive processes, such as large landslides, lahars, badlands etc. ▪ Natural hazards: When desired hazard criteria may be used for sub differentiation, such as flood frequency, duration and depth, fault zones etc. ▪ Selected properties: Generally environmental artifacts, such as mining dumps, refuse pits, sediment trapping areas, levelled ground etc.

5.3.4 Data model

Data model is an abstraction of real world to fulfil the needs of a particular context. The usability of data by different contexts depends on the underlying data model. The model systems should correspond to the real world systems more directly for its use in different applications.

The uses of these common data and their purpose in the different contexts are given in table 5-2. It is seen that the requirements in the data content can be different for different applications. For example, the contents in soil data for use in erosion assessment and for irrigation planning are different. The same is true for data on rainfall or geology. This gives rise to heterogeneity issues in data content. Heterogeneity at this level is due to difference in class hierarchies and attribute structure in the database schemas, differences in rules that assign objects to classes, and differences in geometric representation of the objects. [Bishr, 97] has identified these heterogeneity as schematic, semantic and syntactic heterogeneity.

Table 5-3. Use of common data in different context

Data source/ Data	Irrigation/ drinking water supply	Soil erosion conservation	Land use/ land cover dynamics	Regional water balance
Topographic map (DEM)	▪ Delineation of watershed boundary ▪ Flow channel Elevation (head difference)	▪ Delineation of watershed boundary ▪ Flow channel ▪ Slope ▪ Aspect	▪ Ancillary information for land use/ land cover classification	▪ Delineation of watershed boundary
Aerial photo	▪ Watershed boundary ▪ Extract water bodies ▪ Landuse / landcover	▪ Watershed boundary ▪ Extract erosion features ▪ Landuse / landcover	▪ Land use/ land cover classification	
Satellite imgaes	▪ Watershed boundary ▪ Extract water bodies ▪ Landuse / landcover	▪ Watershed boundary ▪ Extract erosion features ▪ Soil Landuse / landcover	▪ Land use/ land cover classification	▪ Watershed boundary ▪ Extract water bodies ▪ Landuse/landcover
Soil	▪ Evapotranspiration, land suitability, infiltration	▪ Top soil depth ▪ Soil moisture field capacity ▪ Bulk density ▪ Et/Eo ratio	▪ Ancillary information	▪ Evapo-transpiration, land suitability, infiltration
Hydrology	▪ Runoff ▪ Water quality	▪ Discharge ▪ Location of streams ▪ Sediment load	▪ Classification	▪ Runoff
Geology	▪ Ground water	▪ Parent rock type		
Meteorology	▪ Rainfall volume ▪ Rainfall duration/ seasonal variation	▪ Rainfall intensity, volume, duration, no. of rainy days		▪ Rainfall volume ▪ seasonal variation
Land use, land cover	▪ Evapotranspiration ▪ Water use ▪ Water consumption	Vegetation parameters, soil suitability, interception, ratio of actual to potential ET, crop management factor	▪ Ancillary information ▪ Change detection	▪ Agricultural land use

The object oriented modelling approach allows the users to conceive the model in terms of objects with a defined state and behaviour. Every real world phenomenon is defined as an object. The state of an object is given by its attribute values and its behaviour by object-specific operations that are encapsulated within the description of the object. Objects with common attributes and operations are classified into object classes. Classification is the grouping of similar objects incorporating state and behaviour of similar objects. Classes with common attributes and operations can be organized in a generalization or class hierarchy. A class hierarchy represents multiple abstractions for the same object. At a lower level in the class hierarchy the same object is described in more detail. The properties of an object are inherited in a top-down manner, i.e., a class inherits attributes and operations of its superclasses. Aggregation is an object-oriented abstraction in which a relationship among objects is represented by a higher level, composite or aggregated object. The properties of a composite object may be inherited or derived from its constituent objects or it may have its own properties independent of its constituent objects. Association is an abstraction which represents sets of objects which have some common properties.

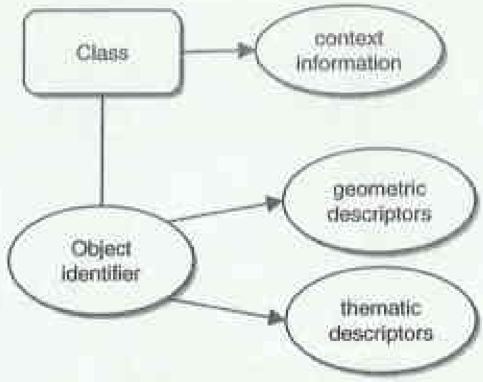


Figure 5-2 Representation of spatial objects in SFDS [Bishr, 97]

The formal data structure (FDS) based on object oriented approach provides a common means for representing real world phenomena mathematically and conceptually [Molenaar, 95]. In FDS, an object that belongs to a class has an identifier for a unique identification in the database. It is linked with the thematic and geometric descriptors of the object. A class has a label and a list of attributes which characterizes the class. The database object is a member of some class and has the attribute structure of the class it belongs to. [Bishr, 97] developed the semantic formal data structure (SFDS) by adding the schematic and semantic layers to FDS to resolve the heterogeneity issues in data sharing.

FDS defines a syntax for both the geometric and thematic descriptors of spatial objects in a vector database. The same syntax can be applied to raster structure and other tessellations by considering as faces in a planar graph. The spatial objects are represented by three types of complex objects – point objects, line objects and area objects. These objects are defined using three geometric primitives – nodes, edges and faces.

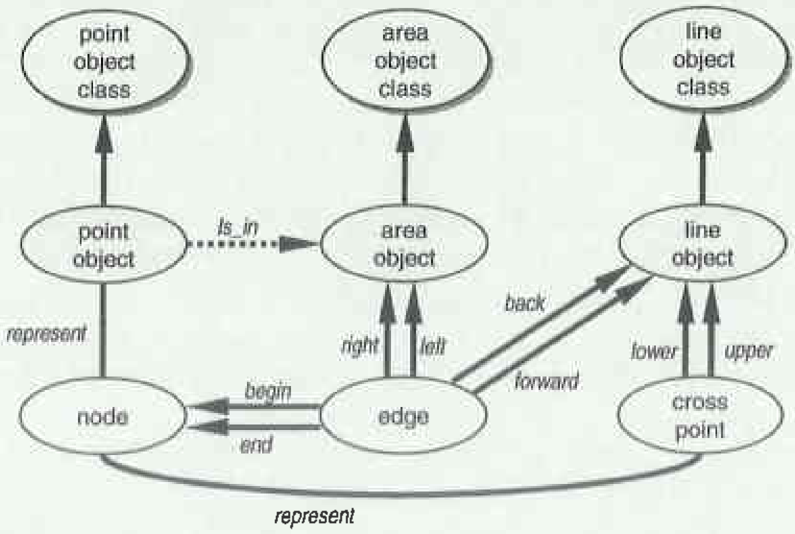


Figure 5-3 Relations between objects and geometric elements in FDS [Molenaar, 95]

The semantic layer provides the explicit representation of context information. Context information is attached to the classes and therefore all the instances of the class will have the same context information. The information in semantic layer will help to solve the heterogeneity problems when the data is used in different contexts.

The data model of objects related to water resources is presented here which is the main interest of the water resources management domain. Only a general structure of object classes are given. A detailed description of the attributes and semantic description for each class in necessary in the real application. The objects in water management can be grouped as – physical spatial objects, water cycle and balance objects, hydrological transport objects, and water use related objects [Mannaerts, 97].

Table 5-4 Water Resources Objects

Object type	Object	Classification	Representation
a. Physical spatial objects	Catchment area	No	Area
	Water course	Yes	Line
	Waterbody	Yes	Area
	Groundwater body	Yes	Area, line, point
b. Water cycle and balance objects	Evapotranspiration	No	Point (temporal)
	Rainfall	No	Point (temporal)
	Runoff and stream flow	No	Point (temporal)
	Soil moisture	No	Point (temporal)
	Ground water	No	Point (temporal)
c. Hydrological transport objects	Sediment transport	Yes	Point (temporal)
	Chemical transport	Yes	Point (temporal)
d. Water use related object	Water use	Yes	Point (temporal)
	Water quality and pollution objects	Yes	Point (temporal)

a. Physical spatial objects

The physical objects consist of the class catchment area, and the hydrographic feature classes water course, water body and groundwater body.

Catchment area: describes the catchment areas like river basins or watersheds. The term river basin is generally used for large catchments with upstream headwaters, middle river reach and flood plain. The term watershed is used for small to mid sized catchments in mountain headwaters and middle river reaches.

Hydrography: describes all the hydrological features
Subclasses:

Water course includes rivers, streams and canals which are further classified based on behaviour, use etc.

Water body includes lakes, reservoirs and wetlands.

Groundwater body includes springs and acquifers.

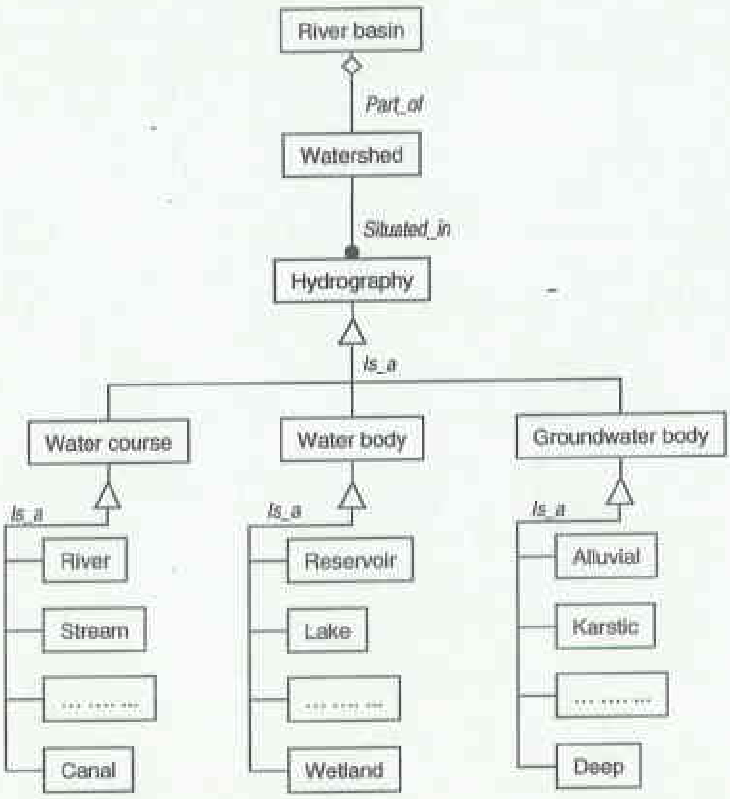


Figure 5-4 Physical spatial objects

b. Water cycle and balance objects

These objects consists of time series observations on evapotranspiration, rainfall, runoff and streamflow, and groundwater at different measurement stations.

