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AN ASSESSMENT OF ENVIRONMENTAL IMPACTS OF INDUSTRIAL DEVELOPMENT

With Special Reference to the Doon Valley, India

Phase I

VOLUME I

THE ENVIRONMENTAL ASSESSMENT

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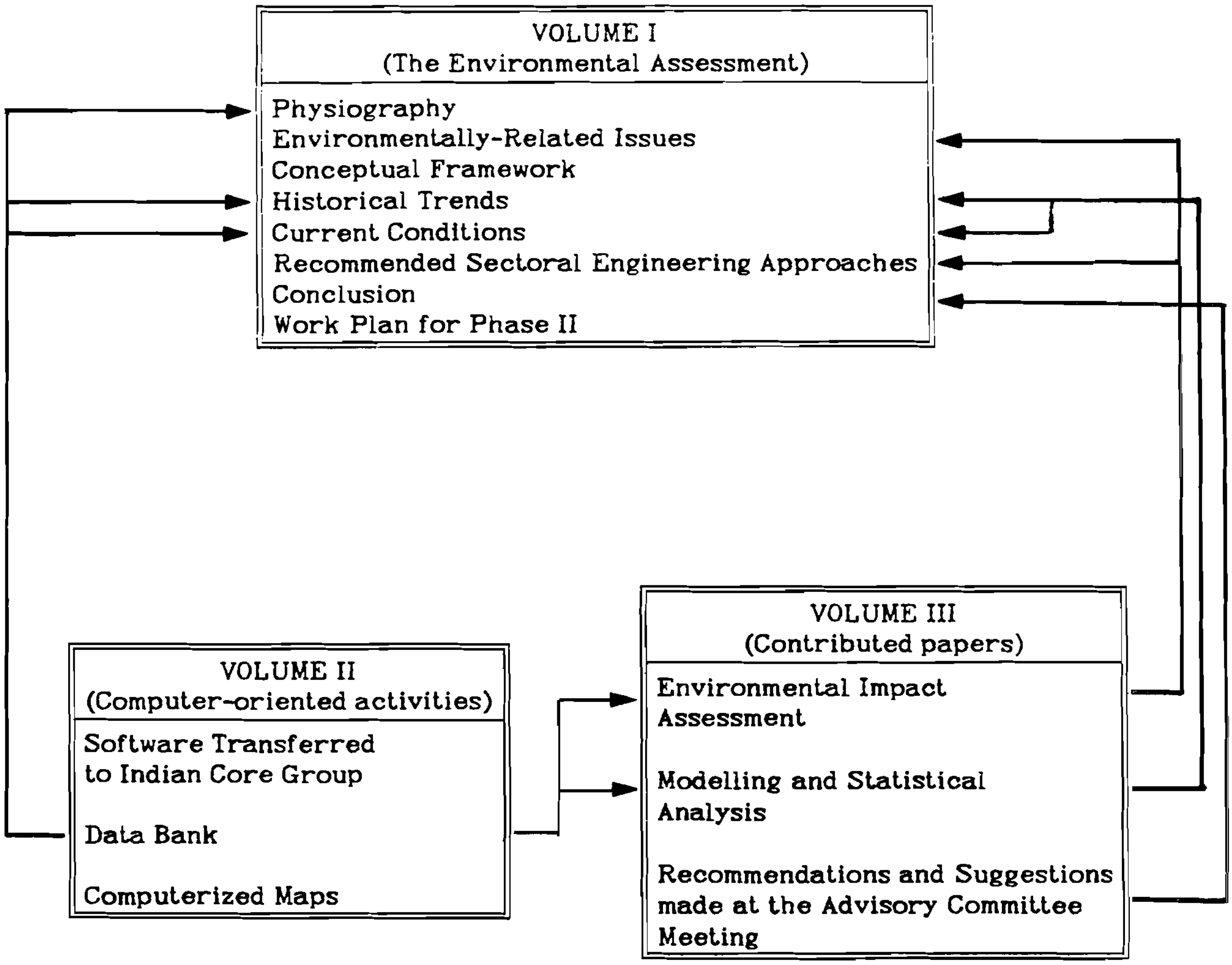
THE STRUCTURE OF THE REPORT



FOREWORD

The Government of India (Department of Environment) has recently become concerned about the environmental problems which could be created by planned industrialization in the Doon Valley, located about 200 km north of New Delhi. Of special concern is environmental degradation due to limestone quarrying and limestone processing.

Through the aegis of UNDP and UNIDO, IIASA was awarded a 7-month contract in September, 1985 to undertake Phase I of an assessment of environmental impacts of industrial development in the Doon Valley, India. The work envisaged was as follows:

a) Development of a conceptual framework for an assessment of environmental impacts of industrial development in the Doon Valley;

b) Preparation of a baseline report describing present environmental conditions and past trends in the Doon Valley;

c) Development of computer software and provision of demonstration models for environmental management in the Doon Valley and elsewhere;

d) Provision of advice to the Indian Department of the Environment with respect to setting up a supporting structure and facilities in India (e.g., national scientific team, monitoring systems);

e) On-the-job training of suitable national counterparts;

f) Preparation of a comprehensive work programme for the second phase of the project.

The present Phase I Report is in three parts. Volume 1 covers items (a), (b), (d), (e), and (f); Volume 2 relates to item (c); Volume 3 contains several papers contributed by the collaborators listed on the cover page.

The principal investigators acknowledge the help that they have received from many persons during this study. (See Appendices 1 and 2 for lists of persons who provided advice.) Professor Fedorov visited India in June and November 1985 while Professor Munn was there in January 1986. These visits were greatly facilitated by UNIDO officers in Vienna (Mr. J.H. Paschke) and New Delhi (Dr. K. Hussain and Mr. B. Singh) and by Dr. S. Maudgal and his colleagues in the Indian Department of the Environment. During the course of these visits, discussions were held with a number of persons in government services and the universities, and it became clear that there are some very competent ecologists, engineers, and environmental scientists in India. One of the main roles to be played by IIASA in the Doon Valley study is that of a catalyst.

A draft of this report was reviewed at a meeting held at IIASA on 3-5 March, 1986. Four members of the Indian Core Group for the Doon Valley IIASA/UNIDO Study were able to participate. That meeting contributed substantially to the focus of the study, and the principal investigators are indebted to the participants. However, errors and omissions are the responsibility of the authors.

Appendix 1 gives a list of participants at the review meeting.

Finally it should be mentioned that Volume 1 contains not only a description of baseline and historical conditions with resulting findings and recommendations, but also conceptual presentations to serve as a reference for future activities of the Indian Doon Valley Core Group. This is also true for several types of impacts that are only indirectly related to industrial development.

SUMMARY OF VOLUME I

People living in the Doon Valley believe that environmental quality has deteriorated during living memory. This perception appears to be supported by the available quantitative data for the Valley. For example, the forest cover decreased by about 25% between 1972 and 1982 (Sharma and Sharma, 1983) while groundwater levels in the City of Dehra Dun have reportedly lowered by about 15 m in the last decade (see contribution by Roy in Volume 3). The most visible signs of environmental deterioration are the scarring of the Himalaya slopes due to limestone quarrying, and the billowing white smoke downwind of the limestone kilns. However, an important reason for the general decline in environmental quality is population pressure, particularly within Dehra Dun City and vicinity.

In Chapters 5 and 6, the results of a baseline study of environmental quality are given. Although the data available to the Principal Investigators are rather limited, there are clear signs of environmental degradation in the Valley.

1. A recent drop in the water-table in the vicinity of Dehra Dun during the dry seasons.

2. Visible scarring of valley slopes due to limestone quarrying, with resultant soil erosion and decreasing forest cover.

3. Poor air quality, particularly in the Dehra Dun - Mussoorie pocket, where limestone kilns are operating.

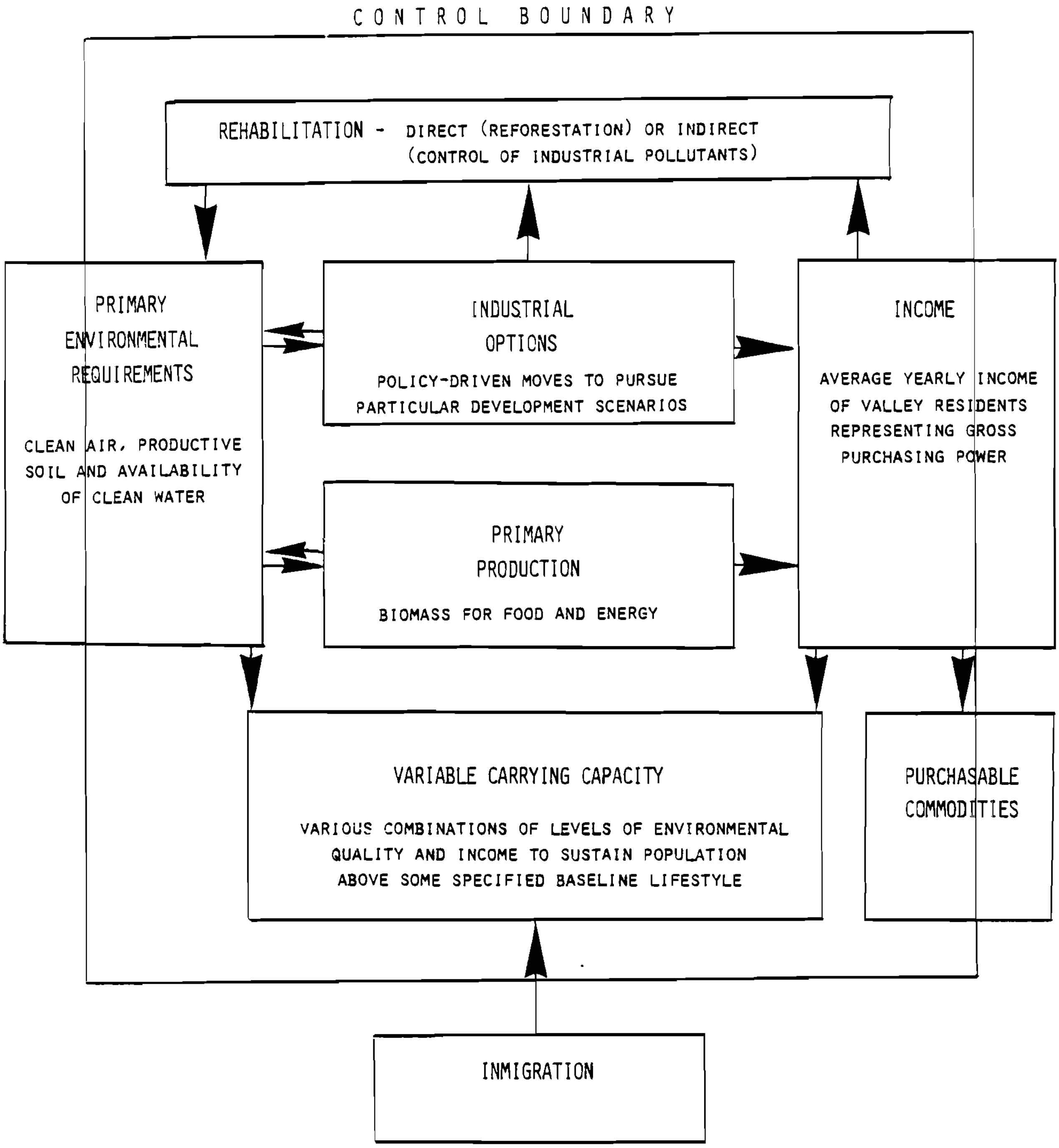
4. Deforestation due to increased firewood demand.

