Institutional Concerns in Watershed Management:

Role of Geographic Information System (GIS)

A Research Proposal

By

K. N. Pandit
and
Charles M. Schweik

Professor Elinor Ostrom

Y673 Institutional Analysis and Development: Micro

April 19, 1994

Paper prepared for presentation at the Spring Mini-Conference, April 30-May 2, 1994, Workshop in Political Theory and Policy Analysis, Indiana University, Bloomington.

INSTITUTIONAL CONCERNS IN WATERSHED MANAGEMENT: ROLE OF GEOGRAPHIC INFORMATION SYSTEM (GIS)

Introduction

Watershed management problems have become extremely acute in developing countries where growing populations are exerting intense pressure on increasingly scarce land and water resources. Traditionally, watershed management was viewed as a bio-physical engineering problem, however, more recent thoughts consider watershed management as an integrated process whereby a natural resource is managed in conjunction with human use to produce a series of goods and services (Dixon and Easter, 1986).

A watershed is a topographically delineated area that is drained by a stream system (Easter and Hufshmidt, 1985). Drainage basin and catchment area are synonymous terms to define a watershed(Fig . 1) . A watershed may contain numerous natural resources such as arable land, forest, grazing land, streams/rivers, occupants/users etc. (Fig. 2) . These resources may be utilized collectively by one group of people but more likely, diverse group of people may all be utilizing different watershed components with varying levels of use activities. As Hewlett (1993) rightly points out that in the context of drainage basin morphology, managerial activities permissible on one part of a basin may not be permissible on another; the efficiency of management in time, money and manpower is directly affected by the spatial pattern of operations. The rules defining when, where and how an individual's allotted resource units can be harvested or how many labor days(in terms of investment) are required also vary considerably across cases (Ostrom, 1990).