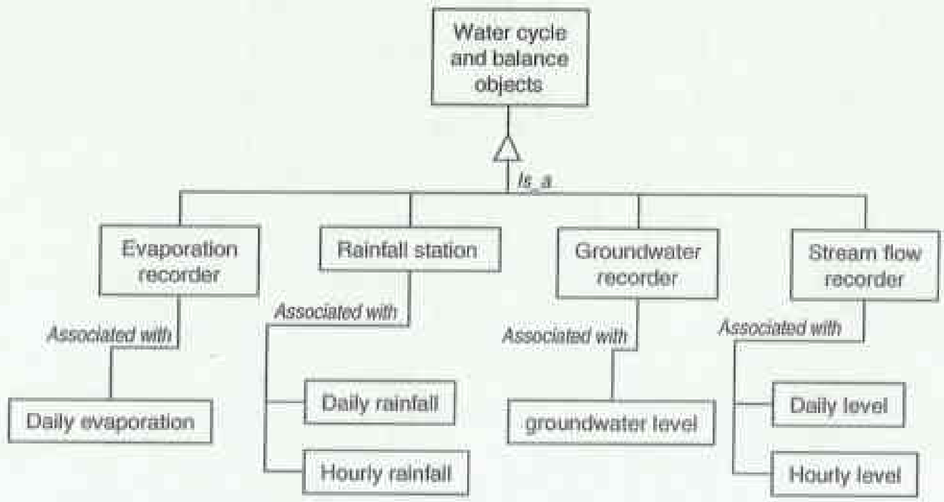


Figure 5-5 Water cycle and balance objects

c. Hydrological transport objects

It represents all constituents transported by the medium "water". Sediment transports include sediment concentration and load data. Chemical transports include chemical loads, salt and mineral compounds, pollutants etc.

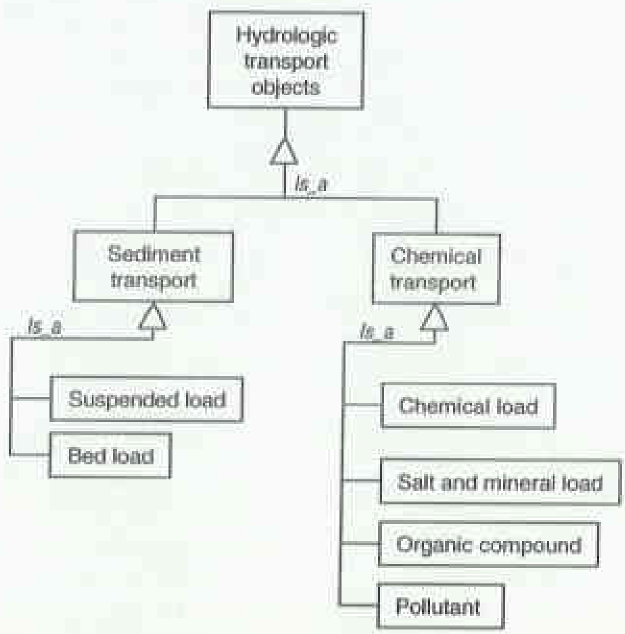


Figure 5-6 Hydrologic transport objects

d. Water use related objects

It includes water use objects, and water quality and pollution objects. The water use includes classes like domestic, industrial, agricultural, recreation and transportation uses. The water quality and pollution objects include point and non-point sources.

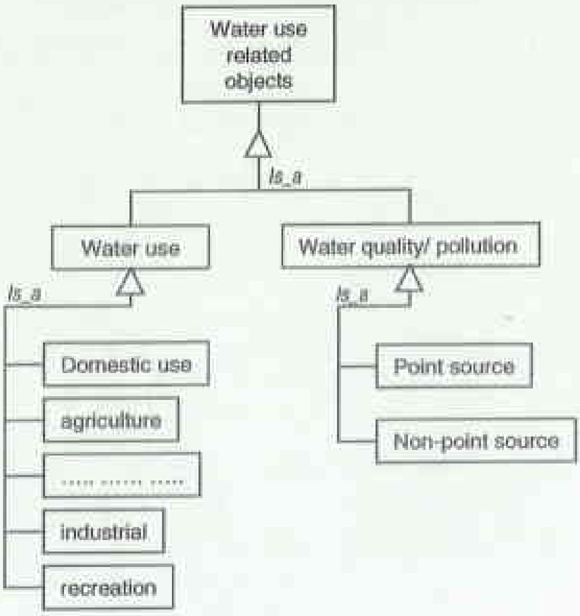


Figure 5-7 water use related objects

5.3.5 Data generation process

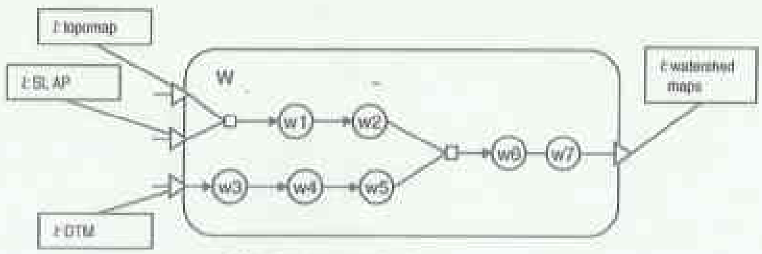
The data collection process can be differentiated as core processes and application specific processes. Some processes are common in all applications such as georferencing, image classification, digitization etc. which can be included among the core processes. As discussed in the earlier section, the use watershed boundaries as the framework for data collection, and the TMU approach will help to better represent the natural processes. Hence, the division of the mandated area into river basins, watersheds and sub-watersheds can be considered as one of the core processes which is needed in all applications in water resources management. Another core process will be to develop databases based on TMU classifications.

The process of watershed delineation is shown in figure 5-5. It involves the use of topographic maps, aerial photographs and a DEM if available. However, the topographic maps are needed for verification when the watersheds are generated automatically using the DEM. The watersheds are then classified as sub watersheds based on the area of the catchment and the linkages.

The process for preparing the TMU database is shown in figure 5-6. Preliminary TMUs are delineated from satellite images and aerial photographs using photogrammetric techniques.

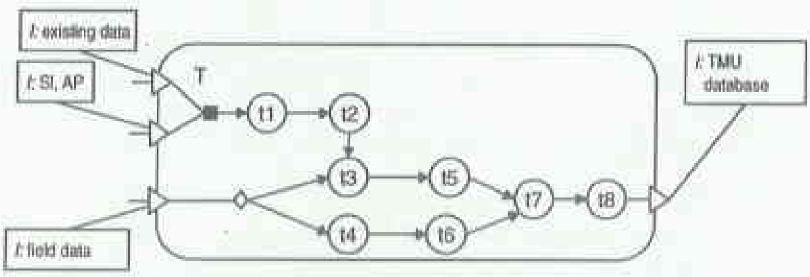
This is verified in the field and attribute data are collected. The final delineation of TMUs are digitized and the attribute data are linked. The TMUs are further generalized using the database processing.

The collection of hydrological data is another core function related to water resources management. The data are collected from the field stations on a regular basis and compiled in spreadsheets or relational tables. The statistical analysis of these data are linked with the spatial point objects for spatial interpolation and deriving information such as rainfall, evapotranspiration zones etc.



W delineate watersheds
w1 manual tracing of watershed boundary
w2 digitize boundary
w3 calculate flow direction
w4 calculate flow accumulation
w5 delineate watershed boundary
w6 verify
w7 classify

Figure 5-8 Delineation of watersheds



T create TMU database
t1 photo/ image interpretation
t2 define provisional TMU
t3 final interpretation and delineation of TMU
t4 attributes on lithology,soils, processes
t5 digitization
t6 attribute data input
t7 link attribute data
t8 database operations, generalization

Figure 5-9 Process for creating TMU database

The various problems related to data sharing are due to differences in the abstraction levels and the differences in use context as shown in figure 1-2 during the problem definition for this study. The adoption of watershed approach and TMU concept in data acquisition provides a basis for different aggregation levels and vertical linkages between these levels. It also helps in solving the problems of data gaps as the information on soil, geomorphology and lithology are inherent in TMU data. The provision of semantic layer in data model facilitates for the horizontal linkages in the use of data in different context.

5.4 Reengineering in information sharing mechanism

5.4.1 Set up a formal data sharing mechanism

As discussed in chapter 3, the present practice of information sharing in the organization is on ad hoc basis. This creates problems in identifying the existing data, their sources and the proper path to acquire them. For a more structured and coordinated data sharing, a centralized unit for handling all spatial data exchange activities is proposed. In the proposed structure, an Information Systems Division (ISD) is responsible for this activity. ISD will maintain a metadata with all the relevant information on existing spatial data. Instead of going to each divisions looking for information, the user or the client will have access to the metadata which will also describe the costs and processes required to get the data. Once the requirements are fulfilled by the client, the data are retrieved from the respective archive, processed and delivered to the client. The data may be located either at the ISD, at the thematic divisions or at other organizations. The system will help in implementing a uniform pricing policy and making the information exchange systematic.

5.4.2 Use IT to setup a network for geoinformation sharing

The development in network technology has made it possible to create linkages and easy communications with organizations which are geographically distributed. The reengineering plan proposes to develop an electronic network of the various organizations involved in use of geoinformation which are willing to collaborate in sharing of these information. The collaboration can work on developing or adapting international standards to suit the local environment. Use of the Internet and Intranet has become quite common in the region, and the organization can benefit from these technologies in developing a network in the field of geoinformation.

5.4.3 Use IT to provide new geoinformation services

The ISD will automate the information sharing mechanism with added geoinformation services. The available functionality of information technology will be exploited in the automation process. The organization can start the following services based on IT which will further facilitate the task of geoinforamtion sharing.

- Catalogue data service
  ISD will develop and maintain a metadata to provide meta information on the existing geoinformation. The metadata structure will be based on international standards, e.g. FGDC, adopted to fulfil the mountain specific issues. The metadata will include information on the contents, lineage, quality, attributes and distribution of the available data. Working closely with the thematic divisions and the collaborating institutions, it will continuously update and maintain the metadata along with the information on the location of the data and procedures to acquire them. ISD also has the responsibility of compiling and maintaining the core databases whereas the thematic divisions will be responsible of collecting the data in their respective fields. The data will be maintained within the divisions and the metadata will be added to the central metadata at the ISD.

- Online GI request and delivery service
  This service will facilitate the users to order the readily available geoinformation through the Internet and will provide the down loading facility after fulfilling the necessary conditions for eligibility to acquire the data and payment of the required charges.

- Online geoinformation processing service
  The developments in Internet GIS technology have made it possible to provide spatial analysis functions through the Internet. A large portion of the users in the region who do not possess GIS facilities can benefit from online geoinformation processing services. The service will include the functions for spatial analyses, which the user needs to perform on the data, and only the final results are downloaded by the users.