5. Declines in the numbers of valued species of birds, animals and fish.

A major cause for this drop in environmental quality is the increasing population of people and livestock in the Valley. For example, the growth rate of the Dehra Dun urban agglomeration between 1971 and 1981 was 44%, which was higher than the national average (DOE, 1984).

Industry is only one of several causes of environmental deterioration in the Doon Valley. It is therefore essential that the environmental impacts of industrial development be viewed within a comprehensive land-use management framework. One such framework reproduced on the following page is based on the idea of <u>sustainable redevelopment</u> where <u>sustainable</u> applies to both ecological and socio-economic processes. Here it should be emphasized that with the technology available today, industry need not cause harm to the environment. Furthermore, industry brings employment opportunities and income to surrounding areas.

Redevelopment of the Doon Valley requires a thorough understanding of the <u>carrying capacity</u> of the region. As suggested in the Figure, however, <u>carrying capacity</u> is not a fixed quantity but depends on:



A tentative conceptual framework for environmental management in the Doon Valley.

-- the levels of environmental quality deemed to be acceptable by society;

-- the lifestyle expectations (incomes, food, shelter, education, etc.) of society;

-- the investments that society is prepared to make on environmental protection and pollution control equipment;

-- externalities such as new technologies, changes in world trade patterns, etc.

From the point of view of carrying capacity, the most limiting factor for further industrial development in the Doon Valley is lack of water during the dry season. Although monsoon rains are very large, most of the water evaporates or is lost as runoff. The highest priority should therefore be given to the design of engineering works that will improve the water storage capacity of the Valley. These facilities must be based on understanding, monitoring and modelling the hydrologic cycle. Several practical suggestions for improving the hydrologic carrying capacity of the watershed are as follows:

-- Control of future tubewell development (e.g., staggering of wells to tap different aquifers);

-- Construction of underground water storage systems;

-- Discouragement of plans to locate water-intensive industries in the Valley.

Other carrying capacity factors that limit development in the Valley include:

-- Migration of people into the Valley; (By improving environmental and economic conditions, planners may encourage immigration, severely taxing the carrying capacity of the region.)

-- The poor assimilative capacity of the Valley atmosphere, placing an upper limit on the pollution that can be emitted if air quality standards are to be met;

-- Availability of arable land;

-- Milk and fuel wood; (These products cannot be imported economically into the Valley, and thus there is a limiting population that can be sustained unless improved or alternative technologies are used.)

-- Livestock populations; (Stall feeding could increase the forestry carrying capacity of the Valley with respect to this factor.)

-- Economic factors such as transport costs to distant markets and within urban areas, energy costs, availability of raw materials, waste disposal facilities, etc.

In all of these cases, carrying capacity/sustainability studies need to be undertaken, based on a system approach, in which appropriate simulation models are adapted and calibrated for use in the Valley.

In particular, there is a clear need for the development of an air quality management strategy. Industry is presently a major offender in the industrial area north of Dehra Dun City. However, the relative contribution of industrial sources to the general air pollution loading of the Valley is not known.

With respect to the broad topic of environmental management (including the management of impacts not caused by industrial development), a number of important suggestions are contained in Sections 7 and 8, including:

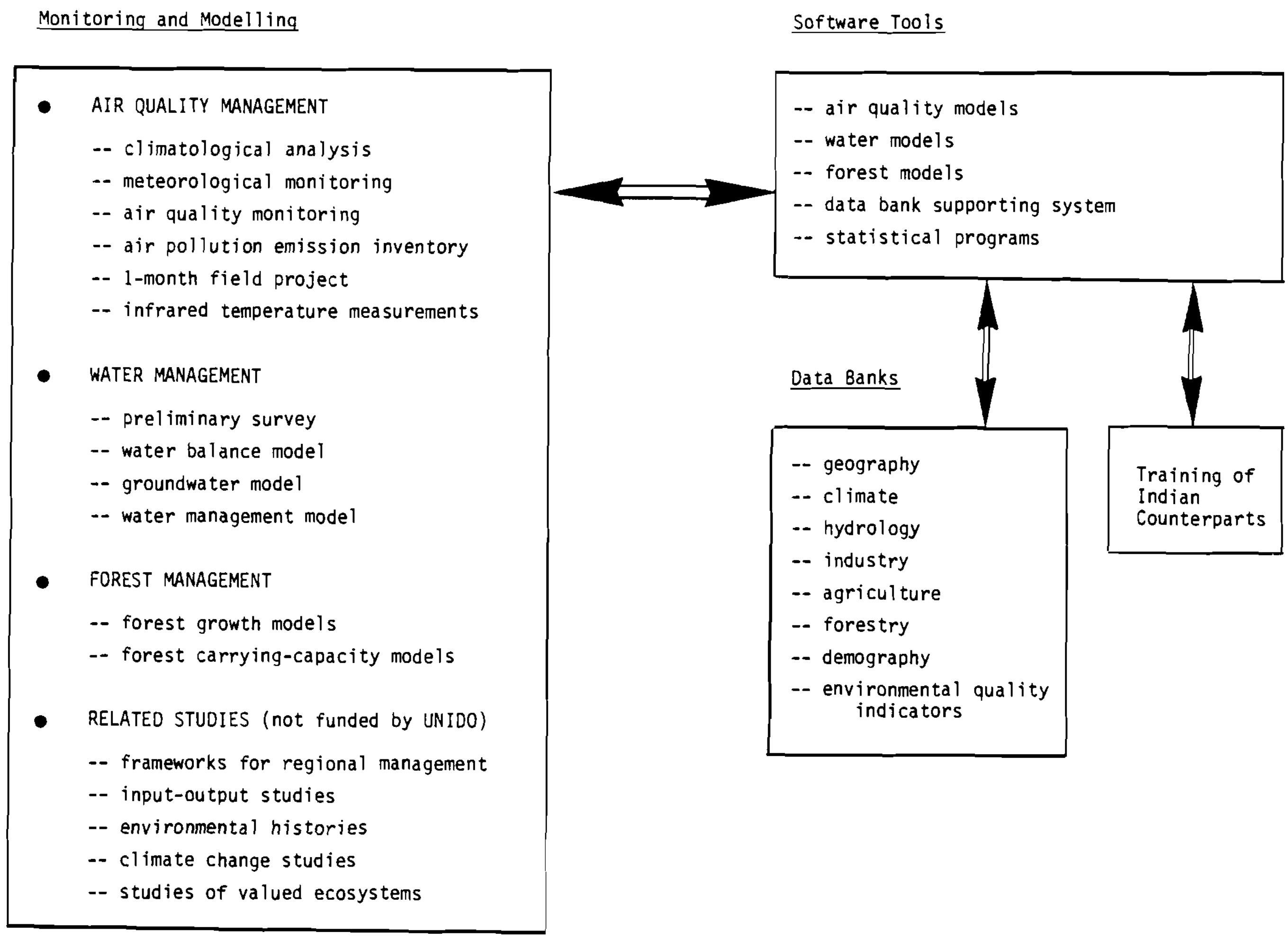
- Afforestation
- Land reclamation
- Stall feeding of cattle
- Development of a leather business (to remove some of the pressure of overgrazing)
- Promotion of various programs that would reduce migration into the cities, e.g., development of food processing and cottage industries in rural areas.

Finally in Section 9 a Work Plan for Phase II is given. This plan is summarized in the following Table which contains 4 components:

- Monitoring and modelling
- Software tools
- Data bank
- Training of Indian counterparts

Details on responsibilities and reporting dates are given in Section 9. Phase II is expected to last about 18 months, with some provisional quantitative policy instruments becoming available at the end of the first 6 months of study.

PROPOSED WORK PLAN FOR PHASE II



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1. INTRODUCTION

The Indian Government has recently become concerned about environmental problems in the Doon Valley, located about 200 km north of New Delhi. The Doon Valley is a typical case where industrial development together with other economic and social pressures endanger ecological stability. The following human activities were identified in the UNIDO Request for Proposal (UNIDO, 1985):

-- limestone mining with subsequent processing into lime, cement, and calcium carbide;

-- heavy and metal-mechanical industry;

-- urbanization and other infrastructure;

-- deforestation due to wood processing industry, increased firewood demand and greater agricultural land use through population and livestock increase;

-- water and sewage problems due to the growing urban population and increasing number of tourists and religious pilgrims;

-- increased transport activities (dust and gas exhausts).

These pressures on the environment arise, of course, because of the growing population in the area.

In the UNIDO Request for Proposal (UNIDO, 1985) it was emphasized that the Doon Valley Project would have to deal with two main problems:

(a) measurement, analysis and modelling of different ecological parameters and estimation of industrial impacts;

(b) identification of a development strategy constituting an acceptable compromise amongst the variety of objectives.

Point (b) is particularly to be noted. <u>The assessment is to provide a framework for a development strategy</u>, in which individual industrial and other land-use proposals can be examined in a cross-sectoral way. Although several land-use proposals for the Doon Valley have recently been implemented or are currently being discussed, one of the main goals of the Phase I assessment is to provide a conceptual model within which a basket of proposals and inter-related impacts can be viewed. Thus the IIASA/UNIDO study is not a conventional environmental impact assessment; rather its goal is to provide a tool for environmental management at the regional level.

As will be elaborated in Sections 4 and 5, the Doon Valley is environmentally stressed, resulting already in some ecological degradation. The stresses have been inevitable in order that short-term development goals could be met. However, economic growth can not be sustained if these pressures continue. So it is necessary to focus on long-term development goals for the Valley.