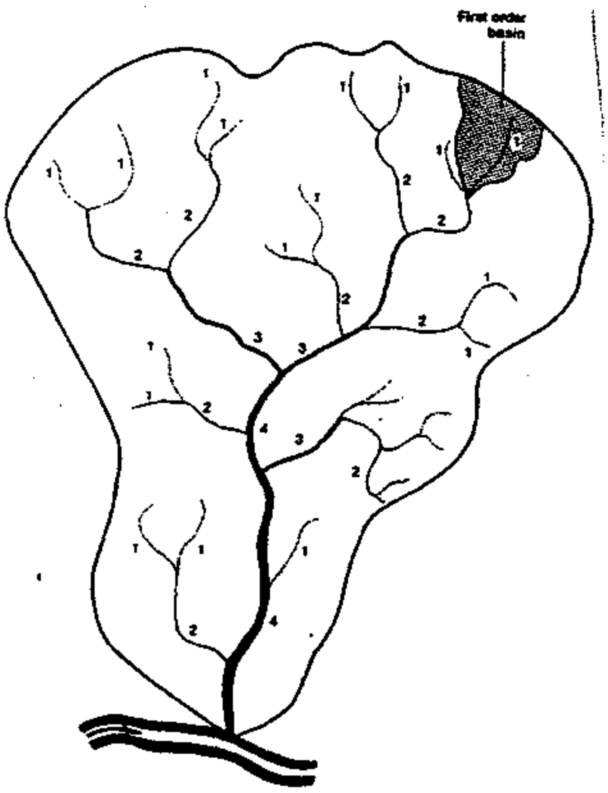

Fig.1 A Watershed with various orders of stream

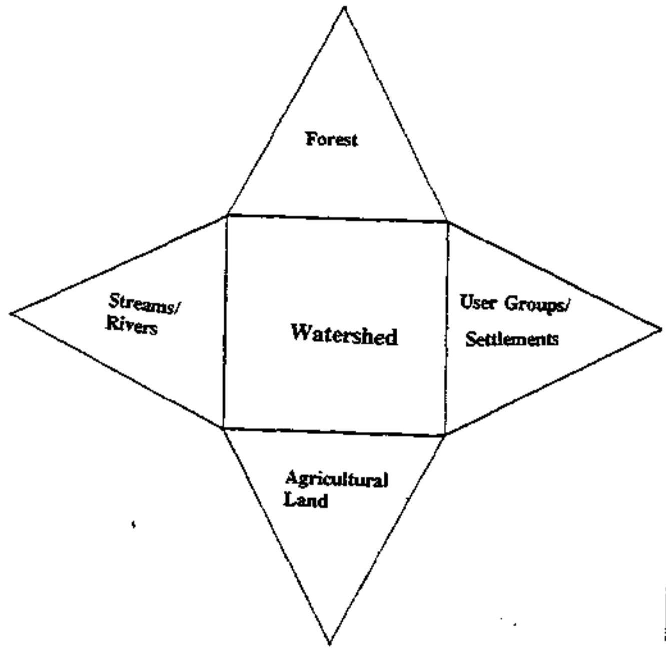

Fig.2 Four major components of watershed

If we consider the upland-lowland interaction in a watershed, the ownership of land as property rights in upland and lowland areas becomes critical factor in the development of institutions for watershed management. In regard to institutions, here we mean the rules and rights that define people's relationship to resources. Institutional rules governing access to watershed resources - forest products, agricultural land and water - are as important as sound technical solutions to forest, soil and water conservation (Gibbs, 1986). Farmers in the upstream watershed usually do not possess secure claims over the long-term benefits of their inputs for protecting the upland vegetation to replenish streams, creeks and rivers and ultimately providing adequate water resources for irrigation, drinking and other uses in the downstream areas. By the term 'upstream watershed', here we mean the upper reach elevation of the watershed. The upland population residing within the upper reach of the watershed are considered as a unit in the context of watershed management and called the "watershed community" (Dani, 1986). The term watershed community has been used specifically to refer to the communities residing in upland watersheds as opposed to lowlanders and the decision makers in the metropolis, who also tend to be lowlanders (Fig. 3). A significant finding of operational research projects in India have indicated that people living in upland watersheds put low priority on soil conservation in the short run but do understand the long term benefits of conservation. Downstream occupants, however perceive immediate benefits because of sediment reduction in the streams/rivers (Tejwani, 1993). A study related to community based forest management systems conducted in the state of Orissa, India by Kant et. al (1991) also brought out the issue of landholding size as an indicator in receiving varied amount of incentives from the resource base. They reported that relative gain from production system of forest is more to the poorer section of the society as their subsistence livelihood depends on the forest products in the upstream watershed. However, improvement in the water regime and subsequent agricultural productivity is more beneficial to the farmers having larger landholding downstream. Findings also indicated that the ecological sustainability of the regenerating forests will most likely be determined by the viability and sustainability of the organizations managing forests.

It is envisaged from the preceding section that the spatial variation of watershed institutions over access, control, monitoring and management of upland and lowland resources among the sub-catchments of a watershed is critical. In addition, the broader issue of developing relationship between upland vegetation and potential of lowland water resources also needs attention.