The system architecture for the proposed information sharing mechanism and the process of on line geoinformation services is presented in the next chapter.

5.5 Conclusion

The reengineering plans for data collection and information sharing are discussed in this chapter. The use of IT for networking the geoinformation community and introducing new geoinformation services are proposed. The next chapter will discuss the development of GII which is necessary for implementing the proposed services and materializing the coordination among the geoinformation users.

6 GII Specifications

6.1 Introduction

Chapter 5 discussed the reengineering plans to achieve a coordinated and integrated data collection and sharing. Development of GII provides a framework for solving the diverse problems in generating geoinformation and facilitating its effective and efficient use by all potential users. In the context of the reengineering plans proposed in the previous chapter, this chapter discusses the various components of GII and proposes a system architecture for its implementation. The vision for GII is presented in section 6.2. The components of GII are discussed in section 6.3. Section 6.4 presents the specifications for GII based on operational, technical and system architecture. Section 6.5 discusses the implementation plan.

6.2 GII vision

GII is proposed as an enabling infrastructure, a collection of people, doctrine, policies, architectures, standards, and technologies necessary to create, maintain, and utilize a shared geospatial framework [NIMA, 97]. The GII establishes a framework for acquiring, producing, managing, and dissemination of geoinformation. It provides the supporting services needed to ensure that the information content meets user needs, is easily accessible, and can readily be applied to support the information requirements. GII ensures the supporting infrastructure components are in place to optimize the use of the geoinformation, products and services provided.

"Systematic exchange of knowledge and experiences through an organized information network" is one of the main objectives of the organization [ICIMOD, 98]. Sharing of information and knowledge is a part of all its activities on different mountain development issues. These activities require the integration of information in different applications and at different levels of decision making. One of the major strategies identified for improving the performance of the organization is the integration of multidisciplinary activities. The coordination with different divisions within the organization and external organizations in data collection and data sharing activities play important role in achieving the integration goal. GII provides a framework to benefit from the potentials of information technology in achieving these goals. In this context, developing a GII in the organization will have the following objectives:

- To achieve horizontal and vertical integration of information for the promotion of data interchange and system interoperability for better decision making
- To facilitate the identification of existing relevant information
- To achieve better coordination in data collection and geoinformation generation

- To develop and maintain key regional datasets
- To provide easier and consistent access to data and information for better sharing of resources

6.3 Components of GII

Components of GII can be classified under two main categories – institutional and economic components, and technical components [Radwan et.al. 98]. These components are briefly discussed here in the context of the organization.

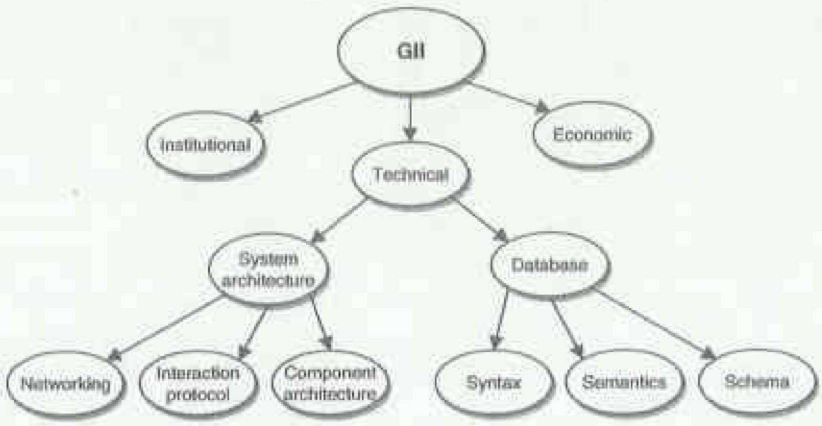


Figure 6-1 Components of GII

6.3.1 Institutional components

Organizations

GII involves all the organizations which are concerned with the task of information generation, sharing and use. This includes all the partner institutes the organization is working with, and the users of the information generated or disseminated by the organization. These collaborating organizations can be seen as international partners, regional partners and national partners. The information generated or sought by these organizations vary in scale, area of coverage and data contents. The responsibilities of the collaborating organizations in the task of generating and disseminating geoinformation should be clear for a better coordination and synthesis of information. Besides, it also includes the national and regional organizations which influence or are responsible for the development of regulations and standards.

A list of the collaborating institutions with the organization is given in Annex 3. The list includes government agencies, NGOs and private organizations which are diverse in their disciplines, physical infrastructure and political setup.

Data resources

The major sources of basic topographic and thematic databases in the region are the national mapping agencies and the government line agencies. The functions of these organizations and linkages with them have big influence in the implementation of GII. Besides, the research institutes and INGO/ NGOs are also the sources of data on various themes. Many of the institutes listed in Annex 3 are also sources of information on their respective themes in these countries.

Human resources

The field of geoinformatics is rapidly changing with the advances in information technology and the organizations need to keep their manpower up to date with the technology. Ability to manage and benefit from geoinformation technology is based on education and experience. In collaboration with thematic divisions and other institutions, MENRIS conducts various trainings on GIS and RS. These training programmes by the organization on the application of GIS to different aspects of natural resources management is contributing to develop awareness and skill on the technology among the personnel of various national institutions. These special training programmes targeted to different functional levels such as policy makers, managers and technical level are important for the development of the proposed GII. However, timely modifications are needed in the contents of trainings to accommodate the changing trends in technology.

Regulations for data acquisition and sharing

Policy issues play major role in collection and sharing of geoinformation. This is more significant when the work area crosses political boundaries. The different legal structures in different countries often become barrier in the development of GII in the regional context. The restrictions in data from different strategic areas (e.g. international borders, disputed areas) create data gaps.

Data access policy

Many government organizations require long formalities to be completed before releasing data. There are difficulties in mechanisms for sharing data between the public and government agencies as they have different data access policies, and many times, restrictions to releasing information. These restrictions are stronger when the information needed cross the political boundaries. However, the availability of satellite images from commercial sources has helped to overcome these difficulties to some extent.

Pricing policy

Most of the data are generated using government funds and there are no fixed policies regarding the cost recovery of the process. The pricing issues are more complex with digital data as their nature is totally different from conventional analogue products. Cost is also a major factor for use of data by potential users. The organization should work out a pricing policy such that the data are available to the users at reasonable cost, the activity of data sharing can be supported by the revenue generated, and more organizations are willing to participate in the common platform for sharing their data.

Copyright issue

The enforcement of copyright law is not strong in the region and this hinders the sharing of digital information as it can be easily manipulated and misused. The owners of information should be protected by laws to reduce the mistrust among the users. The development of GII requires the cooperation among organizations involved in various aspects of geoinformation production and application. A formal committee with representatives of these organizations will be needed to recommend policies and pressurize concerned authorities for the enforcement of these protecting laws. With ICIMOD's linkages to many government organizations, research institutes, and NGOs, it can facilitate to form such formal committees for geoinformation sharing.

6.3.2 Technical components

The technical components of GII include the techniques for the provision of up to date inventory of available data, mechanisms for seamlessly sharing information, update and consistency constraints [Bishr, 97]. The technical issues mainly focus on providing interoperability at various levels for information sharing. These are viewed from two different perspectives - data modeling perspective and system architecture perspective.

Data modeling perspective

The three components of data modeling perspective are syntax, semantics and schema. *Syntax* defines the classic data structures in GIS such as the field and the objects. GIS theory formalizes the handling of geometry and topological relationships of fields and objects. *Semantics* is defined as the discipline which deals with relationships between words and the things which these words refer. In the data modeling domain, semantics is concerned with the study of the meaning and relationship between real world features and database objects [Bishr, 97]. *Schema* is the structured description of the information available in a database. It provides a consistent framework for object hierarchies such as generalization and aggregation in data models.

Systems architecture perspective

The system architecture deals with information systems, and information networks and services. These include different geoinformation and database management systems, system platforms and network protocols.

6.4 Architecture of GII

Architecture is defined as "*the structure of components, their interrelationships, and the principles and guidelines governing their design and evolution over time*"[NIMA, 97]. The guidelines for architecture planning and development established by the C4 (Command, Control, Communications, Computers, Intelligence) Integration and Support Activity (CISA) decomposes architecture into three views – the operational architecture, the technical architecture and the system architecture.

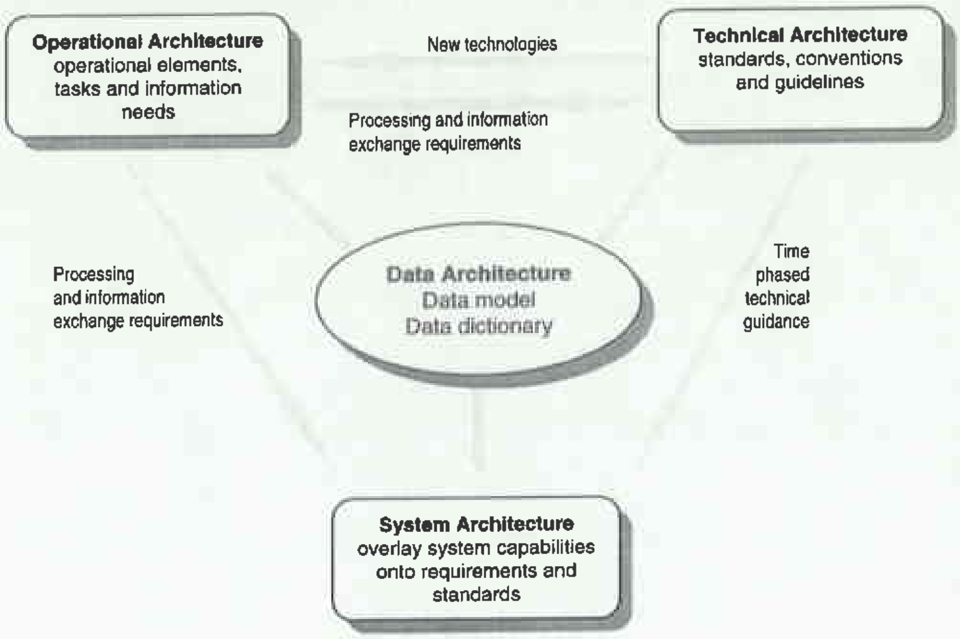


Figure 6-2 Architecture views [NIMA, 97]

The *operational architecture* describes operational elements, tasks and information exchange required to accomplish the mission functions. It is driven by mission needs and operational requirements of the users.

The *technical architecture* documents the standards, standard profiles, and reference models to support interoperability.

The *system architecture* describes the component hardware, communications, and software systems that support accomplishing the mission. Primary function of system architecture is to provide a basis for an affordable, mission supporting evolution of the future systems.