The essence of an appropriate long-term strategy is captured in the words sustainable redevelopment. This phrase, which has recently been coined by Regier and Baskerville (1986), implies that industrial and economic growth and environmental restoration are mutually reinforcing goals if sound ecological practices are introduced into the planning process. In other words, environment ought to be included in the set of factors (employment, industrial, production, consumption, etc.) normally used to describe the "quality" of development. In the process of redeveloping a region, certain readjustments may of course have to be made within and amongst sectors but the losers, if any, should be compensated. Here it should be emphasized that development strategies cannot be formulated in terms of environmental/ecological factors alone but must be in the context of prevailing legislative, administrative, technological, social and cultural practices and norms (Munn, 1979, 1982).

As agreed by UNIDO, the activities related to assessment of the environmental impacts of industrial development in the Doon Valley are being undertaken in two phases:

-- a first phase, to define the conceptual framework for a regional environmental assessment using modern techniques of systems analysis, and to undertake a study of baseline conditions in the valley, including the identification of data gaps;
-- a second phase during which the environmental assessment would be quantified. One of the main goals of Phase II would be the transfer of computer software developed at IIASA and collaborating institutions, together with the capability of adjusting this software, whenever necessary, to conditions in other parts of India.

On-the-job training of Indian scientists would begin in Phase I and would be accelerated in Phase II.

2. PHYSIOGRAPHY OF THE DOON VALLEY

The Doon Valley lies about 200 km north of New Delhi, in the foothills of the Himalayas. Fig. 2-1 provides a general idea about the valley, which is oriented in a NW-SE direction, with the Lesser Himalayas to the NE and the Shivalik* range of hills to the SW. The valley is about 70 km in length; the width of the valley floor varies from 10 to 20 km.

The name Dehra Dun is used in several different ways:

1. The administrative District of Dehra Dun (308,800 hectares) which is about 30% larger than the area shown in Fig. 2-1, the additional area being the tahsil or subdistrict of Chakrata (136,000 hectares), a montane tract to the northeast; a map of the Administrative District is given in Fig. 2-2;

2. The area shown in Fig. 2-1, viz., the tahsil of Dehra Dun;

3. The administrative sub-divisions of the tahsil of Dehra Dun, viz., Dehra Dun (the valley) and Mussoorie (the Himalayan areas);

4. The City of Dehra Dun;

5. The watershed of the Dehra Dun valley; this area is larger than that of the Tahsil of Dehra Dun but it does not correspond with Administrative District of Dehra Dun.

Two major river systems divide the valley into two hydrologic basins - the Ganga to the east, and the Yamuna to the west. The demarcation zone between these two river systems occurs near the City of Dehra Dun, which is the main population centre in the region (metropolitan population of approximately 350,000 and area of 31 km^2). The next most important centre is the hill town of Mussoorie (population of 10,000 in the winter but up to 30,000 during the hot season), located north of Dehra Dun.

Cross-sections through the valley are shown in Figures 2-3 while a satellite photograph is given in Fig. 2-4. The steep slopes to the north and northeast of the valley are particularly to be noted.

With respect to the valley floor, the highest elevation above sea level (600 m) is in the vicinity of Dehra Dun, the land sloping downward from that area both to the southeast and to the west. Slopes average about 3% for the first 2 kilometers in both directions, then less than 1% to the Ganga (300 m above sea level) and Yamuna (also 300 m above sea level) rivers.

Although the Shivalik hills are rather uniformly oriented on a NW-SE line, there is an important off-shoot - Lachhiwala - to

*Sometimes spelled Siwalik.

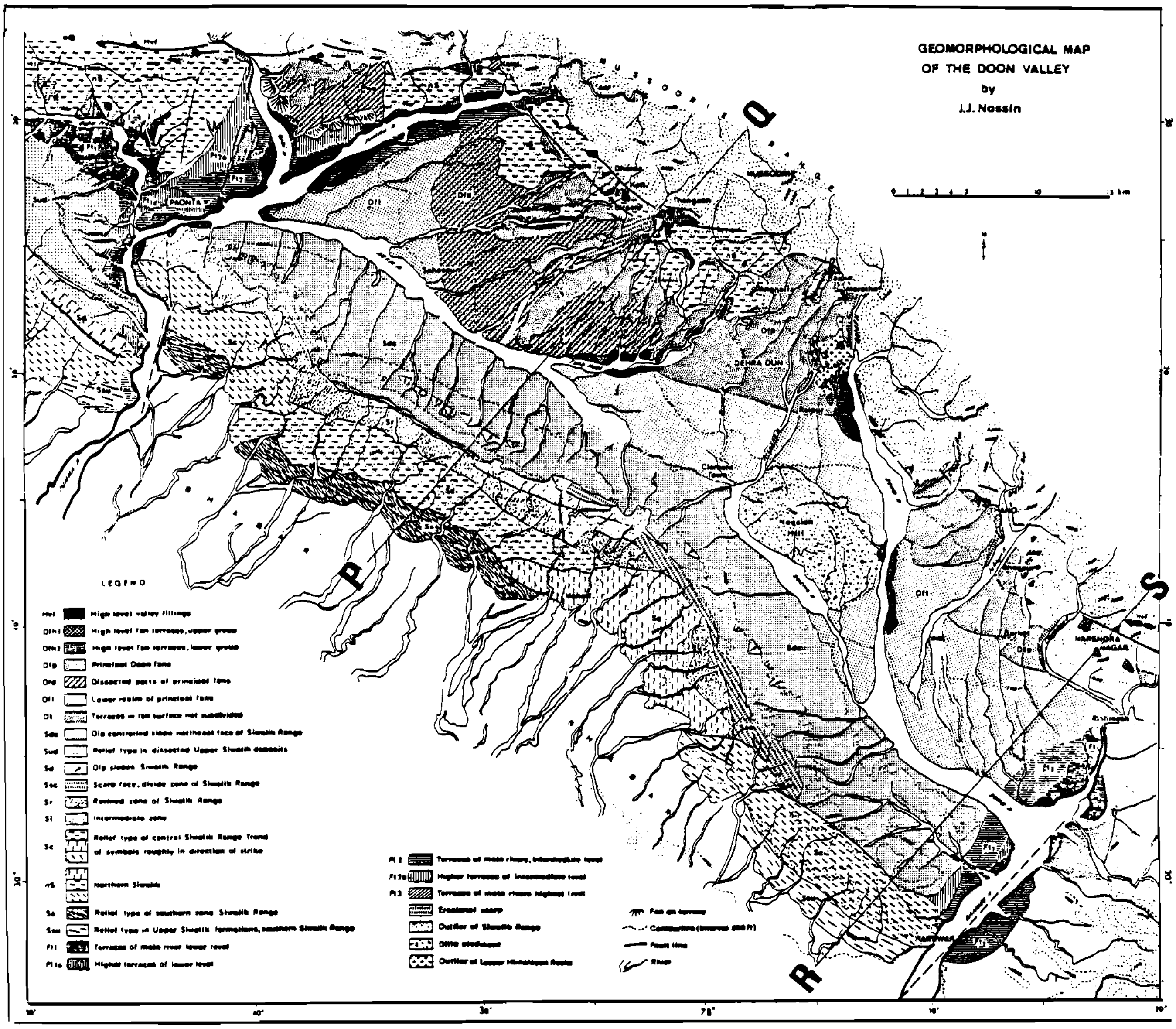

Fig. 2-1 Geographical and land-use map of the Doon Valley (obtained from the Indian Department of the Environment)

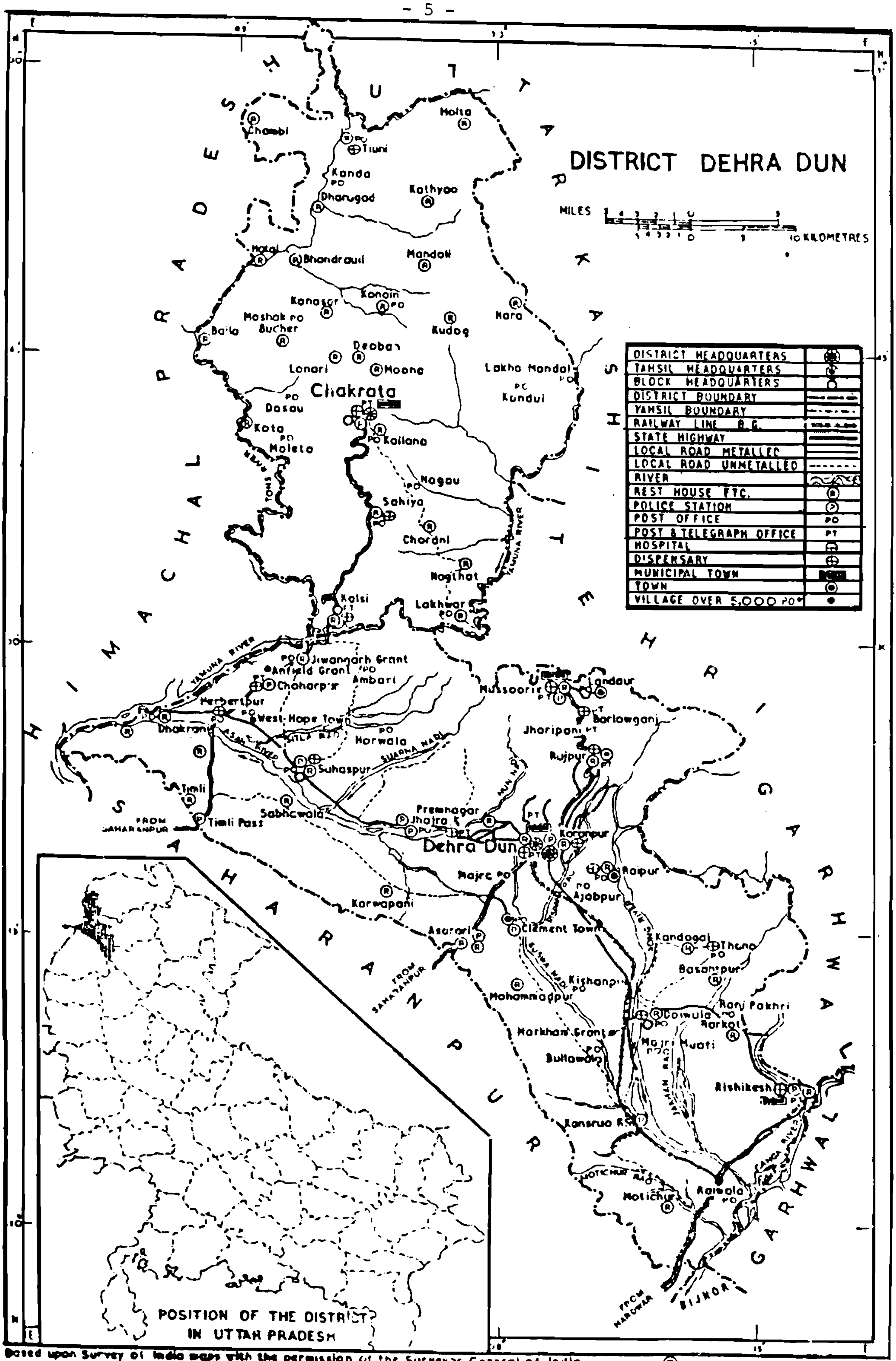

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Fig. 2-2 Administrative District of Dehra Dun