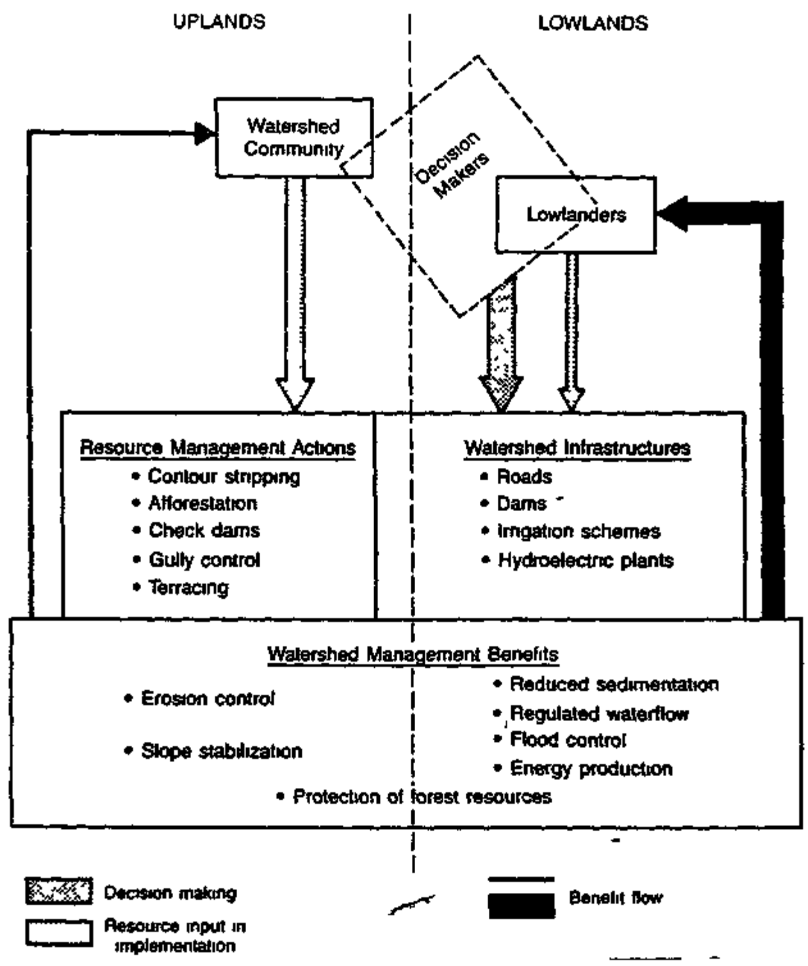

Fig.3 Highland-lowland relationship in watershed management (Source: Dani, 1986)

Keeping in view the nature of the problem to be addressed, use of geographic information system, GIS as a tool for spatial analysis of institutional patterns of forestry and irrigation resources have been proposed.

Context of Forest and Irrigation

The relationship between forests and water sources is important in considering the management of trees and forests as common property, however the issues related to common forest - water management arrangements have received little attention so far (FAO, 1993). In the context of hilly countries like Nepal and many other asian countries having diverse agro-ecological setting, the potential irrigated agricultural lands are generally encountered in the foothills or *tars* (land system developed through alluvial flood plains).In the majority of the cases, the upland areas of watersheds are characterized by the forests and rainfed agricultural land, the middle slopes characterized by a series of terraced land, and the low lying downstream areas characterized by flat irrigated paddy fields *(khet).* This type of watershed setting raises the problem of maintaining a dense forest condition on the upstream side for the prosperity of irrigated agriculture downstream. Studies have shown that good forest cover intercepts precipitation during rainy season and recharges the streams in the dry season for better productivity of agricultural land in the downstream side by way of making adequate water available at the source and ultimately to the irrigation canals (Gibbs, 1986; Metz, 1990; Kant et.al.,1991). In fact, the forest protection controls soil erosion, increases soil fertility, enhances occurrence of rainfall and recharges/replenishes streams/rivers. Alternative studies have shown that deforestation in the upstream side of the watershed causes increasing flow of soil, nutrients and rainy season river/stream water and ultimately the diminished flow of the forest products such as fodder, fuel-wood, bedding material, compost material and dry season discharge (Gill, 1991). Hence, in the context of watershed institutions and resources, the broader chain of forest production system to farming system to multi- farmer irrigation system in terms of technology, process and organizational structures that link them together must be understood in a more explicit manner.

Because of the lack of research studies concerning the issue of physical with respect to institutional arrangements, a study reflecting the role of watershed institutions to manage these resource systems in a spatial pattern is proposed.

Research Problem and Objectives

Units of Analysis

To develop a better understanding of the relationship between the governance of upland forest resources and downstream irrigation resources, the units of analysis for this study would be resource boundaries (geographic domain) of the agricultural (cropped) and forest land. The different user groups[1] responsible for the management and governance of a definite physical boundary of the resource will be selected as the respondents. In order to conceptualize the boundary of the resource, design principle no. 1 illustrated by long enduring CPR institutions (Ostrom, 1990) will be used as the guideline.

Theoretical Foundation on Common Pool Resources (CPR)

The term "common pool resource"(CPR) refers to a natural or man-made resource system that is sufficiently large as to make it costly (but not impossible) to exclude potential beneficiaries from obtaining benefits from its use (Ostrom, 1990). A common pool resource

---

[1] The user group in the context of forestry is a group of people who use the forest who may or may not be formally organized but share the same customary and/or legal rights to products from the forest(s) (IFRI Team,1993)

may be owned privately, publicly or communally. When no one has clear property rights to a common pool resource it is considered to be an "open access" resource.