6.4.1 Data architecture

The standardized development of data models and data dictionaries is central to the GII architecture. Data models are needed to support the seamless information access and interoperability. Data architecture provides the common data modeling and semantic base needed to integrate each of the other component architecture views. The data models should meet the requirements of the operational architecture to support the different activities of the organization. The data model for water resources management has been discussed earlier in chapter 5.

6.4.2 Operational architecture

The operational architecture describes the context, activities, operational relationships and internal and external flow of information and services. The operational concept diagram shows the flow of information within and outside the organization.

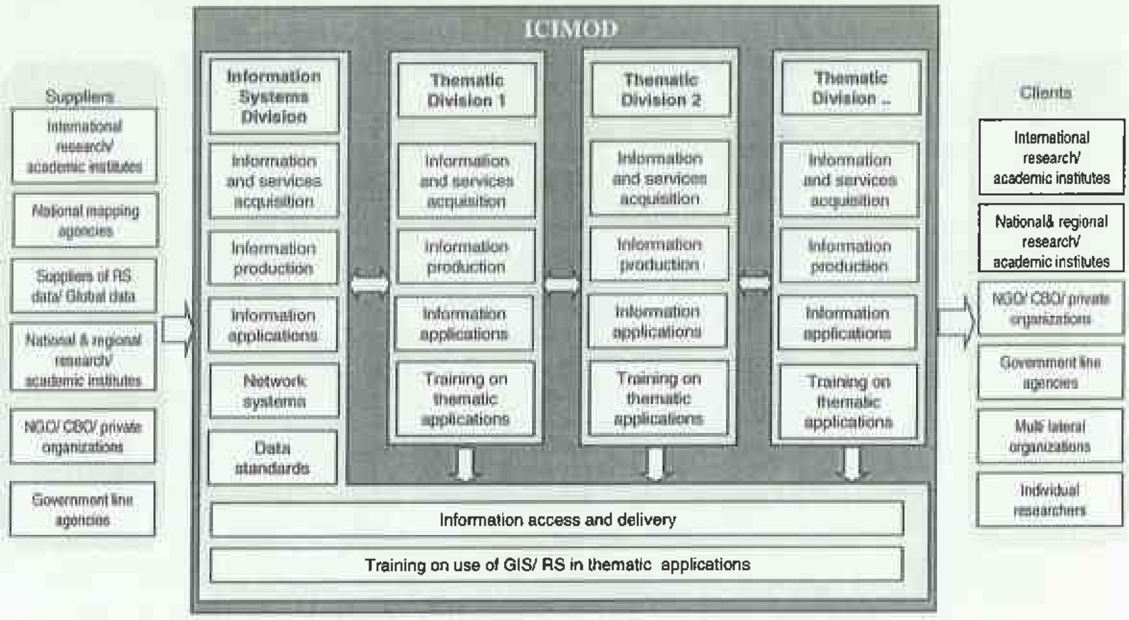


Figure 6-3 Operational Concept Diagram (only the activities related to geoinformation are considered)

The GII architecture is based on the existing organizational structure with the thematic divisions and a support division for information systems, ISD to handle the exchange of geoinformation within and outside the organization. The external organizations are viewed as suppliers and clients. However, the same organizations can act as suppliers as well as clients.

The suppliers

The suppliers are the providers of information and services to the organizations. These include the national and international research and academic institutes which provide data and research findings, the national mapping organizations which provide the foundation data, the vendors of RS images, the government line agencies, NGOs and private organizations. The suppliers are either national organizations in the regional countries in case of local level data, or they are international organizations which provide global datasets.

The clients

Clients are the users of information produced or disseminated by the organization. These are again the national and international research institutes, government agencies, multilateral organizations, NGOs and CBOs, and individual researchers.

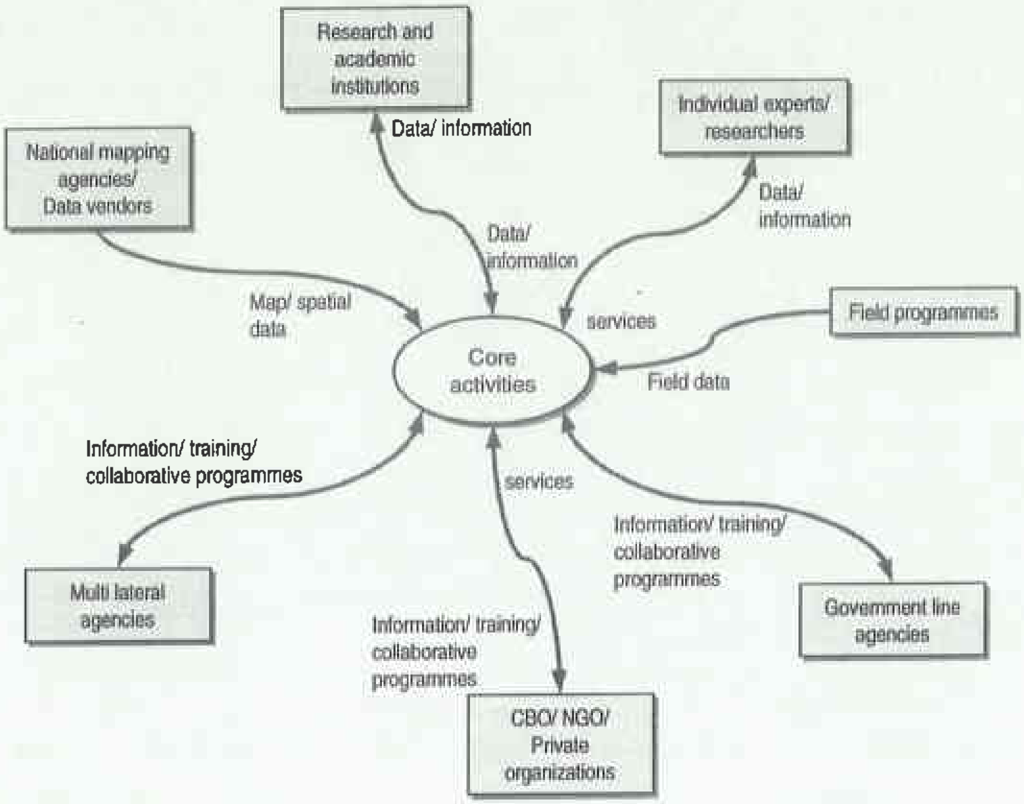


Figure 6-4 Top level context diagram

Business functions

The functions common to all divisions of the organization are identified as information and services acquisition, information production, information applications and training on thematic applications. The functions of the Information Systems Division are related to development and maintenance of the information sharing mechanism. These are developing network systems, standards for acquisition and sharing data, information access and delivery, and training on application of geoinformation technology. This will be the major division responsible for implementing GII.

1. Information and services acquisition

   This includes the purchase of maps, data or images and services such as digitization, aerial photo/ image interpretation from the outside organizations for use in its GIS/RS works. The information or service providers are the government or non-government agencies and private organizations. This activity takes place in different divisions according to the needs in the respective research/ project work.

2. Information production

The activities on development of key spatial and non-spatial databases of the region have been envisaged as a major effort in the development of GII. Apart from that, information is produced from the various studies carried out under divisional, interdivisional or collaborative programmes. The development and maintenance of core data sets is the function of ISD. The thematic divisions are responsible for developing the application specific or mission data.

3. Information applications

The different case studies and research programmes are targeted to the application of geoinformation technology to various themes. These functions acquire data from internal and external sources as well as generate their own databases during the process.

4. Information access and delivery

The above three functions take place within each division as well as interdivisional activities. Information access and delivery has been proposed as a function of the ISD. This division is responsible for all the technical support needed for the development of GII. This includes the following activities:

- Development of guidelines for standards in acquisition and sharing data
- Development and maintenance of network systems and applications for information access, query and delivery
- Development and maintenance of metadata
- Training on application of geoinformation technology
- Develop, compile and maintain core databases

This division can be seen as a clearinghouse of information and knowledge for the use of geoinformation technology in the region. Figure 6-5 shows the operational architecture of the GII based at ISD. The suppliers and clients in this figure represent the suppliers and clients shown in figure 6-3.

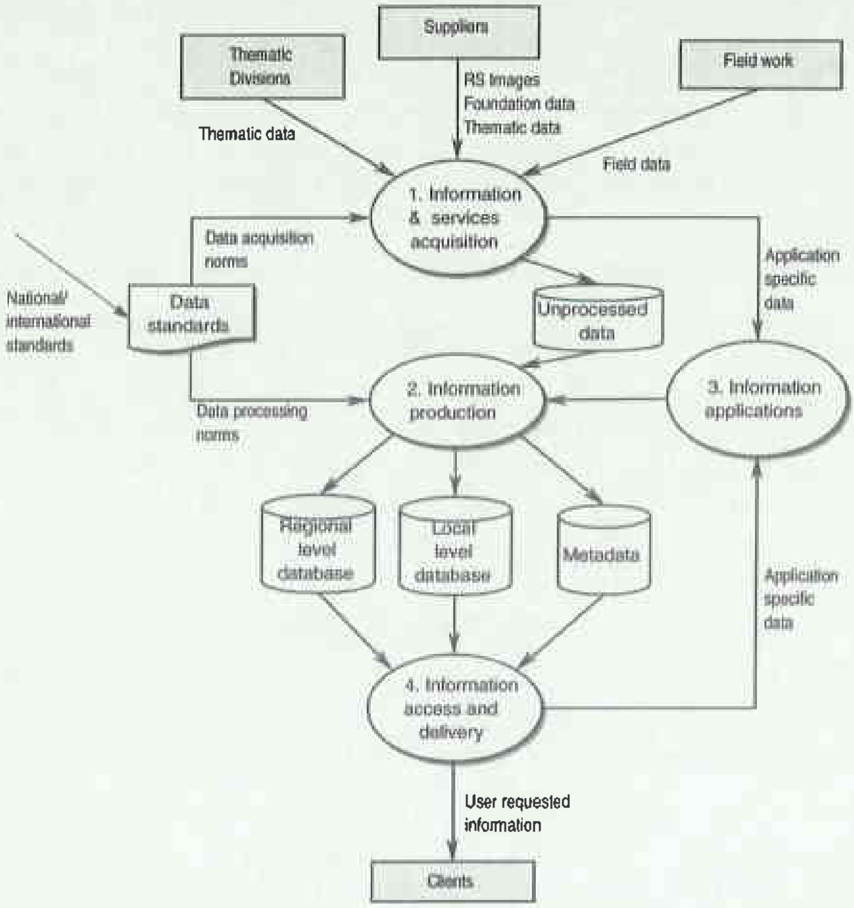


Figure 6-5 Data flow in Operational architecture of ISD.