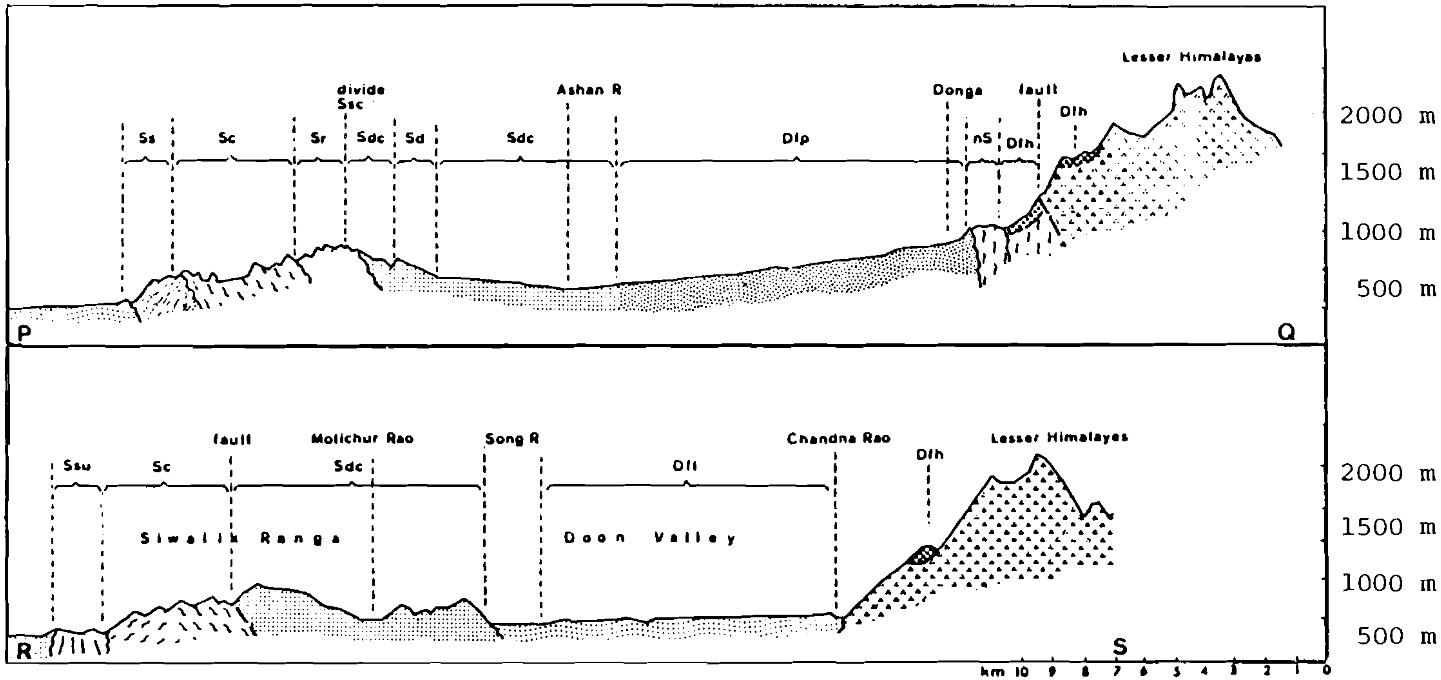

Fig. 2-3 Cross-section P-Q and R-S at right angles to the Doon Valley. For orientation, see Fig. 2-1.

Fig. 2-5 A satellite photograph of the Doon Valley

the SSE of Dehra Dun, lying between the Suswa and Song rivers in the eastern half of the valley. This forested promontory is 10 1/2 km long, about 5 km wide and rises 60 to 100 m above the valley floor. Lachhiwala blocks, to a certain extent, the atmospheric ventilation of the Dehra Dun urban area.

3. THE ENVIRONMENTALLY-RELATED ISSUES IN THE DOON VALLEY

As a first step in undertaking an assessment of the environmental impacts of industrial development, it will be helpful to summarize the main environmentally-related issues in the Doon Valley, including those not associated with industry. These issues have attained very high public visibility both locally and nationally for several reasons.

-- The environmental degradation that has occurred within living memory is clearly visible.

-- A public interest group, the Rural Litigation and Entitlement Kendra (Chairman, Shri A. Kaushal), has played an active role in promoting environmental causes. For example, the organization has successfully fought a case in the Supreme Court of India, resulting in a reduction in limestone quarrying in the Valley.

-- A Doon Valley Board has recently been established whose membership includes several federal Cabinet Ministers, the Principal of the Doon Public School, the Chairman of the Rural Litigation Kendra, and Dr. S. Maudgal from the Department of the Environment (Ramamurthy, 1985).

-- An environmental group is actively campaigning for better environmental management in the valley. The Group is currently undertaking a study, "Ecosystems Evaluation and Planning in the Himalayan Watershed of Ganga and Yamuna," sponsored by the Indian Department of the Environment (Moench and Bandyopadhyay, 1985).

-- Several national research institutes are located in the Valley and in the neighbouring towns of Roorkee and Hardwar. The relative number of professionally trained ecologists and environmental scientists in the area is rather high.

-- The level of education of residents of Dehra Dun is also rather high. The city has more than its share of retired professionals while several nationally important public schools are located there.

-- The hill town of Mussoorie is a popular vacation site for people from New Delhi. Some of the visitors have observed, or have been told about, the environmental changes taking place in the valley below.

-- Many religious pilgrims from all parts of India come to the Yamuna and Ganga rivers.

With this degree of local and national awareness, it has been relatively easy to identify the main environmental issues. Here it should be emphasized that these issues should all be included in an initial environmental "scoping", whether an issue appears to be real or imaginary, important or unimportant, to the assessor (Beanlands and Duinker, 1983), and whether an issue is related to industrial development or not.

In order to compile the list of issues, the following publications and persons were consulted:

1. The UNIDO Request for Proposal (UNIDO, 1985);

2. Official publications dealing with the Doon Valley, particularly the Uttar Pradesh District Gazetteer (Varun, 1979), the review of mining/quarrying in Dehra Dun-Mussoorie region (MSM, 1984) and the Master Plan, Regulated Area, Dehradun, 1982-2001 (TCPD, UP, 1982);

3. A large number of scientific publications; (See references at the end of this Volume.)

4. A large number of persons whose views were solicited through interviews; (See Appendix 2 for details.)

5. Relevant local, state and national standards, guidelines and regulations. (See Appendix 3.) This kind of information provides an indication of the "worth" that society places on the environment.

6. A number of contributed papers from Indian scientists and from the proprietor of a hotel in Mussoorie; (See Volume 3 of this report.)

The resulting list of issues is rather diverse. In this connection it was not possible to detect any patterns when comparing the responses of different types of respondents (e.g., laymen vs. specialists).

We conclude that all of the important environmentally-related issues in the Doon Valley are included in the following list, although a consensus on the relative importance of each issue would be impossible to achieve.

a. <u>Meeting the basic needs of the people, especially the poor</u> (drinking water, food, clothing, shelter, energy, health and education).

   Note: This is a general issue in developing countries, and is the case specifically in India (Maudgal, 1985).

b. <u>Limestone quarrying</u> (on the steep slopes of the southwest-facing slopes of the Himalayas), causing air pollution, soil erosion, and aesthetic damage to the landscape.

   Note: (1) A recent decision of the Supreme Court of India (March 12, 1985) called for 35 quarries to be permanently closed, and 16 others to be temporarily shut down pending appeal; a further 6 quarries were allowed to continue operating. See Ramamurthy (1985) and Shiva and Bandyopadhayay (1985).

(2) The Mussoorie hills have important phosphate deposits, which may be developed in the next decade or so (DOE, 1984).

c. Air pollution

Note: (1) The main industrial sources of pollution are cement plants, lime kilns and chemical plants but there are several small chimneys in the rural areas emitting black smoke, e.g., from sugar processing plants.

(2) The Doon Valley has been designated as an industrial growth area, and incentives are provided to attract new industry.

(3) There are many non-industrial sources of pollution. One respondent was of the opinion that the vikram (a locally manufactured type of taxi) was a major contributor to pollution in crowded city streets. However, domestic cooking stoves and outdoor fires also add to the problem.

d. Deforestation (due to commercial logging, cutting of trees for personal use as fuel wood, large-scale road construction, cultivation on steep slopes, death of chir pine stands through persistent resin tapping, quarrying, etc.).

Note: (1) There has been a recent decision to ban cutting of live trees in the Doon Valley for 12 years.

(2) Monocropping of the forest was once a problem but this practice has stopped.

(3) An extensive program of reforestation has begun, very often using volunteers.

e. Monsoon flooding, soil erosion and landslides (due to deforestation, road construction and quarrying). These phenomena are believed to have increased in recent years; (See Section 5 below)

Note: (1) A bridge on the Rajpur creek near the City of Dehra Dun was 15 m above water level in 1919; sediment is now up to top of the bridge and the road has had to be diverted (Narayana and Babu, 1983).

(2) Siltation has had a harmful effect on irrigation canals.

(3) An extensive program of mine rehabilitation and terracing of slopes is under way.

(4) The Central Soil and Water Conservation Research and Training Institute, Dehra Dun has developed innovative ways of reclaiming derelict lands (CSWCRTI, 1984) and of controlling landslides (Sastry et al., 1981).

f. <u>Decreasing water tables and smaller dry-season river flows</u> (due to deforestation, quarrying, and increasing water consumption).