Forests as Common Pool Resources

Forests are common pool resources (CPRs), the sustainable use of which entail intricate relationship between village groups and local institutions; between the individuals and laws that govern the forest; and between governments and villages (IFRI Team, 1993). While a particular forest may be held as communal property, exclusion of potential users who do not possess rights to its use, or effective regulation of users who do possess such rights, cannot be guaranteed in every instance. Such situations not only create the issue of incentives among the consumptive and non-consumptive users [2] of the forest but also among the occupants spatially because topography plays a dominant role.

Irrigation Systems as Common Pool Resources

Once water is flowing in a canal, it is not very costly for a farmer, whose fields are adjacent to the canal, to construct outlet to allow water to flow onto his plot. The water that a farmer takes out of an irrigation canal is subtracted from the total volume of the water in the canal and is not available for use by other farmers except in case of drainage water where favorable topography exists.

[2] Consumptive users are those who harvest forest products for subsistence needs, for commercial purposes or for transfer to others. Whereas non-consumptive users harvest other products such as worshipping in a sacred shrine, bird watching, or taking a walk in the forest (IFRI Team, 1993).

With regard to asymmetry of interests, farmers located at a higher elevation or at the upstream of a river/stream or canal have an opportunity to take water with relative ease and do not realize effect of scarcity of water on those who are on the downstream side. In addition, farmers located upstream in the irrigation system receive fewer benefits from works devoted to repairing canals since the benefits are compounded along the length of the canal(Lam, Lee and Ostrom, 1993). This asymmetry is a result of the cumulative nature of the process of water loss in conveyance and can cause differences in incentives among irrigators/appropriators.

Research Problem

The broad question of this research would be to focus on the spatial arrangement of watershed institutions with emphasis on forestry and irrigation resources and how they may influence the incentives among the upland and lowland occupants within a watershed as well as the condition of these resources.

Research Goals

The broad goals of this study would be :

- to provide policy-makers and researchers an insight into the effects of institutional arrangements on watershed resources and
- to develop a methodology for institutional analysis of a watershed using GIS.

Specification of Variables

In order to address the issues related to upland- lowland interaction in an watershed with emphasis on various institutional arrangements and incentives, a set of dependent and independent variables have been proposed to be included (Appendix 1). Among many factors affecting institutions within the watershed, only those related to forestry and agricultural land-irrigation system governance will be included in the proposed study as these two resource governance systems play a key role in deciding incentives among the occupants.

Model 1

1A. Forest condition = f (operational rules, rule makers, forest soil type, terrain, regeneration capacity, location of settlements, orientation of irrigation canal through the forest, road construction, proximity to urban area, livestock population)

In the proposed model, the forest condition as a dependent variable will have different dimensions of performance measure, such as crown density, soil erosion status and relative density of trees.

Similarly, in case of irrigation systems, the model is described below.

1B. Physical condition of the canal system = f (governance type, headwork, lining, terrain along the route, canal length, system area, fines for the absentees during repair and maintenance works, vegetation on the canal banks, cross drainage structures)

Physical condition of the canal will be assumed better if the conveyance loss along the canal is less than 40 %, if the canal passes through relatively stable land and has less number of cross-drainage structures.

Model 2

2A. Forest product distribution = f (governance type, rules, level of penalty, number of livestock, variations in income among appropriators, ease of transport, harvesting season, number of appropriators)

The spatial variation of settlements using a particular forest and network of roads/trails will provide some idea to understand the flow of forest product movement.

2B. Irrigation water delivery = f (governance type, system area, shape of the service area, number of irrigators, length of canal, number of outlets/branches, soil type at different sections of command, lining, topography, forest condition in the catchment)

Measurement of discharge (volumetric rate of flow) of the water at each outlet of the canal may provide the performance of irrigation water delivery.

Model 3

3A. Sustainability of forest = f (governance type, tree density, species density, commercial value, type of conservation measures, external intervention)

Sustainability of the forest can be evaluated on the basis of change in forest area and species diversity over time.

3B. Agricultural productivity = f (water availability, cropping intensity, rules, soil type, average slope of the land, landholding size of the appropriators, termrial status, forest condition in the catchment)

Productivity of crops grown in the service area of the irrigation system will provide a key performance measure of irrigation system.

Scope of the Study

Geographic Information System *(GIS)*

Geographic Information System (GIS) is a computer based technology which is capable of holding and analyzing data describing places on the earth's surface.