6.4.3 Technical architecture

The technical architecture defines the rules governing the arrangement, interaction and interdependence of the system components. It is based on the requirements defined by the operational architecture and analyses of possible enabling technologies. The technical architecture view provides the technical systems-implementation guidelines upon which engineering specifications are based, common building blocks are established, and product lines are developed. Information system paradigms for data processing, database design and communications network design strongly influence the technical architecture. The technical architecture accounts for the requirements of multi platform and network interconnections among all systems that produce, use and exchange information electronically. It should accommodate new technology, evolving standards, and the phasing out of old technology. The rules of the technical architecture are defined in terms of nonproprietary specifications reducing the reliance on proprietary technologies. The technical architecture in thus study is proposed to be based on distributed systems and web technology.

Enabling/ emerging technologies

According to [NIMA, 97], the key technologies that enable to enhance production, exploitation and dissemination of geoinformation can be organized into three broad categories – the core technologies, the common support technologies, and the important technology trends (table 6-1).

Table 6-1. Categories of technology [NIMA, 97]

Core Technologies	Common Support Service Technologies	Important Technology Trends
▪ Computing infrastructure and hardware ▪ Computing model ▪ Operating systems ▪ Communications ▪ Networks ▪ Database management systems	▪ Information production and information applications ▪ Imagery and Image processing ▪ Geographic information systems ▪ Document management ▪ Automation products	▪ Componentware ▪ Object technology ▪ Applets ▪ Open computing ▪ Intelligent software agents ▪ Open agent architecture ▪ Collaborative computing ▪ Multimodal user interface

The *core technologies* category includes data repository services, platform and operating system services, network services and other hardware services. There are only a few needs specific to geoinformation community at this level. However, the developments in this area greatly effects the performance of the geoinformation applications. *The common support service technologies* rest above the communication and base system services, but below the layer of mission specific applications. These provide tools for geospatial analyses, database services, geospatial catalogues, image processing services and other support activities. The *technology trends* show the future direction of the industry with the new developments in the technologies. The vision of how today's technologies will evolve and the new technologies will become prominent is important for a sustainable GII.

The GII architecture is built using distributed or network centric computing models which demand platform independent technologies, open standards and scalable technologies. The relevant technologies are discussed in annex 1.

6.4.4 System architecture

The system architecture defines the physical connections, location and identification of key nodes, networks and platforms to satisfy the operational architecture requirements on the basis of technical architecture.

The proposed system architecture for GII is shown in figure 6-6. The system consists of the internal and external environment with ISD as the central component. The system can be grouped into three components – the client or the front end, the ISD in the centre, the thematic divisions and the regional and international data providers at the back end. The system configuration is shown in figure 6-7.

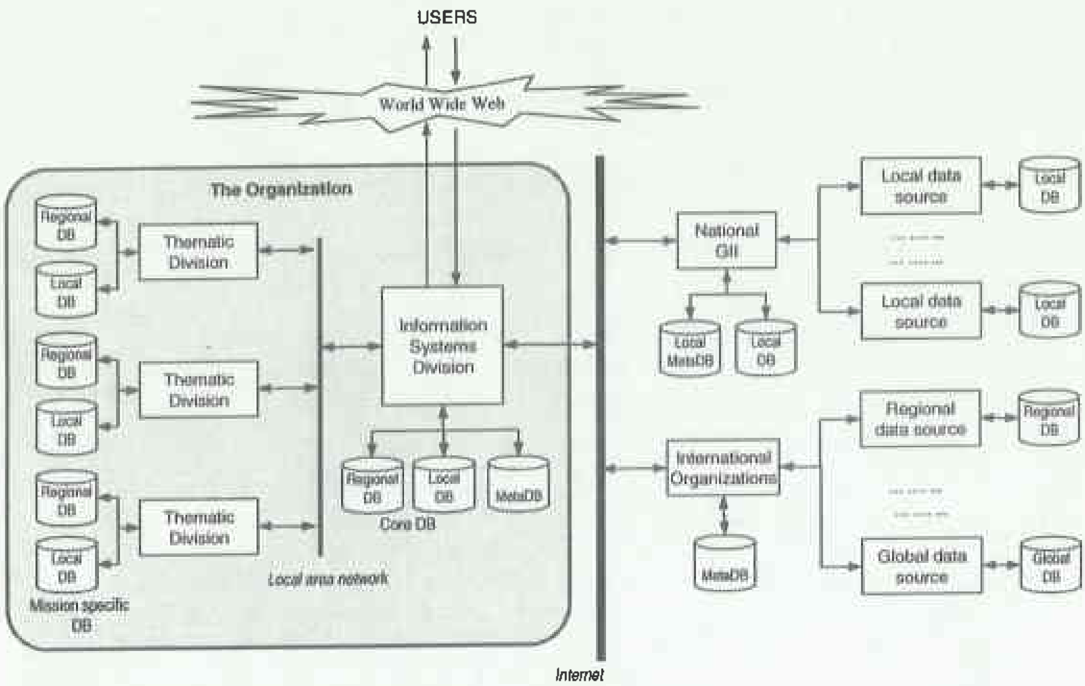


Figure 6-6 The system architecture of proposed GII

The client (front end)

The client or the front end contains the graphical user interface for the WWW browser. It gives the user to browse the metadata, send request for the available services, and download the requested data and services.

The Information System Division (central part)

The ISD plays the central part in the system architecture, linking the users to the various data sources, and providing the requested services. It consists of metadata server, web server, application server, and data servers to provide the core local and regional databases.

The *metadata server* stores the information on the available databases and services in ISD, in the thematic divisions, and other national and regional organizations which are accessible through the system. It provides the facility to browse and query the meta information. The *web server* maintains the web page on the WWW, and provides functionality for service request and delivery through the Internet. It provides a link to browse the metadata or send requests to the application server. The *application server* provides data retrieval service, GIS functions, and mapping operations for the databases as required. The *data servers* store the core databases of the region at local and regional scales which are most widely requested by the users and the thematic applications.

The thematic divisions (back end)

The thematic divisions are the users and producers of application specific data. They are linked to the ISD through local area network or the Intranet. They consist of the data servers for local and regional databases on the related themes.

The national and regional data providers (back end)

These are the national and international institutions collaborating with the organization in the task of geoinformation development and sharing. These include national and regional GII centres and clearinghouses which further link with other data sources. Hence, the system can be visualized as a network of networks.

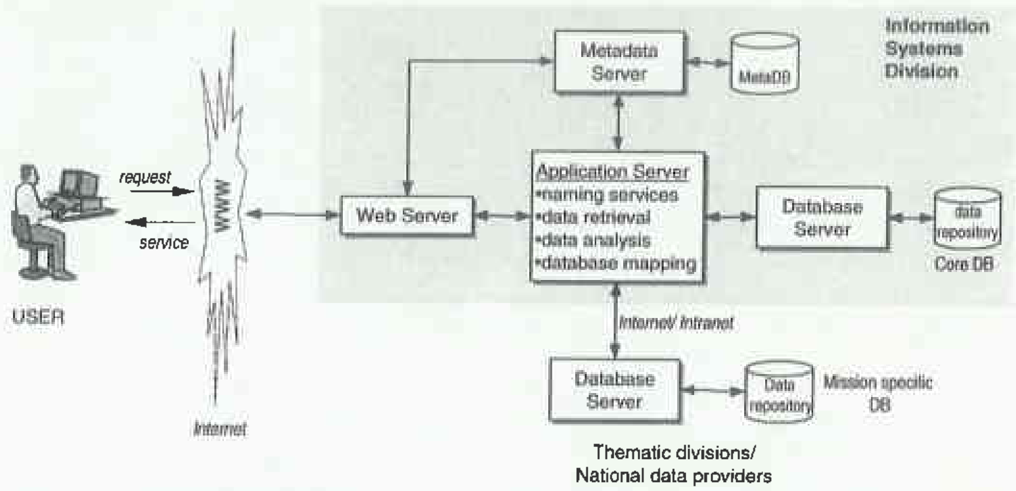


Figure 6-7 System configuration

Multi Level Decision Support System

The ISD is mainly responsible for facilitation of information flow within the organization and the external users. The thematic divisions are involved in the different research and management activities. These divisions possess the expertise and mandate on specific disciplines related natural resources and ennvironment management. The need for MLDSS are in these divisions where the studies on linkages at local and regional levels are carried out. The proposed architecture of MLDSS adapted form [Radwan et.al. 96] is shown in figure 6-8.

Each division has data at local level to support the requirements at local scale. The regional level database supports the needs at regional scale. The multilevel global server provides the linkages at different levels. These systems are connected to ISD with intranet for the core datasets. There are also linkages with the external data providers through the ISD network.

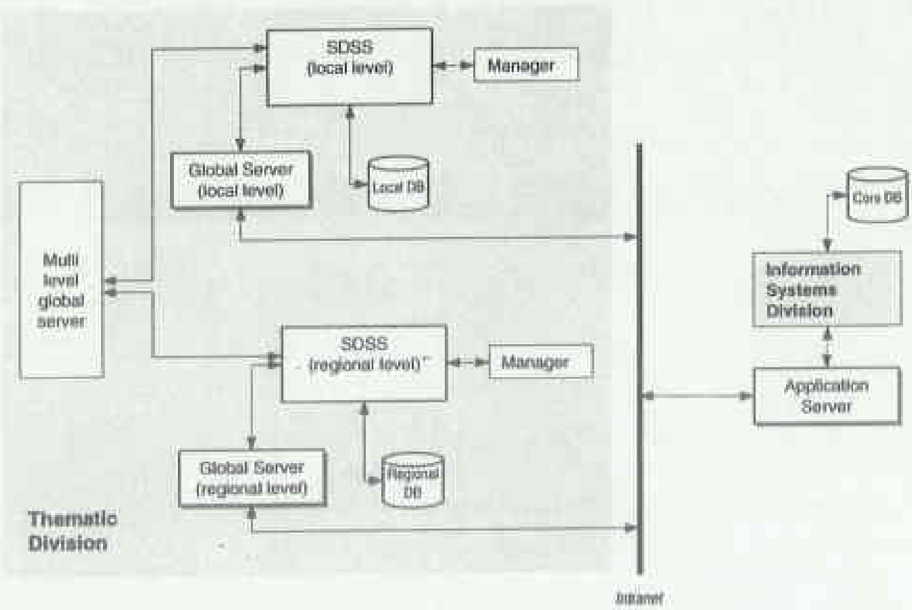


Figure 6-8 MLDSS at the Thematic divisions

On-line GeoInformation services

Automation of information sharing and introduction of new geoinformation services based on the potentials of IT are among the reengineering plans proposed in the previous chapter. Figure 6-9 shows how the on-line geoinformation services are handled by the system.

The user has assess to the metadata through the Internet. The request for the data or services is sent through the Internet using the standard forms provided in the web page. First, the information on the requested data is searched in the metadata to find out whether the data is available in its local server, the servers of the thematic divisions or other organizations collaborating in data services. If the data is available and the user is eligible for the requested data and/or services, the data is retrieved from the respective servers. The data is offered for downloading if no processing is requested. Data processing and analyses are carried out if requested and the results are offered to the user through the Internet.