Note: See the contribution by A.K. Roy in Volume 3 of this Report for a discussion of changes in water table in the vicinity of Dehra Dun City. The water supply in Dehra Dun is already deficient during the dry season (DOE, 1984.) A similar situation exists in Mussorie during the peak of the tourist season. (See contribution by Prem Thadhani in Volume 3.)

g. <u>Climate change</u>

Note: Many people are convinced that local climate in the Doon Valley has become hotter and drier with less monsoon rainfall in recent years. The most frequently cited cause is deforestation. A possible economic impact of this change has been mentioned by two respondents; viz., that the productivity and quality of tea bushes have drastically fallen in recent decades.

h. <u>The Tehri dam development</u>

Note: This dam development is in the adjoining watershed to the east and thus will not affect the hydrologic cycle in the Doon Valley. However, displaced persons from some of the villages to be submerged have been given 2000 acres (800 hectares) of forest land in the southeast corner of the Doon Valley (Lall, 1986), increasing the population pressures.

i. <u>The increase in human population</u>

Note: There is a general impression that the human population is increasing beyond the level that can be sustained by the renewable resources of the valley. The Tehri Dam development adds to these pressure.

j. <u>The increase in livestock population</u>

Note: (1) There is general agreement that as the cattle population of a region goes up, the productivity of the land goes down. Overgrazing is difficult to reverse, particularly the practice of allowing animals to feed in the forests, preventing the development of new seedlings.

(2) A special problem area is the Shivalik hills where an estimated 400 nomad families each manages a herd of about 200 buffalo, donkeys and horses (a total of about 80,000 animals). It should be mentioned, however, that buffalo do not graze in the forests and therefore are preferable to cows. These Gijjars sell milk to the town people.

k. Disruption of elephant migrations

Note: (1) Elephants have traditionally inhabited the Shivaliks and forested areas to the southeast of the Valley. About 7 years ago, a water channel was built on the east side of the Ganga river, disrupting migration patterns. About 50-100 elephants remain in the Shivaliks and another 150 are on the other side of the canal. The elephants are showing the characteristic restless behaviour that results when migration routes are closed, trampling the forest and occasionally moving out over adjoining agricultural fields. Several persons have been killed trying to chase the elephants away, and there is growing conflict amongst gijjars and farmers.

(2) There is a proposal to establish the Rajaji National Park, which would encompass the migration routes of the elephants.

l. Spread of the weed lentana

Note: The weed lentana is increasing every year and is now spreading into the forests where it inhibits the growth of seedlings.

m. Disappearance of wildlife

Note: Within living memory, the wild animal populations in the Shivaliks are said to have decreased dramatically. See, for example, the contribution by R. Tilak in Volume 3 of this Report. Even in the Himalayas, several species are locally endangered, e.g., mountain quail once lived just behind Mussoorie and some pheasants have changed their habitats.

n. Disappearance of fish

Note: Due to river beds drying up in the dry season, and due in some cases to overfishing, some species of fish are disappearing. In particular, the Mahseer, as dietary source of protein, is now very rare (Tilak, 1983). See also the contribution by R. Tilak in Volume 3 of this Report.

o. Decline in the tourist industry

Note: There is concern in Mussoorie that the tourist industry may some day decline due to unfavourable media-reporting of the Doon Valley problem and due to local climate changes that are believed to be taking place. See the contribution by P. Thadhani in Volume 3 of the this Report.

p. Pilgrims to Hardwar

Note: Practically on the southeastern boundary of the Doon Valley, nearby Hardwar is a holy city with influxes of pilgrims every March - April. Once every 12 years there is a massive influx, with 8 million persons expected in 1986. Whether there are significant interactions with the Doon Valley remains to be investigated.

q. Reduction in yields of some cash crops

Note: Several persons mentioned that the yields of several cash crops (e.g., tea, lichi, rice) had decreased significantly in recent times.

Interestingly enough, several environmental questions are not perceived to be major issues in the Doon Valley. Here one could mention water pollution (except in the immediate vicinity of industrial and domestic sources), noise, forest fires, vector-borne diseases, and the harmful effects of irrigation, e.g., salinization of soils. As for high-impact low-probability risks (a major public issue in Western Europe and North America and at Bhopal in India), the only example of such a risk mentioned by respondents was the possibility of increased earthquake hazard due to construction of reservoirs and dams in adjacent areas and due to local quarrying which would increase the severity of landslides if an earthquake did occur.

4. A CONCEPTUAL FRAMEWORK

Once there was a woman who came into possession of a million acres of forest land. She knew nothing of managing a forest, so she advertised far and wide for a forest manager, offering the successful applicant the largest salary ever paid a forest manager. She ranked the hundreds of applicants and began the interviews.

The first applicant, a successful captain of industry, was asked, "If I hire you, what will you do for me?

The answer came quickly, "I'll maximize your income through modern management principles and ruthless efficiency."

His smile faded as the owner said, "Goodbye."

The second applicant, a forester, answered the owner's question with, "I'll maximize the production of wood products from your forest while protecting the ability of that forest to produce trees."

Another brief "Goodbye."

A wildlife biologist said he would produce a diversity of wildlife habitats, protect the threatened species, and provide excellent hunting for the owner. The answer? "Goodbye."

Finally a wise man with appropriate credentials answered the question with, "What do you want from your land?" The interviews were over. She had her manager. *

4.1 The Valued-Ecosystem Approach to Environmental Impact Assessments

When environmental impact assessments first became mandatory in North America 15 years ago, developers were forced to consider environmental factors within the planning process. This was a major step forward, although the quality of environmental assessments left much to be desired.

A major advance in improving the usefulness of environmental/ecological assessments was made by Beanlands and Duinker (1983), whose approach has been adopted by many agencies in North America. The essence of the method is as follows:

1. The first step in an assessment procedure is to identify a set of valued ecosystem components. In the underlined expression, the word valued refers not only to components that have high economic value but also to those that are believed by ecologists to

*Thomas, Jack Ward, "Towards the Managed Forest: Going places that we have never been", Forestry Chronicle, vol. 61, no. 2 April 1985, pp. 168-170.

be essential to the well-being of the system being examined and by public groups to have intrinsic value.

If a component is highly valued, then it is necessary to ask the questions: "Valued by whom, and why?"

Some of the valued ecosystem components, e.g., the forests, will be immediately selected by the assessor. In other cases, it is helpful to catalogue the environmental and natural resource issues that are important to representative persons and groups, including the public. This is the approach that was taken in Section 3 above.

2. The next step in an assessment is to try to seek a consensus on guidelines that will permit determination of whether postulated changes in ecosystem components will improve or diminish the worth of the ecosystem.

3. Thirdly, it is necessary to specify assessment boundaries in space and time.

4. Next it is essential to develop an explicit strategy for investigating the interactions between possible human interventions (both deliberate and inadvertent) and each valued ecosystem component, and to demonstrate how the strategy will be used.

5. Fifthly, it is essential that predictions of change (or of no change) be stated explicitly, and that the underlying assumptions be clearly specified.

6. Finally, a commitment should be made to monitor environmental and ecological changes. The main object for monitoring should be to test the predictions in the assessment, so that mitigative action could be taken if the predictions prove to be incorrect (an adaptive strategy) (Holling, 1978; Sonntag, 1984).

An objection is sometimes raised that the Beanlands-Duinker assessment framework is unworkable in regions where there are few data and where many of the ecological relations are poorly understood. However, the valued-ecosystem approach is in fact particularly effective in such areas. Where the money available to undertake an assessment is limited and the data gaps are large, the Beanlands-Duinker approach forces the assessor to focus on a relatively few interconnected parameters. (Many environmental assessments in the 1970's in North America were so comprehensive that they were of little use to policy makers). Another benefit of the Beanlands-Duinker approach is that during the course of the assessment, a framework is developed for long-term environmental management of the area or resource being assessed.

4.2 Identification of Valued Ecosystem Components and Indicators

There are several lists of factors that need to be drawn up before valued ecosystem components and indicators can be identified:

-- relevant local, state and national standards, guidelines, regulations, etc. These provide a baseline for environmental management, indicating in some sense the value that society places on the thing or process being regulated (see Appendix 4);

-- ecosystem components that are essential in meeting the basic needs of the poor;

-- issues in environmental and resource management that are perceived to be important by one or more groups in the area; (See Section 3 above);

-- ecosystem components and indicator organisms where the impact of human development could be much greater and/or could occur more quickly than elsewhere in the ecosystem (e,g. destruction of nesting habitats for valued species of animals and birds), thus providing early warning of unwanted conditions.

4.3 Bounding the Doon Valley Problem

Bounding the problem in space

Several hundred years ago, the Doon Valley might have been considered as an economically closed system. Today, however, there are important interactions with the outside world:

-- industrial and economic interactions (imports and exports; raw materials; energy prices; subsidies; etc.).

-- population interactions (tourists; pilgrims; resettlement of displaced persons; etc.).

-- technology interactions (rapid and sometimes inappropriate transfer of new technologies; etc.).

-- ecological interactions (not important except for species migrations).

-- physical interactions (not important).

Bounding the problem in time

Reasonable time horizons for bounding of the Doon Valley assessment are:

Time dimension	Issue
Short-term (next several years)	The issues for which immediate practical steps could be taken. (See Section 7)

Medium-term (next 10 years)	Valued ecosystem components/ indicators that are greatly at risk, with some danger of irreversibility in current trends.
Long-term (next 50 years)	Identification of development pathways that are sustainable over the long term; (An outline, admittedly sketchy, of a strategy for sustainable redevelopment should be prepared.)

4.4 Developing A Conceptual Framework for the Doon Valley Assessment

4.4.1 The Array of Possible Frameworks

Several conceptual models are available for use in environmental/ecological assessments. Briefly, these are:

1. The hydrologic cycle.
2. Biogeochemical cycling.
3. Input-output models of matter.
4. Input-output models of energy.
5. Pathway analysis, e.g., food chains (in the case of pollution).
6. Life cycles of selected species (habitats, nesting characteristics, migration patterns, etc.).
7. Population dynamics within an ecosystem (competition, predator-prey relations, etc.).
8. Interactions between ecosystems.
9. Sustainability analyses, e.g., of the human population that the Doon Valley forests can support (See contribution by Fedorov and Lenko in Volume 3 of this Report for an example).
10. Stress-response models of indicator species and of ecosystems.
11. Recycling of usable wastes
12. Supply-demand models or submodels.

Note that frameworks 2 and 3 could be applied to towns and villages as well as to the more conventional types of ecosystems. See, for example, Moench and Bandyopadhyay (1985) for an analysis of the biomass flow system in the village of Munglori, 11 km north of Mussoorie.

Two or more of these system models could, of course, be applied in an interactive way to the Doon Valley system.

4.4.2 Constraints on System Outputs

In devising a systems approach to long-term environmental/ ecological management, a number of constraints must be recognized with respect to the types of system outputs, if the recommendations are to be implemented.

-- There is an over-riding short-term requirement to meet the basic needs of the people living in the valley; (This is often in conflict with long-term goals).