A GIS has five major components, which include :

- Hardware - used to store, process and display the spatial and non-spatial data,
- Software - used to perform GIS operations,
- Geographic data - used to manipulate, analyze,
- Analytical functions - followed to perform various operations, and
- Personnel - the people who have the knowledge to use the system. Of all the components, people who know how to use the system are the most important.

A GIS is not only a computer system for making maps but also an analytical tool. Spatial data associated with the real world location of earth surface features and non- spatial (or attribute) data representing the characteristics of the features are the two types of data stored in a GIS (ICIMOD, 1992).

Among the two representation techniques of digital data, vector based method describes the locational data in the form of points, lines or arcs, and areas or polygons as they appear on the ground whereas the raster based method records the conditions or attributes of the

earth's surface in an array of grid cells or pixels. Raster systems are more appropriate for studying temporal phenomena such as vegetation, soil erosion, soil salinity, rainfall etc.
The major advantages of GIS include: the ability to create new relationships among the data, to identify the spatial relationship between features, and to associate new attributes with map features. To generate new information that have never been mapped and combine multiple themes so as to extract spatial relationships between the data are the analytical functions needed to solve problems faced by our natural and man-made environment.

Study Site

This study is proposed to be carried out in the catchment of Malekhu *Khola*[3], in the southern part of Dhading district, central Nepal where multiple forests, multiple user groups for forest use and governance organization and multiple irrigation systems with different water users organization exist. The basic aim of selecting Dhading district for the study is due to the existence of topographical variation of resource settings in that district, thereby to observe the spatial variation of institutional arrangements in a upland-lowland interactive scenario. As the proposed area is accessible within a walking distance of about 1.5 to 2 hours south-east from Kathmandu - Mungling highway at Malekhu, it will be easier for the researchers to frequently visit the site for collection of data. Malekhu is a small market center located almost mid-way while driving from Kathmandu to Chitwan, Rampur (where the researchers will be stationed most of the time).

Data Requirement

Collection of data necessary to examine the variables that guide this research will require

[3] khola stands for streams/creeks in Nepali

number of field visits by the researchers having a set of questionnaire/check lists.

Information on irrigation systems of Dhading district was made available to the workshop in Political Theory and Policy Analysis by the Dhading District Development Project(DDDP) which will provide us preliminary idea about the clusters and locations of irrigation systems in a particular setting. These data contain information on - location, service area, governance type, name of basin/sub-basin, length of canal, type of headwork, number of households, canal lining and few other variables. In order to collect data on forestry variables mentioned earlier in different models, IFRI Data Collection Instruction Manual (IFRI Team, 1993) will be used as a guideline for developing specific questions. A specific questionnaire will be developed after finalizing the number of variables needed in the analysis apart from those which are already available or can be availed through some secondary source.

Data collection procedure for this research will be developed after discussing this proposal in the mini conference and receiving comments from the participants of the seminar.

Maps:

Paper maps of Dhading district published by Ministry of Land Reform of the government of Nepal are available for different themes and purposes (land use, land capability, topography). With the help of these maps and the maps produced by DDDP for water resources development study, more information on the selected site of the watershed having multiple forests and irrigation systems will be collected.

It has been proposed that during the fall of 1994, a real time mapping of forests and irrigation systems service area will be conducted by using Global Positioning System (GPS) receivers in the field.

Attribute data:

Some of the attribute data in case of forest can be, the historical changes in forest condition, number/name of settlements using the forest, user groups, monitors etc. Whereas in case of irrigation systems number of labordays required to repair and maintain the system, productivity, type of irrigation system governance etc. can be captured.

Coverage/Themes:

Tentatively, the following coverage are proposed to be developed through the use of Geographic Information System (GIS) .

1. Types of forest (national, community, private etc) depending upon the condition of the forest (dense forest, sparse forest, degraded forest etc.).
2. Settlements/households in point coverage (communities managing these forests).
3. Network of village trails/tracks to reach and move around the forest and other destination are made in another coverage so that a network analysis can be done in one way and a preference to a particular forest for different communities can be generated (based on shortest route).
4. Forest product harvesting rules (Example: forest A for fuel-wood only; forest B for fuel-wood and fodder; forest C for timber and medicines; forest D for bushes and leaves with special emphasis of using such products for repair and maintenance of irrigation systems' headwork etc.).
5. A possible zone of shifting cultivation/forest clearing can be separated out by making a separate coverage of encroachment regions (through buffering or proximity

analysis).