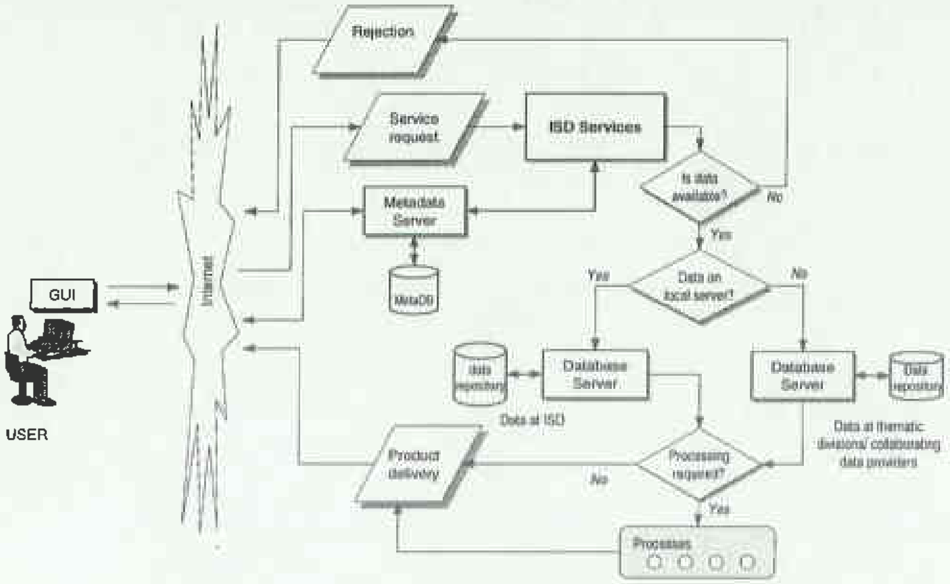


Figure 6-9 On-line geoinformation services (developed from Radwan, 98a)

6.5 Implementation plan

The implementation of the plans at strategic and functional level needs consideration from different perspectives. From the institutional point of view, the organizational structure will remain the same. The proposed activities of ISD can be seen as the responsibilities of the MENRIS division in the present structure (see discussions in chapter 2). However, some responsibilities of the present ICOD division, which is looking after the management aspect of the electronic networking of the institutions, may fall within the activities of the proposed ISD.

The existing collaboration with national and regional organizations will be a foundation for making the necessary arrangements for data collection and sharing network. However, the collaboration will be needed on long term for institutional development rather than on project basis. Cooperation among organizations related to geoinformation technology and applications can be intensified by creating a wider cooperation committee with representatives from sectors of data production, research and education, and the business sector. These collaborations will be necessary to develop standards, and make recommendations for policies at various levels. On the regional perspective, collaboration with regional bodies like South Asian Association for Regional Cooperation (SAARC), which is a political commitment on regional development, will be beneficial. Its technical committees on science and technology can play an important role in the development of regional GII.

From the technical point of view, the organization is well equipped with the hardware and software, and networking infrastructure. The existing activities on electronic networking like

NepalNet can serve as a foundation for developing GII and implementing the new on-line geoinformation services. There are not much technical difficulties except differences in telecommunication infrastructure in the countries of the region. However, with growing use of the Internet technology and the initiations from the public organizations, a better environment can be expected in the near future.

The training programmes by the organization on application of GIS/ RS is contributing in developing the human resources which is important for the developing and sustaining GII. These programmes are creating awareness among the policy makers as well as generating operational skill among the users. This can be seen as a good environment for developing GII.

The major drawback and the acute need for GII in the region has been due to poor information resources. The difficult natural setup creates complexity in data collection. With the proposed collaboration activities and the development of standards, the activities on development of metadata and foundation databases can be implemented. However, it will be a long term process and needs commitment and patience from all the stakeholders.

Another important aspect for implementation is the financial resources. In the beginning, contribution from the regular programmes of the organization can be used to initiate the implementation. Pricing policies for generating revenue from information sharing activities to sustain the system will be needed on the long term. Eventually a clearing house as a separate institution, self sufficient for regular functioning, may be developed.

6.6 Conclusion

This chapter discussed the development of GII in an architectural framework. The operational architecture, technological trends and the system architecture are presented for the organization in the context of local and regional data sharing. The next chapter will provide the overall summary of the study and conclude with recommendations for further work.

7 Conclusion and Recommendations

7.1 Introduction

The work described in this thesis is summarized in this chapter. Conclusions are drawn and issues for further research are indicated.

7.2 Summary

Management of natural resources has become a challenging task due to rapid population growth, poverty, marginality, inaccessibility and limited understanding of environment in the mountainous region like the Hindu Kush Himalayas. The advances in information technology and GIS have provided promising tools for decision support in managing these resources. However, the potentials of these technologies are underused due to absence of a proper framework for database development and sharing. There is a need for a formal approach to provide a common ground in developing data models to resolve the heterogeneity in data and reuse them in different applications. The present practice of data collection and sharing on ad hoc basis is the main factor for inefficient use of GIS technology in the region. The reengineering of different processes in data collection, database design, and data sharing mechanisms is needed for a more economical and useful development of information base. The rationale of this thesis is to identify the problems in data collection and sharing practices, and to set reengineering plans to support the development of GII for natural resources management, namely the water resources. The study is carried out taking ICIMOD as a case, which is involved in various issues of mountain development in the region.

A general overview of the problems and the research objectives are presented in Chapter 1. It gives a general outline of the need for GII to solve problems in use of geoinformation. The organizational setup of ICIMOD, its activities on water resources management, and the current practices in spatial data collection and sharing are presented in chapter 2. The performance issues are discussed. The main problems are identified as lack of sufficient integration in interdisciplinary activities such as water resources management and lack of coordination in geoinformation generation and sharing, which is also contributing to the earlier integration problem. Chapter 3 studies the external and internal environment of the organization using the SWOT analysis as well as the opportunities offered by new IT to formulate the improvement strategies. The strategies are proposed for improved integration of multidisciplinary expertise, exploiting the potentials of available IT for better sharing of information and introducing new services, and stronger partnerships with the collaborating organizations in the field of geoinformation. The need for reengineering of the current practices, development of GII and MLDSS are realized to implement the improvement strategies.

The understanding of the management processes is necessary to identify reengineering plans. For this, the processes in various activities in water resources management are studied in Chapter 4. The management objectives at local and regional level are discussed. The processes in irrigation and drinking water supply, soil erosion and conservation, land use/ land cover dynamics, and the estimation of regional water balance are analysed and modeled to identify the information needs at different stages of management. Chapter 5 presents the reengineering plans. The watershed approach for data collection framework, TMU approach, and object oriented data modeling with semantic information are proposed for improvement in data collection activities. Setting up of a formal data sharing mechanism within the organization, networking, and introduction of new services based on the emerging information technology are proposed as the reengineering of geoinformation sharing process. These reengineering processes are essential for the development of GII.

The specifications for GII are presented in chapter 6. It discusses the operational, technical and system architecture for GII in the context of the organization. The proposed system architecture using the web technology, MLDSS and the implementation plans are discussed in this chapter. This fulfils the research objective of developing a system architecture for GII for water resources management.

7.3 Conclusion

The following conclusions are drawn from the research.

- The region is data scarce and a lot of activities are focussed on data collection. There is a need for a formal approach to provide a common ground for developing data models so that better sharing of information can be facilitated.

- The major factors contributing to problems in data collection and sharing are – lack of coordination and integration in multidisciplinary activities, lack of data, lack of quality standards, and lack of data sharing policies.

- Reengineering in various practices of data collection and data sharing is necessary to support GII. Process modelling tools and formal structures for data modelling are useful for reengineering and designing interoperable systems.

- A spatial reference system is needed for integrating data at local and regional levels. The use of watershed and TMU approach for data collection provides a spatial framework for aggregation at different levels. The use of formal techniques in data modelling and process modelling helps in identifying possibilities of sharing data across different disciplines for various interrelated processes.

- IT has provided many new possibilities for networking and sharing of information. The organization can achieve much of its objectives on "information and outreach" by exploiting the potentials of IT. The use of Internet technology for sharing geoinformation and introduction of on-line geoinformation services will have a big impact on the application of GIS technology in the region.

- Development of MLDSS and GII will help in integration of various activities of the organization between different disciplines and at different levels. It will facilitate information flow at different decision levels, thus providing better understanding of linkages at micro and macro scales.

7.4 Recommendations for further research

- The information needs presented in this research are in general terms. Numerous models are common in hydrological modelling, water resources management and soil erosion modelling, each having its own assumptions for natural processes and consequent information requirements. The usefulness of these models depend upon physical conditions and scale of the area considered. A detailed study in the field, with concentration to a particular geographical area can come up with better linkages in information requirements and with better optimization possibilities in collection and sharing of data.

- This study has been carried out taking the case of only one organization. Although the mandate of the organization involves multiple disciplines, multiple nations, and multiple scales, a detailed study involving more organizations in different political and institutional setup is needed to come up with regional solutions for GII.

- The concept of providing on-line GIS functionality through the Internet is new and still to be proven in the real applications except for some examples provided by the commercial software developers. The field provides great opportunities for research on data processing, security and reliability issues of such systems.

- Both water resources management and GII involve complex political, institutional, technical and economic issues of their own. The scenario is more complicated when dealing at regional scales involving multi national and multi cultural issues. Much research work is needed on institutional aspects of GII for benefits of GIS technology in integrated water resources management.

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Annex 1

Enabling/ emerging technologies for interoperability and distributed systems

Distributed systems

Distributed system refers to a distributed collection of users, data, software and hardware whose purpose is to meet some defined objectives [Radwan et.al., 98]. The description of a distributed system includes the specifications for physical networking, system services and application software. The computer systems provide in general four types of interrelated services – data storage services, data access services, application services and presentation services. These services can be distributed in several ways in distributed systems. In the context of GII, distributed systems provide the GIS users a means to share spatial information, application and representation services in a heterogeneous, distributed environment.

Client server architecture

Client-server computing is now synonymous with any form of distributed computing [Bakman, 95]. In a client server model, one application, the client, sends requests to another application, the server, for services. The requests are processed by the server and sent back to the client. The client server designation is not a physical attribute, but a role that an application takes on particular point of time. The application that is a client in one instance can become a server in another instance. The components of a client server model can are – the client, the server, and the connectivity.

- Client is primarily the consumer of services provided by one or more server processors. The client always sends requests and receives results. The communication is always initiated by the client.
- Server provides the requested service e.g. application, file, database, print, communications, security, network management etc. to the clients.
- Connectivity between the client and the server is the most important component. It includes the physical connectivity and the protocols for communication at different levels.