-- The cost of implementing particular measures, no matter how beneficial they may seem, must not be excessive, and the recommended strategy should include, if possible, a cost-recovery clause.

-- Recommended measures must be practicable to implement within the social, administration and legislative fabric of the Doon Valley.

4.4.3 Narrowing the choice of frameworks

The participants of the Task Force Meeting (IIASA, 3-5 March 1986) considered a range of possible conceptual frameworks for the Doon Valley assessment. Two proposals were made, recognizing that considerable elaboration would be required in each case. The two frameworks are discussed in the following two sub-sections.

4.5 The Valued-Component Approach: Applicability to the Doon Valley

As pointed out by Beanlands (see Volume 3 of this Report), the valued-ecosystem-component (VEC) approach to assessment has only been tested in cases where there is a firm development proposal to be examined, with alternatives. Further, the approach has not been applied to situations with such a large number of environmental/ecological issues as in the Doon Valley.

Some Task Force Meeting participants expressed the view that a matrix of human actions vs. VECs in the Doon Valley would be unmanageable. After trying to construct preliminary lists of human actions and VECs, this fear seemed to be justified, as the number of columns and rows grew and grew. However, the act of preparing a matrix provided insight into the nature of the problem, revealing differing perceptions of the participants concerning the main issues and VECs in the Doon Valley.

The general conclusion was that it would be valuable if a few people were encouraged to develop an appropriate matrix during the next several months. In the meantime, the skeleton framework given in Fig. 4-1 was suggested,* in which the items listed within each circle are very tentative, and need to be discussed with members of the Core and Support Groups to the Doon Valley Study, as well as with representatives of local organizations.

Although Fig. 4-1 provides a skeleton framework for examining the environmental issues of the Doon Valley, the diagram is not action-oriented. Fig. 4-2 has therefore been added to provide a context. Conceptualizing in terms of a triple-layer projection, the upper-layer action model contains activities such as:

-- economic development

-- environmental/ecological protection

-- monitoring

-- modifications in institutional frameworks

-- modifications in infrastructures

The intermediate layer is the same as that shown in Fig. 4-1 while the lowest layer is a geographic projection intended to suggest that the Doon Valley is not a single homogeneous medium; the actions, activities, VECs, VDCs and VACs are all location specific.

4.6 An Alternative Framework for Environmental Management in the Doon Valley

Fig. 4-3 provides another tentative conceptual framework for environmental management in the Doon Valley.** The most important rectangle is the one labelled variable carrying capacity, the use of the word variable being intentional. Carrying capacity is not a fixed quantity but is a function of two sets of factors:

1. social goals (specified lifestyles, incomes, environmental quality, etc.).

2. externalities (new technologies, changes in world trade patterns, climate, etc.).

Fig. 4-3 is not intended to provide the basis for a "big" environmental-ecological-economic model of the Doon Valley. It is merely a framework that may help the various groups identify their particular roles/actions. What the block diagram does

*The basic ideas contained in Figs. 4-1 and 4-2 were developed at the Task Force Meeting by Peter Nijkamp.

**This block diagram was suggested by G. Beanlands and elaborated by participants of the Task Force Meeting in IIASA (3-5 March, 1986).

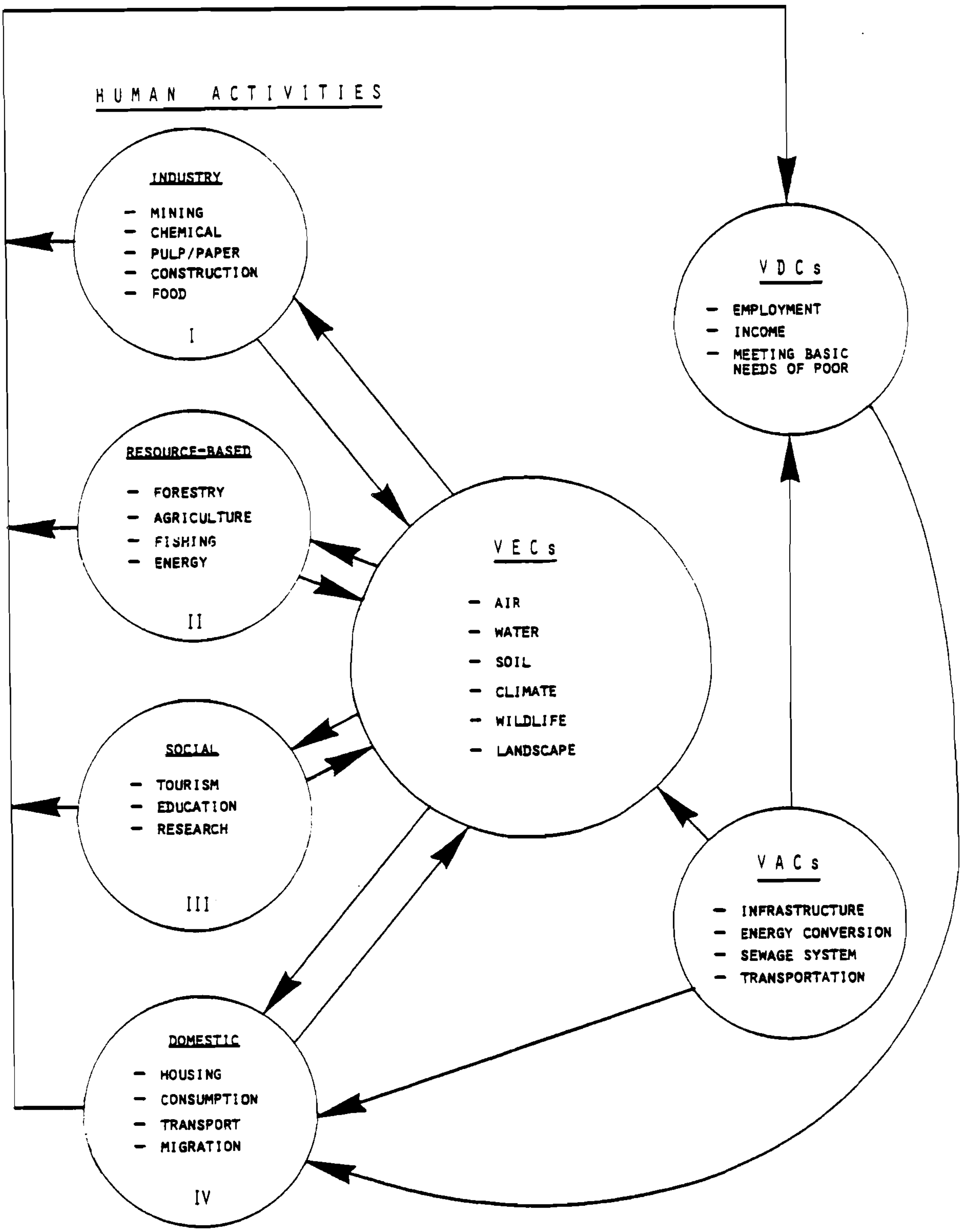

Fig. 4-1 Proposed skeleton framework for environmental management in the Doon Valley.
VEC- valued environmental/ecosystem component
VDC- valued economic development component
VAC- valued administrative component

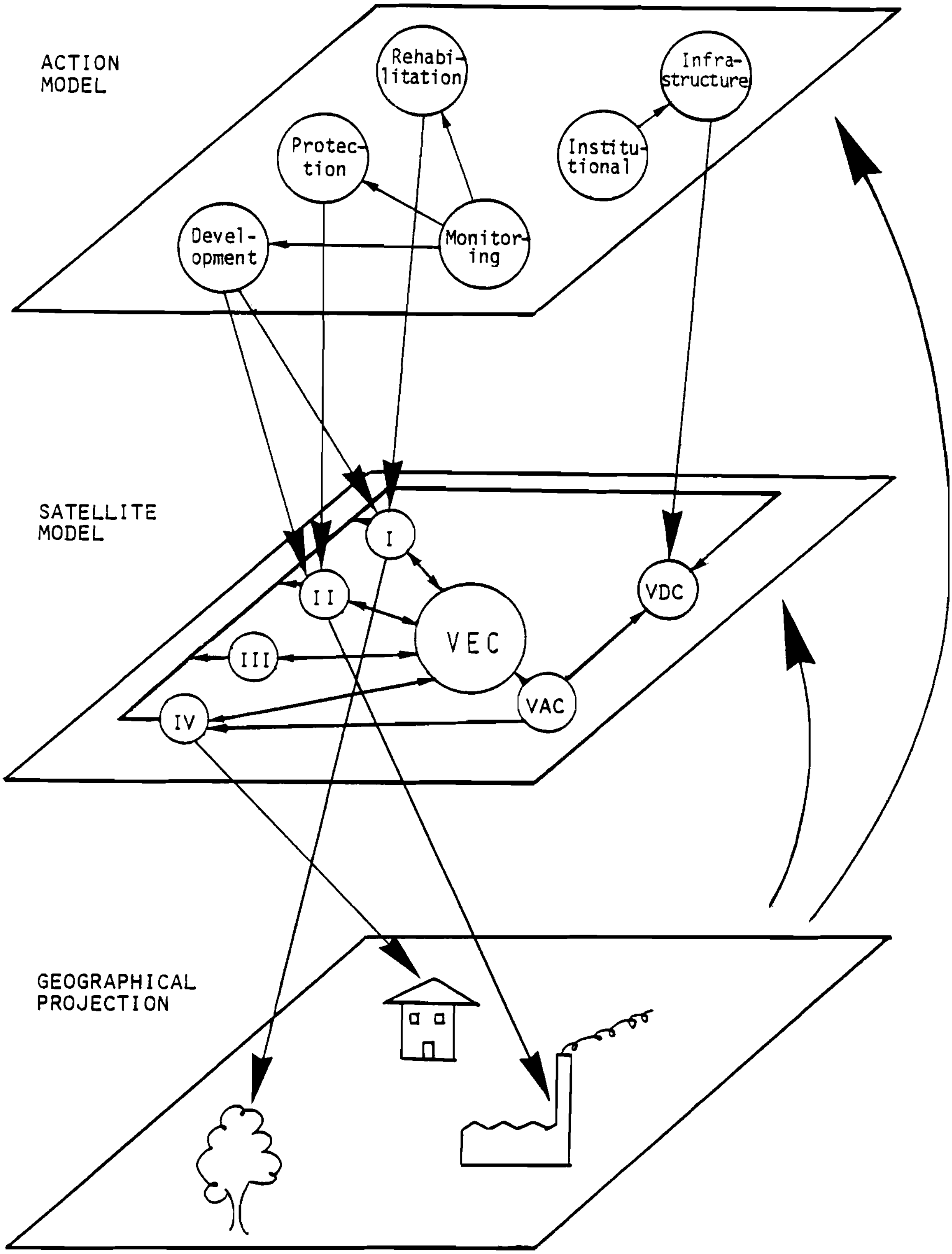

Fig. 4-2 A triple-layer projection intended to help elucidate the development of appropriate environmental management strategies in the Doon Valley.