6. Service area of individual irrigation systems /or whole irrigated paddy fields within the watershed.

Data Analysis

Data on the dependent and independent variables of the models discussed in the preceding section will be analyzed through multivariate regression analysis. The importance of independent variables in different models will be critically reviewed after estimating the coefficients of model parameters.

In regard to the use of GIS to this study, spatial operations such as reclassification and aggregation, connectivity, and measurement analysis (Star and Estes, 1990) will be used. For instance, if we have to measure the possible landslide area caused by constructing a canal or road across a forest, it can be easily computed and displayed through proximity analysis of GIS.

Significance of the Research

While this study is primarily intended to look at the spatial arrangement of watershed institutions with a major focus on forestry and irrigation resources. This study attempts to develop relationship between the governance of resources among watershed community and the lowlanders by drawing inferences on incentives they face. It is also envisaged that through the spatial analysis of resource condition and human habitation, factors affecting institutional changes within the watershed can be obtained.

References

Dani, A. A. 1986. Annexation, Alienation, and Underdevelopment of the Watershed Community in the Hindu Kush- Himalayan Region. In: *Watershed Resources Management- An Integrated Framework with Studies from Asia and the Pacific,* eds. Easter, K. W., J. A. Dixon and M. M. Hufschmidt. Westview Press/Boulder and London.

Dixon, J. A. and K. W. Easter. 1986. Integrated Watershed Management: An Approach to Resource Management. In: *Watershed Resources Management- An Integrated Framework with Studies from Asia and the Pacific,* eds. Easter, K. W., J. A. Dixon and M. M. Hufschmidt. Westview Press/Boulder and London.

Easter, K. W., and M. M. Hufschmidt. 1985. *Integrated Watershed Management Research for Developing Countries.* East-West Center Workshop Report, Honolulu, Hawaii.

FAO, 1993. *Common Forest Resource Management: Annotated Bibliography of Asia, Africa and Latin America.* Community Forestry Note 11. Food and Agriculture Organization of the United Nations. Rome, Italy.

Gibbs, C. J. N. 1986. Institutional and Organizational Concerns in Upper Watershed Management. In: *Watershed Resources Management- An Integrated Framework with Studies from Asia and the Pacific,* eds. Easter, K. W., J. A. Dixon and M. M. Hufschmidt. Westview Press/Boulder and London.

Gill, G. J. 1991. Indigenous Erosion Control Systems in the Jhiku Khola Watershed. In: *Soil Fertility and Erosion Issues in the Middle Mountains of Nepal.* Integrated Survey Section, HMG, Kathmandu, Nepal and Department of Soil Science, University of

British Columbia, Vancouver, Canada .

Hewlett, J. D. 1993. *Principles of Forest Hydrology*. The University of Georgia Press, Athens.

ICIMOD, 1992. Applications of GIS for Natural Resource Management in Dhading District, Nepal. Mountain Environment and Natural Resources' Information System (MENRIS), International Center for Integrated Mountain Development (ICIMOD), Kathmandu, Nepal.

IFRI Team, 1993. IFRI Data Collection Instruction Manual. International Forestry Resources and Institutions (IFRI) Research Program. Workshop in Political Theory and Policy Analysis, Indiana University, Bloomington, USA.

Kant, S., N. M. Singh and K. K. Singh. 1991. *Community Based Forest Management Systems: Case Studies from Orissa*. Indian Institute of Forest Management, Bhopal; Swedish International Development Authority, New Delhi and ISO/Swedforest, New Delhi, India.

Lam, W. F., M. Lee and E. Ostrom. 1993. The Institutional Analysis and Development Framework: Application to Irrigation Policy in Nepal. Workshop in Political Theory and Policy Analysis, Indiana University, Bloomington, USA.

Metz, J. J. 1990. Forest-product use in upland Nepal. The Geographical Review. 80(3): 279-287.

Ostrom, E. 1990. *Governing the Commons: The Evolution of Institutions for Collective Action*. Cambridge: Cambridge University Press.

Star, J. and Estes, J. 1990. *Geographic Information System: An Introduction*. Prentice Hall, Englewood Cliffs, New Jersey.