The client server architecture distributes the workload between the client and the server. In the *thin client/ thick server* configuration, the data and the functionality remain in the server computer and the major application processing occurs on the server side. In the *thick client/ thin server* configuration, the user requests for the data and functionality which is then downloaded on the client computer for local processing. Figure 1 shows the assignment of functions to the client and server components in different configurations.

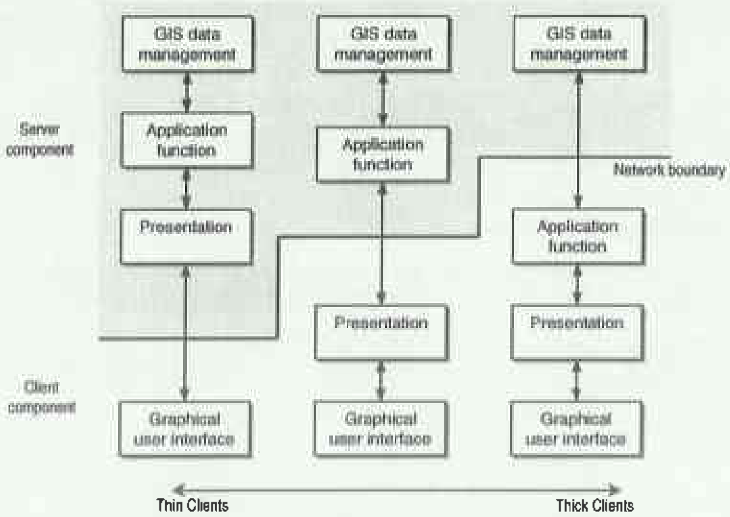


Figure 1 Assignment of functions in client server architecture (adapted from Abel et. al., 98)

The Internet

The Internet originated in 1969 as a special communication tool among selected academic and governmental researchers [Lu et.al. 98]. The major Internet applications were email, file transfers and list servers. With the development of user friendly browsers, increase in World Wide Web (WWW) applications have been exponential. Many businesses are using the Internet as a new information exchange channel. The Internet has changed the way information can be accessed, shared, disseminated and analyzed.

The Internet GIS is an emerging technology which provides widespread accessibility to spatial data and GIS functions over the Internet. It has made possible to publish interactive maps and spatial data on the Web. GIS on the Internet gives interactive query capabilities, and the Internet mapping is coming up as an inexpensive method for reaching a vast audience. The easy to use browser based formats has made sophisticated GIS applications usable by everyone over the Internet.

Distributed Computing Environment (DCE)

Distributed Computing Environment (DCE) is a suite of technologies from the Open Group, a consortium of computer users and vendors who work together to advance open systems technology. DCE technology was designed to operated independently of the operating system and networking technology that the applications use, thus enabling the interaction between clients and servers in any type of environment.

DCE consists of software services that reside on top of the operating system, middleware that employs lower-level operating system and network resources. It provides tools for developing distributed applications, and services for running distributed them. The DCE services include:

- *Remote procedure call* (RPC) facilitates client-server communication for the applications to effectively access resources distributed across a network.
- *Security Service* authenticates the identities of users, authorizes access to resources on a distributed network, and provides user and server account management.
- *Directory Service* provides a single naming model throughout the distributed environment.
- *Time Service* synchronizes the system clocks throughout the network.
- *Threads Service* provides multiple threads of execution capability.
- *Distributed File Service* provides access to files across a network.

Common Object Request Broker Architecture (CORBA)

The Common Object Request Broker Architecture (CORBA) was introduced by the Object Management Group (OMG) to answer the need for interoperability among the rapidly proliferating number of hardware and software products available today. CORBA allows applications to communicate with one another no matter where they are located or who has designed them. CORBA defines true interoperability by specifying how Object Request Brokers (ORB) from different vendors can interoperate. The ORB is the middleware that establishes the client-server relationships between objects. Using an ORB, a client can transparently invoke a method on a server object, which can be on the same machine or across a network. The ORB intercepts the call and is responsible for finding an object that can implement the request, pass it the parameters, invoke its method, and return the results. The client does not have to be aware of where the object is located, its programming language, its operating system, or any other system aspects that are not part of an object's interface. In so doing, the ORB provides interoperability between applications on different machines in heterogeneous distributed environments and seamlessly interconnects multiple object systems.

With an ORB, the protocol is defined through the application interfaces via a single implementation language-independent specification, the Interface definition Language (IDL). ORBs let programmers to choose the most appropriate operating system, execution environment and even programming language to use for each component of a system under construction.

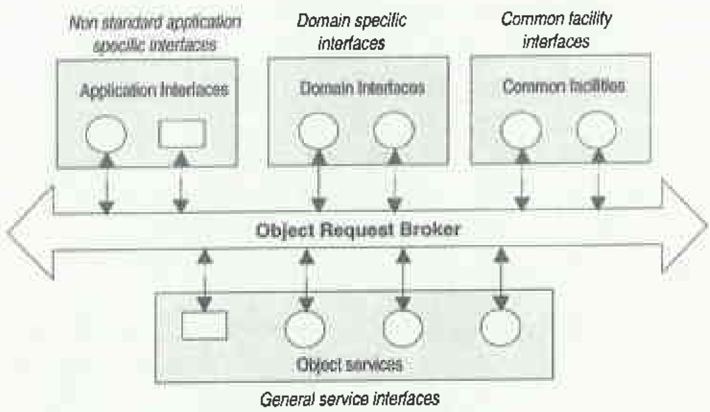


Figure 2 The OMG reference model (OMG)

They allow the integration of existing components. In an ORB-based solution, developers simply model the legacy component using the same IDL they use for creating new objects, then write "wrapper" code that translates between the standardized bus and the legacy interfaces.

Distributed Component Object Model (DCOM)

The Distributed Component Object Model (DCOM) by Microsoft is a protocol that enables software components to communicate directly over a network. DCOM is designed for use across multiple network transports, including Internet protocols such as HTTP. It is based on the Open Software Foundation's DCE-RPC specifications and works with both Java applets and ActiveX components through its use of the Component Object Model (COM).

DCOM is able to run clients and servers in different processes across an intranet or internet. A client asks the registry where the server is located and, instead of pointing it to someplace on the local machine, it points to an IP address. DCOM processes are spread across a network. DCOM directly and transparently takes advantage of existing COM components and tools. Any component that is developed as part of a distributed application can be reused to raise the level of functionality in the future. With DCOM's location independence, the application can combine related components into the machines that are close to each other onto a single machine or even into the same process. Components can run on the machine where it makes most sense. Its language independence enables rapid prototyping as the application developers can choose the tools and languages they are most familiar with. Another feature of DCOM is that the functionality is grouped into interfaces so that new clients can be designed that run with old servers, new servers that run with old clients or a mix and match to suit the programming resources.

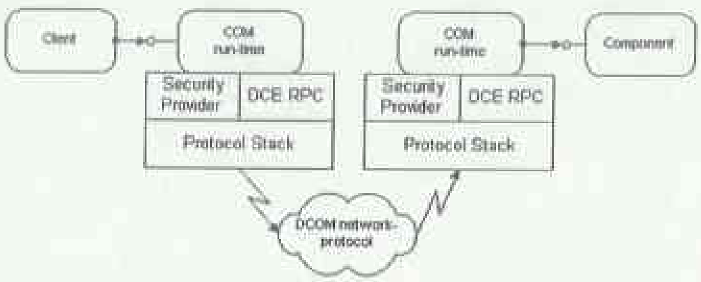


Figure 3 DCOM Architecture

Open GIS technology

The Open GIS Consortium (OGC) is a broad based alliance of government agencies, research organizations, software developers and system integrators [Gardels, 97]. The activities of OGC are aimed at solving the problem of data sharing through a mechanism which ensures that data transfer is application independent. The fundamental requirements of open GIS are interoperable application environment, shared data space, and heterogeneous resource browser. All these capabilities must coexist in a common framework that defines how system components interact. The open systems model is an approach to software engineering and system design that enables and encourages sharing of data, resources, tools etc. between different users or applications. The Open GeoData

Interoperability Specification (OGIS) is an attempt to design methods that provide an object oriented architectural framework for access to geodata, independent of the specific data structures and file formats used to model the data. From a user's point of view, OGIS allows access to geodata at remote locations in any format whereas from an application developer's view, it provides a set of network services to identify, interpret, and represent a dataset from a geodata server to a geoprocessing client. OGIS is an operational model and not a data standard. The overall premise of OGIS is a specific set of software tools for dynamically translating geodata from various sources into a single, comprehensive object based data model which can be directly accessed from applications using basic toolkit or primitive operations.

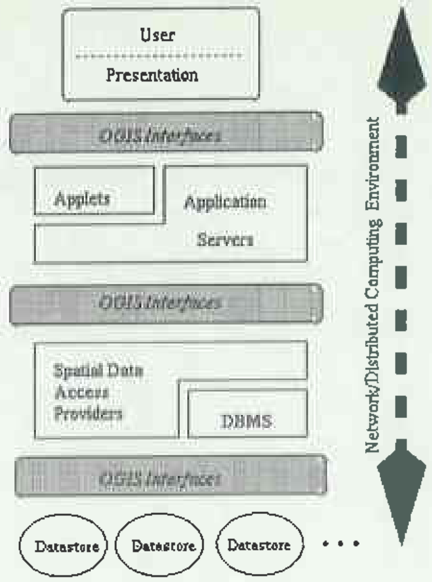
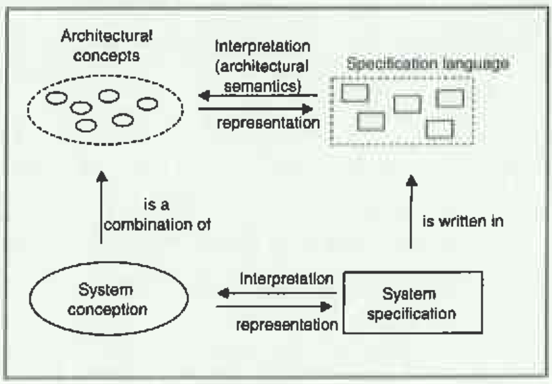


Figure 4Interoperable Geoprocessing Model [Gardels, 97]

Annex 2

Introduction to architectural approach for distributed system specification (UT model) [1]

Architectural Concepts



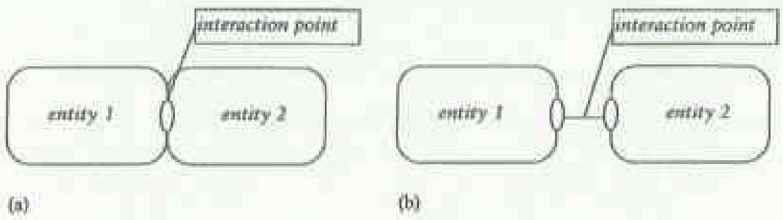
Architectural concepts are abstractions of system elements and model required characteristics of systems. They are the building blocks available to developers for modeling systems. The basic architectural concepts are based on elementary building blocks which include entities with behaviors, actions, interactions and relations between activities.