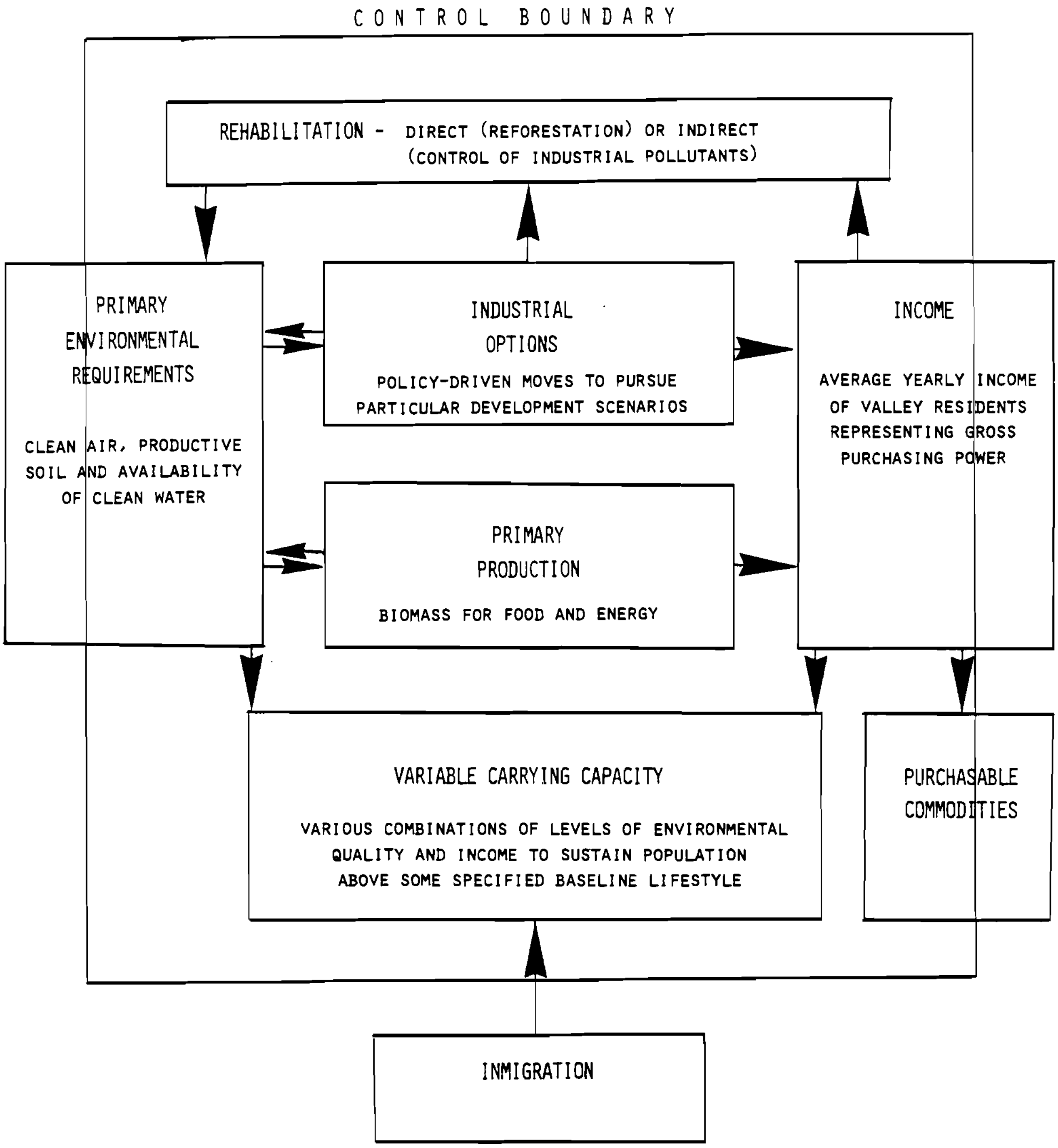

Fig. 4-3 A tentative conceptual framework for environmental management in the Doon Valley.

suggest is that emphasis should be given to the task of defining the carrying capacity of the Valley for various sets of social goals and changing externalities. A 50-year time scale should be used, and the objective should be to identify a small set of sustainable development/redevelopment pathways.

Lifestyle is of course a difficult idea to quantify. In this connection there is an array of lifestyles and we recognize that no segment of the population should be excluded in development plans. Fig. 4-4 shows conceptually the idea but does not reflect the enormity of the task of shifting from the solid to the dotted curve.

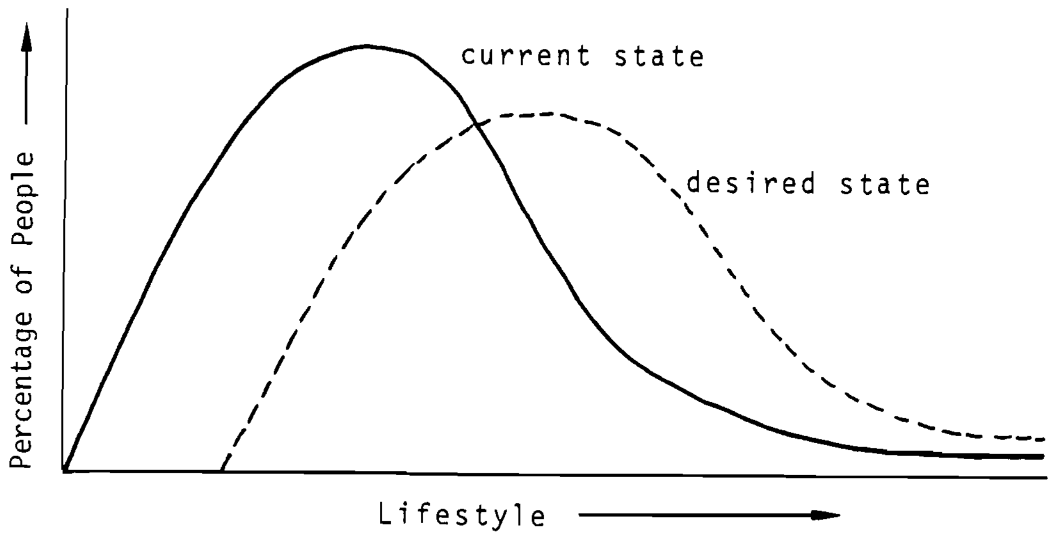

Fig. 4-4 A schematic representation of a development goal.

The task of defining the carrying capacities of the Valley is itself long-term and could not be completed even in Phase II of the IIASA/UNIDO Project. It will require the involvement of Indian scientists from many disciplines. Provisionally, however, a few factors can be mentioned that limit the kinds of sustainable redevelopment that could be envisaged for the Valley:

1. Migration of people into the Valley, particularly into the City of Dehra Dun, due to increasing industrialization. A preliminary analysis by Fedorov and Lenko (see Volume 3 of this Report) indicates that the rural population in the Doon Valley is reaching a saturation level but the urban population is still growing. This raises a serious social problem for the various levels of government in India. If uncontrolled migration is permitted on the one hand, ecological and economic sustainability will not be possible. If efforts are made to limit immigration without appropriate incentives, on the other hand, the social fabric of the country would be strained.

2. Ground water shortages during the dry season. This clearly is a limiting factor for future industrial development.

3. The assimilative capacity of the airshed and of the watershed with respect to pollutants emitted by automobiles, industries, etc.

4. Fuel wood. This cannot be imported economically into the Valley.

5. Agricultural products. Current technology and land availability can sustain a population of about 250,000. Additional food must be imported.

6. Livestock populations. There must clearly be an upper limit to the number of domestic animals that the Valley can sustain.

7. Economic variables such as financing, availability of raw materials, distance to markets, energy costs, relative competitiveness vis-a-vis other sites in India and abroad. These factors provide brakes on certain kinds of development, but do not close other options.

These factors limit sustainable redevelopment but to what degree? And how can the upper bounds be increased? (In the case of groundwater shortages, for example, it has been proposed by Roy and by Kaden (see Volume 3 of this Report) that spacing of tubewells be staggered and that the possibility of underground storage of surplus water be examined.)

With respect to industrial development, the way to begin is to create a plausible set of options, and to test each one in terms of ecological sustainability. In the case of air pollution, for example, this will require a detailed multiple-source air pollution model which will permit estimates to be made of the assimilative capacity of the Valley and of the impact of proposed new factories on air quality. Similarly, input-output models of flows of energy and mass need to be elaborated both for the Valley and for the City of Dehra Dun. Based on sectoral models of this kind, the ecological sustainability of each of the development strategies could then be examined. In the meantime, however, preliminary studies of the plausibility of a few options ought to be explored. Here the following factors should be taken into account:

1. Local availability of the raw materials required, discouraging industries that are dependent on scarce local resources, e.g., water and firewood;

2. Feasibility of the option in both an administrative and a social-cultural sense.

4.7 An Example: The Forestry Sector*

Forests provide a number of useful products and amenities, tangible as well as intangible.

(a) Tangible Forest Products: The tangible products are generally exchanged in the market and, therefore, often have a monetary value (e.g., wood and grass). The principal products are timber and fuelwood. Other commercial forest products are livestock fodder (i.e., leaves, grasses and shrubs) and medicinal products, e.g., katha, sal seeds and grasses.

(b) Intangible Forest Products: The indirect use of the forest resource is made through its capability with respect to soil and water conservation, flood control, aesthetics, clean atmosphere, wildlife and outdoor recreation. The intangible forest products are usually externalities whose economic values are difficult to quantify (e.g., flood control and scenery). These may, however, be crucial for the very survival of a region. For instance, the collapse of an ancient civilization in what is now Iraq was undoubtedly the result of overgrazing and deforestation in the upper drainage basins of the Tigris and Euphrates rivers (Ramade, 1980, p. 145).