Tejwani, K. G. 1993. Water Management Issues: Population, Agriculture and Forests - a Focus on Watershed Management. In: *Hydrology and Water Management in the Humid Tropics,* eds. Bonell, M., M. M. Hufschmidt and J. S. Gladwell. Cambridge University Press.

APPENDIX 1: Explanation of Independent Variables

<u>Model 1A</u>

OPERATIONAL RULES: Rules related to day-to-day management activities of the forest. *(For example: harvesting, monitoring, conservation etc).*

RULE MAKERS: Appropriators and or irrigators who govern and manage the forest. *(They should have the capacity to modify the forest operational rules).*

FOREST SOIL TYPE: Heavy, medium and light soil. *(If the soil condition of the forest is fragile or light, there might be chances of degradation of forest through landslides and erosion).*

TERRAIN: Topography of the forest land and underlying strata.

REGENERATION CAPACITY: Growth rate of shrubs and bushes according to local climate and soil condition.

LOCATION OF SETTLEMENTS: Disperseness of settlements with respect to forest. *(Nearness of settlements to the forest may have increased rate of harvesting).*

ORIENTATION OF THE IRRIGATION CANAL: Orientation of canal with respect to existing forest topography, if any. *(Construction of irrigation canal across the existing slope of the forest may have landslide and erosion problem downhill).*

ROAD CONSTRUCTION: Road networks and orientation. *(Construction of roads through forest may increase the soil erosion and forest product movement).*

PROXIMITY TO URBAN AREA: Distance to nearby market center. *(Increased degradation of forest due to better marketing situation of forest products in the urban area).*

LIVESTOCK POPULATION: Herd size per household. *(More the livestock population in the settlements, more will be harvesting of fodder and bedding material from the forest).*

<u>Model 1B</u>

GOVERNANCE TYPE: Agency managed or farmer/community managed irrigation systems. *(Farmer-managed irrigation systems have better physical condition of the canal as the farmers understand the problem and have capability to devise sustainable technology).*

HEADWORK: Type of headwork/diversion weir. *(Temporary headwork need more frequent repair and under such conditions the canal system is considered as weak).*

LINING: Sealing of canal bottom and sides by cementing material. *(A substantial portion of water is lost through leakage along the canal and in case when the bottom and the sides are lined with some cementing material, the* *physical condition of the canal is said to be better).*

TERRAIN ALONG THE CANAL ROUTE: Light soil, heavy soil, rocks, gravel etc. *{Rocky terrain is considered to be better provided no frequent substantial investments are required to repair such sections/zones).*

CANAL LENGTH: Length of canal from the intake to the tail end. *{Longer the canal, more the resources required to maintain the canal in a physically good condition).*

SYSTEM AREA: Area commanded by a canal system. *{Larger system area may have increased problem of labor mobilization and equity and hence may not have good condition of the canal).*

FINES FOR ABSENTEES DURING REPAIR AND MAINTENANCE: Amount of fine in kind, cash or labor. *{Substantial amount of fine and well enforcement of sanctioning mechanism will lead to good condition of canal).*

VEGETATION ON THE CANAL BANKS: Type of vegetation such as trees, bushes, shrubs or grasses. *{Well vegetated canal banks are more stable against landslide and if some trees are planted on the uphill and downhill of the canal bank then, they will protect the mass movement of soil during rainy season),*

CROSS-DRAINAGE STRUCTURES: Structures to convey irrigation water across natural gullies, streams, roads etc. *{More number of cross-drainage structures across gullies and streams may cause poor condition of the canal system).*

Model 2A

GOVERNANCE TYPE: User groups, local administration, national government. *(Appropriators among irrigators or non-irrigators should have the capacity to formulate or modify the rules pertaining to governance of forest).*

RULES: Rules related to harvesting of forest products. *(User groups living in different settlements participate in making collective-choice decisions to harvest the forest products).*

LEVEL OF PENALTY: Penalty imposed to defaulter. *(A significantly higher level of penalty impose to the defaulter than usually expected may help in making near equitable distribution of forest product).*

NUMBER OF LIVESTOCK: Herd size of each household in the settlement. *(Users having large herd size may harvest more forest product).*