Entities

An entity is the carrier of properties. It models a logical or physical system or system part that carries behavior. The entity concept makes it possible to structure systems and their models as compositions of entities. When designing a new business process, structuring in terms of entities is important because the design serves as a prescription for implementation.

Interaction points

An artificial system is developed to perform a certain function in its environment. A logical or physical location at which an entity can interact with its environment is called an interaction point. Since an interaction point is a carrier of interactions, it can be viewed as an (abstract) entity. The interaction points allows to model a system in terms of solely the locations where the environment can interact with the system, thus shielding all other internal locations at which activities of the system takes place.



Two entities and their interaction point.

[1] Based on "Structuring of Business Processes – An architectural approach to distributed systems development and its application to business processes", Mark de Weger, 1998.

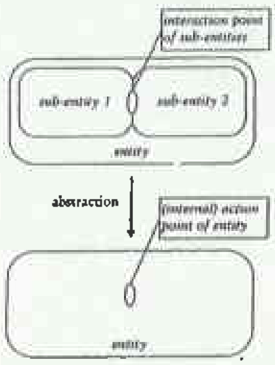
Entity (de)composition

An entity may consist of other lower level entities. By abstracting from the difference between these lower level entities, the higher level entity is viewed as an integrated whole. In tern, the higher level entity can be refined into the lower level entities. When the abstraction is not done from the interaction points of the entities, the result of abstraction is an entity with one or more internal interaction points called action points. The action points allows to specify where internal activities of an entity take place, without specifying which sub entities are involved.

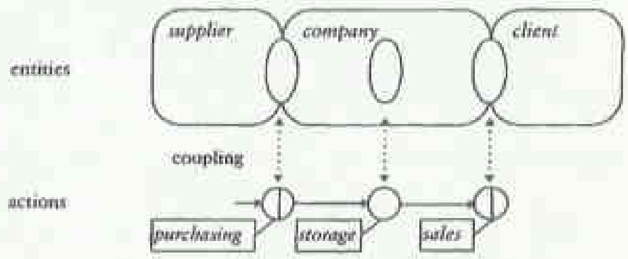
Actions and interactions

An activity is some happening in the real world. An action is an abstraction of an activity. The choice of aspects of an activity that are ignored by an action is based on the use of abstraction levels in the development process. At each level we would model what happens, whereas only at a lower abstraction level we model how this happens.

An action may be jointly carried out by multiple entities. Such an action takes place at an interaction point of these entities. An interaction is an action carried by multiple entities. It models a common activity of these entities.



Abstraction from difference between entities, resulting in higher-level entity with (internal) action point.



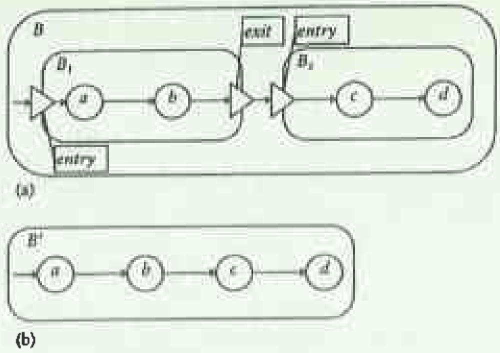
Coupling of actions and entities.

An activity has three essential characteristics that can be modelled as attributes. Alternative attribute values that can be established when an action occurs may act as constraints on these attributes. These attributes are:

- Information, I : result established in action
- Time, τ : time at which information is established and becomes available
- Location, λ : physical or logical location at which action occurs

Behaviors

A behavior is a set of related actions. A causality relation of an action defines the conditions for this action to occur. The causality condition defines how the occurrence of an action depends on the occurrences or non-occurrences of other actions in the behavior. A probability attribute defines the probability of occurrence of the action when the causality condition is satisfied. In monolithic behaviors which contain more than two actions, the occurrence of an action may depend on a combination of elementary causality conditions that involve multiple other actions.



Example behaviour represented (a) as causality-oriented composition of sub-behaviours, and (b) monolithically.

Behavior Composition

Behaviors are structured as compositions of sub-behaviors. In a causality-oriented behavior composition conditions in one behavior enable actions in another behavior. A causality relation whose result action depends on conditions defined in other behavior contains an entry point in its causality condition. A causality relation that defines conditions for one or more result actions in other behaviors contains an exit point instead of a result action. Entry points and exit points are only the syntactical constructs that represent conditions and result actions. In a constraint oriented behavior composition actions are, together with the conditions for their occurrence, distributed over multiple sub-behaviors.

Annex 3

List of institutions collaborating with ICIMOD (Source: ICIMOD - Annual Report, 1997)

Afghanistan

- Kabul University

Bangladesh

- Bangladesh Forest Research Institute
- Special Affairs' Division of the Prime Minister's Office
- Chittagong Hill Tracts' Development Board
- Local Government Engineering Department
- Jahangirnagar University
- Other Government and Development Institutions at Rangamati Khagrachari, Chittagong, Sylhet, Coxes' Bazaar
- District Local Government Engineering Department Offices
- Bangladesh Institute of Development Studies, Dhaka
- Institute of Appropriate Technology, Bangladesh University of Engineering & Technology, Dhaka

Bhutan

- Forestry Services' Division, Bhutan
- WWF Bhutan Programme
- Department of Survey
- Ministry of Agriculture
- Ministry of Environment
- (NRTI) Natural Resources' Training Institute, Labeysa.
- Ministry of Works and Transport

China

- Office of Agriculture, Chinese Academy of Sciences, Beijing
- Kunming Institute of Botany, Chinese Academy of Sciences (CAS)
- Chengdu Institute of Mountain Hazards and Environment, CAS, Chengdu, Sichuan
- Institute of Geography
- Commission for Water and Irrigation
- Chengdu Institute of Water Conservation
- Commission for Agriculture, Forestry and Animal Husbandry Research Council, Tibet
- Chengdu Institute of Biology
- Chinese Academy of Agricultural Engineering, Research & Planning (IAAERP), Beijing
- Institute of Energy and Environment, CAAERP, Beijing
- International Centre for Small Hydropower, Hangzhou
- Line agencies under the provincial governments in the Chinese HKH
- Chinese Association of Agricultural Science Societies
- Sichuan Association for Science and Technology
- Government of Panzhihua City, Sichuan Province
- Government of Xizang Autonomous Region (Tibet)
- CIMDE Chengdu
- Yunnan Provincial Institute of
- Geography, Kunming

- Bureau of City Planning, Lhasa
- Chengdu Energy Environment International Corporation , Chengdu
- Chengdu Institute of Mountain Hazards and Environment CAS, Chengdu West Sichuan
- Social Science Academy of Yunnan, Kunming

India

- G.B.Pant Institute of Himalayan Environment & Development
- Academy for Mountain Environics
- HNB Garhwal University, Srinagar,
- Wadia Institute of Himalayan Geology, Roorkee University
- Y.S. Parmer University of Horticulture and Forestry, Solan, Himachal Pradesh (H.P.)
- TATA Energy Research Institute
- Ministry of Environment and Forests
- IIRS - Deharadun
- State Council for Science, Technology & Environment, Simla, Himachal Pradesh (H.P.)
- Arunachal Pradesh Energy Development Agency, Itanagar, Arunachal Pradesh (A.P.)
- Indian Institute of Technology, Delhi
- Council for Science, Technology and Environment, Himachal Pradesh
- Alternate Hydro Energy Centre, University of Roorkee
- Line agencies under the provincial governments in the Indian HKH (Assam, Sikkim, UP, HP, West Bengal)
- Indian Council of Agricultural Research
- Wadia Institute of Himalayan Geology
- Kumon University, Nainital
- Entrepreneurship Development Institute of India, Ahmedabad
- Tata Energy Research Institute, NE Centre, Guwahati
- Council for Advancement of People's Action and Rural Technology (CAPART), Guwahati
- SBMK Shree Bhuvaneshwari Mahila Ashram, an NGO in Tehri Garhwal, Uttar Pradesh (U. P.)

Nepal

- National Planning Commission
- King Mahendra Trust for Nature Conservation
- Nepal Agricultural Research Council
- Department of Forests
- Department of Hydrology and Meteorology
- Department of Soil Conservation
- Water Induced Disaster Prevention Technical Training Centre
- Dept. of National Parks and Wildlife Conservation
- CTEVT - Karnali Technical School, Jumla
- Krishi Nirantarta Sanstha Nepal (KNSN), Bhaktapur
- Rural Women's Dev. and Unity Centre (RUWDUC), Dadeldhura
- Dept. of Agriculture
- Himalayan Bee Concern, Kirtipur
- HMG Nepal/FAO Vegetable Seed Production Project, Khumaltar
- National Herbarium & Plant Laboratories, Godavari
- Environment and Forest Enterprise Project (EFEP)
- Market Access for Rural Development Project
- Centre for Resource & Environmental Studies (CREST) Kathmandu
- Centre for Applied Research and Development
- DCS, Butwal
- Balaju Yantra Shala
- Tribhuvan University and its institutes and centres
- Silk Association of Nepal
- Kathmandu University

- Kathmandu Metropolitan City Office
- Dept. of Water Supply and Sanitation
- Dept. of Housing and Physical Planning
- Dept. of Roads
- Centre for Rural Technology, Kathmandu
- DECORE Consultancy Group, Kathmandu
- No Frills Consultancy, Kathmandu
- Women's Forums Development Division of the Ministry of Agriculture

Myanmar

- Myanmar Agricultural Services
- Progress of Border Areas and National Races' Department,
- Forest Department, Ministry of Forests
- Institute of Forestry (Yezin)

Pakistan

- Pakistan Forest Research Council, Peshawar
- WWF Pakistan
- Pakistan Agricultural Support Programme
- Aga Khan Rural Support Programme
- University of Punjab, Lahore, Department of Geology
- Pakistan Agricultural Research Council
- Environment Ministry
- KARINA
- Sarhad Tourism Corporation, Pakistan
- National Aridlands' Development and Research Institute, Islamabad,
- Pakistan Forest Institute, Peshawar
- Rangeland Research Institute, National Agricultural Research Centre
- Aga Khan Housing Board for Pakistan
- University of Engineering and Technology, Peshawar
- Pakistan Council of Appropriate Technology, Islamabad
- Line agencies under the provincial Governments in the Pakistani HKH (Balochistan, AJK, NWFP)
- Federal Ministry of Agriculture
- Department of Agriculture and Livestock, Balochistan
- Agricultural Universities
- University of Peshwar
- Balochistan Rural Support and Development Programme
- Sharad Rural Support and Development Programme, Peshawar
- Extension Services' Management Academy, Garhi Dopata, Azad Jammu and Kashmir