VARIATIONS IN INCOME AMONG APPROPRIATORS: Poor, rich appropriators. *(Poorer people may harvest more forest products for their subsistence needs rather than rich who may have trees on their own land).*

EASE OF TRANSPORT: Road/trails facility and transporting technology. *{Difficulty in transporting forest material will have diminishing flow of forest product).*

HARVESTING SEASON : Special months or days in a year. *(If the season is favorable for all appropriators, for example when they are free from all agricultural and cultural activities then harvesting rate of forest product will be* *more).*

NUMBER OF APPROPRIATORS: Who use forest products for their subsistence needs and own consumption. *(Increased population may cause less share of forest product per person).*

<u>Model 2B</u>

GOVERNANCE TYPE: Agency or farmer/community managed. *(Farmer designed indigenous methods of water delivery sustain longer than agency constructed sophisticated hydraulic structures).*

SYSTEM AREA: Area under the command of a canal system. *(Larger the area, poorer will be the performance of irrigation water delivery).*

SHAPE OF THE SERVICE AREA: Symmetry of service area from head to tail reach. *(Service areas having many irregularities in distribution of irrigation water may cause poor delivery performance).*

NUMBER OF IRRIGATORS: Distribution of irrigators from head to tail reach. *(Higher the number of irrigators in a dispersed pattern, more complexities in delivering the water in time and space).*

LENGTH OF CANAL: Length of canal from intake to tail end. *(Longer the canal, more will be the time of travel of canal water and may have less delivery performance).*

NUMBER OF OUTLETS/BRANCHES: Number of outlets/branches from the main or secondary canal. *(Higher the points of delivery, lesser will be the delivery performance).*

SOIL TYPES AT DIFFERENT SECTIONS OF COMMAND: Soil types at head, middle and tail reach of the service area. *(Depending upon the varied water holding capacity of soil, water delivery time will vary).*

LINING: Sealing the bed and sides of the canal by cementing material. *(Water delivery time will be less in lined canals than unlined or leaking canals).*

TOPOGRAPHY: Variation in elevation at different sections of the canal and service area. *(Topography will have direct relationship with velocity of flow of water and hence to the delivery performance).*

FOREST CONDITION IN THE CATCHMENT: Dense ,sparse forest. *(Densely forested watershed will provide regulated flow of water in the streams and hence will have better delivery performance of the irrigation system).*

<u>Model 3A</u>

GOVERNANCE TYPE: User groups, local administration, national government. *(Forests governed by user groups will last more because of better monitoring).*

TREE DENSITY: Number of trees per unit area of a given forest.

SPECIES DENSITY: Number of plants (including shrubs and bushes) of a particular species over a given area.

COMMERCIAL VALUE: Forests having trees of high timber value

TYPE OF CONSERVATION MEASURES: Afforestation, gully control structures, other bio-engineering measures, *(Inappropriate and untimely conservation measures of forest may have poor sustainability of the forest).*

EXTERNAL INTERVENTION: Intervention by government agency, NGO, volunteer groups, clubs. *(External intervention to forest governance and management might have negative impact on forest sustainability because of short term objectives of such agencies).*

Model 3B

WATER AVAILABILITY: Availability of water at different sections of the service area over seasons.

CROPPING INTENSITY: Acreage of crops over different seasons in different sections of the service area.

RULES: Rules related to water allocation and distribution. *(Water allocation rules, fines for defaulters and effective sanctioning mechanism will have positive effect on agricultural productivity).*

SOIL TYPE: Soil texture. *(Fine loamy soils are best suited to rice production; fertility and water holding capacity are some of the properties of soil to look at for better agricultural productivity).*

AVERAGE SLOPE OF THE LAND: Slope of the service area from fertility view point. *(Fertility of soil gets reduced in sloppy areas due to downward movement of nutrients).*

LANDHOLDING SIZE OF THE APPROPRIATORS: Distribution of landownership among irrigators. *(Lesser the landholding size of the farmers, more will be the labor input on crop management and more will be the productivity).*

TENURIAL STATUS: Potential cultivators. *(More the number of owner operators, more will be the productivity).*

FOREST CONDITION IN THE CATCHMENT: Dense, sparse forest. *(Better forest condition in the watershed will provide material for organic farming such as mulch, fodder and regulated water supply in the streams feeding irrigation systems and hence better agricultural productivity).*