Forestry can exist as an important economic activity for a region only as long as there are adequate forests of various age classes and a sufficiently large area of forest is harvested and regenerated periodically. At the same time it is necessary that interference with the forest ecosystem be kept within limits. For instance, deforestation to meet the needs for industrial and urban development may accelerate road construction, soil erosion and other processes that cause further forest degradation; as another example, converting natural mixed forests into artificial monospecific forests may appear to be financially profitable and administratively convenient in the short run, but may impose huge hidden costs (Auclair, 1983,

*An early draft of this Subsection was prepared by J.C. Nautiyal, Faculty of Forestry, University of Toronto.

p. 71). The basic needs of the local population for fodder and fuel must be met systematically if haphazard pilferage of these products and consequent damage to timber production is to be avoided. Existing forests create conditions of flora, fauna and soil that are conducive to the subsequent regeneration of the forest itself and, hence, to the continuation of forest economic activities.

Fig. 4-5, which summarizes these ideas, could provide a framework for estimating the long-term human "carrying capacity" of the Doon Valley forests. Such a framework will need to include assumptions about the nature of the processes involved. One such assumption is that the firewood, housing construction, agricultural implements, fodder and grazing needs of the entire rural population in the valley will be supplied from the forests in the area and that even parts of the fuel and construction needs of the urban population will be met. Another assumption is that the cattle population in the rural areas is sufficient to meet the entire milk requirements for the Valley. Hence the fodder and grazing needs of the rural population must take the needs of the urban dwellers into account. A third assumption is that a much larger proportion of cattle can be stall-fed than is presently the case and that the number of cattle left for grazing in the forested areas is limited to the number that does not harm the forest.

The magnitude of carrying capacity is primarily and ultimately a function of primary-resource availability within the environment as defined by the size of the particular area and by the level of technology available at that particular time. Certainly, the desired level of economic well-being also figures prominently as a determinant of human carrying capacity since an environment can sustain many more people at a low level than at a relatively high one. Determining optimum or preferred levels is a difficult matter in itself, but the important point here is that carrying capacity is quite flexible and subject to change - both for and against the benefit of society.

Three possible methods could be used for determining the carrying capacity of the Doon Valley: "trial and error" (or simulation), linear programming "optimization" (Shoemaker 1977 p. 105) and non-linear dynamic methods. In the trial and error approach, the predictive equations relating components of the system must be solved, analytically or numerically, for each new value of the decision variable. For a complex model for which many alternatives exist, it is usually too expensive to test each admissible policy. One may first choose a few of the policies that appear most promising and then test their outcomes by simulation. Unfortunately, the best policy can be overlooked in this procedure.

A second method often used (but not necessarily the best method) to determine the optimal management of systems is to described them by a set of linear equations and to solve then by linear programming (Shoemaker 1977 p. 106). Linear programming is a very powerful optimization tool because it can be used for systems with a very large number of variables. Solutions can be obtained for different objective functions, and the sensitivity of the solution to one or another variable can be investigated.

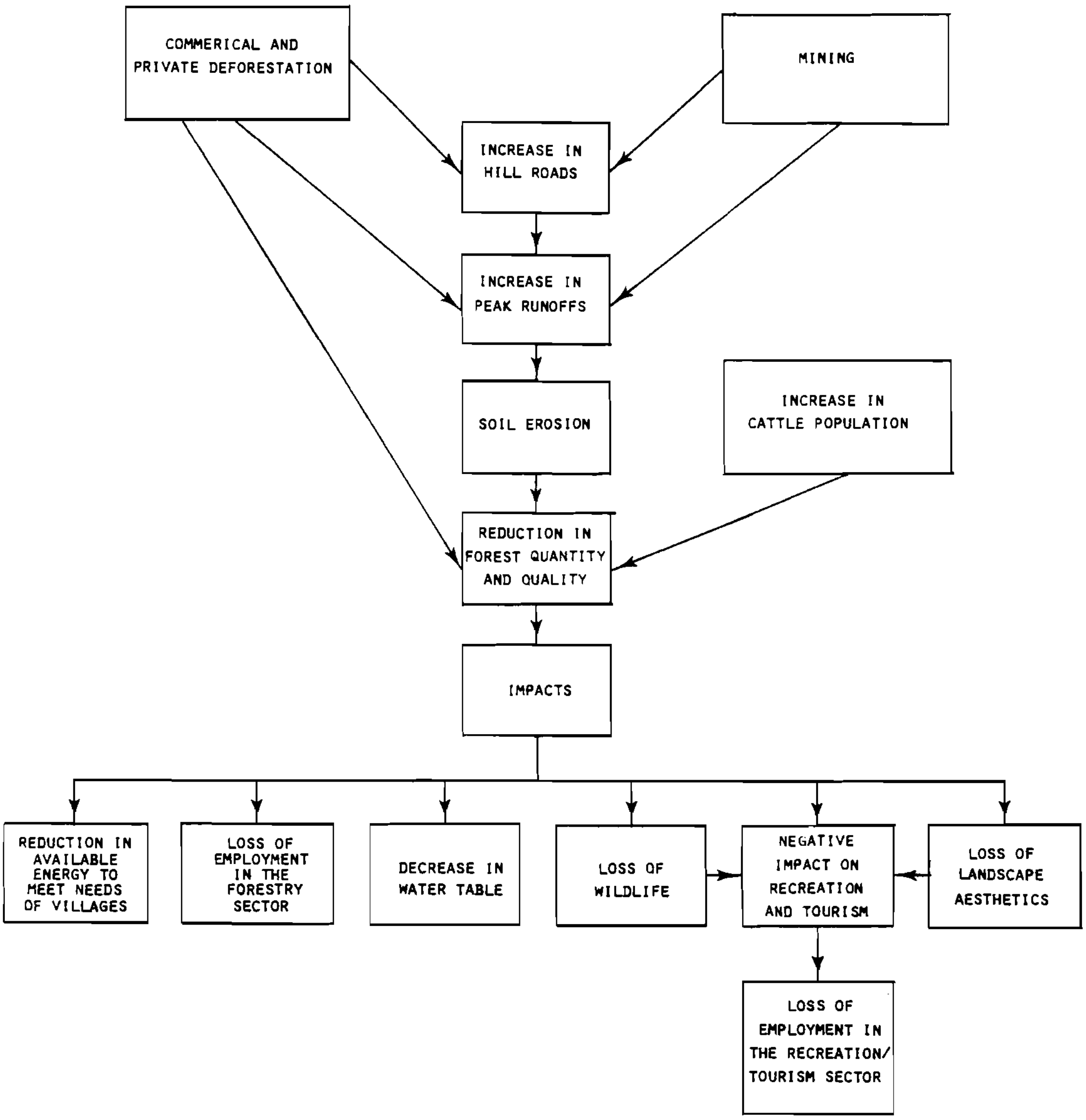

Fig. 4-5 A schematic diagram showing the relation between the forest sector and other components in the Doon Valley. With increasing populations of people and cattle, the sustainability of the forest sector needs to be carefully assessed.

Its major limitation is that it is only suitable for models with linear constraints and criterion functions.

The third method to be used when the functional relationships amongst the variables are very non-linear is the dynamic model approach. However, the input data requirements then increase greatly. Of course a non-linear module can be hooked to several linear modules of a large model; see, for example Brouwer et al. (1983).

Development of an appropriate sustainability model will need input data not yet available to the Project, including yields of various agricultural crops and the annual production of fuelwood, fodder, timber, resin, and milk. Much of the effort required in developing a model must be devoted to selecting and obtaining these data.

4.8 Planning Ahead in an Uncertain World

Planners usually assume that their task is to help society move towards some desired state. There are several problems with this approach:

-- Current aspirations of society are in fact a collection of conflicting sectoral aspirations.

-- These aspirations change from decade to decade. For example, the relative importance of good environmental quality has increased tremendously in the last two decades.

-- Strategies proposed by planners to move society forward sometimes lead to unexpected results, because of our incomplete knowledge of the environment, and of society's response to the changed environment.

Thompson and Wharburton (1985) have given an example of this very last point:

> Appropriate Technology solutions of fuel-efficient stoves and solar cookers to combat deforestation are environmentally appropriate only if the forest is being viewed as a renewable resource - a perception to which the providers of that technology are deeply attached. But what if those to whom they wish to deliver this technology see the forest not as a source of fuel but as a source of fresh agricultural land? Give them the technology and the last obstacle to the full clearance of the forest is removed. As we go from one institutionally induced perception to another, so the Appropriate Technology becomes supremely inappropriate.

Should the planner have been suprised? Without answering the question, the point to be made is that land-use simulation models should be sufficiently flexible to permit examination of alternative linkages and inter-relations amongst components and subelements. The possibility of surprise should never be overlooked, and the implications should regularly be explored that society and life-supporting ecosystems will behave differently than expected.

5. BASELINE REPORT: HISTORICAL TRENDS*

5.1 Introduction

Having identified the main environmental issues, it is now appropriate to consider the data bases that substantiate or dispell the concerns raised. In this Section we provide a historical perspective to the assessment. In Section 5, we shall examine current conditions and very recent trends over the last few years.

The area to be discussed in this Section is the Dehra Dun administrative district (See Fig. 2-2), for which long-term statistics are available. The period covered is the one hundred years between 1880 and 1980, and the indicators included are human population, land-use, vegetation cover, animal populations and man-land ratios.

The land-use and other time-series data to be presented rely in large measure upon official colonial and Republic of India statistics. The Agricultural Statistics of India annual series is especially valuable for this purpose. Estimates of vegetation cover in particular years depend upon close reading of additional narrative descriptions and correlation of these with land-use statistics. This systematic approach is described more fully in Richards et al. (1985, pp. 702-705). Human population figures are taken from the decennial census volumes. Animal population numbers are found in official livestock censuses taken at varying intervals. Other data on forests and forestry policy come from the gazetteers and from official Forestry Department publications.

Dehra Dun District, in common with other Himalayan hill districts, underwent great changes in the century under review. Human pressures on vegetation, soils, wildlife, and water supplies have grown steadily. The period after independence has been one of intensified alteration of the landscape and increasing consumption of the natural resources of the district. Both qualitative and quantitative evidence demonstrate the strength and consistency of these longer-term historical trends.

5.2 Population and Urbanization

Between 1880 and 1980 the number of inhabitants in the district rose from 144,000 to 758,000 persons enumerated in the 1981 census. As Fig. 5-1 shows, the most dramatic growth in population has occurred since 1940. In the four decades since that date the district's population shot up by 185% from 230,000 to its 1981 level. Population density, a sparse 47 persons per sq. km a century ago, had reached 246 persons per sq. km in 1980. While not high by all-India standards, this figure is considerable for the resources of a mountain valley.

The rising size and importance of the Dehra Dun metropolitan area has driven much of this population increase. In 1880 the

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*J. Richards, Department of History, Duke University, Durham, N.C., U.S.A.

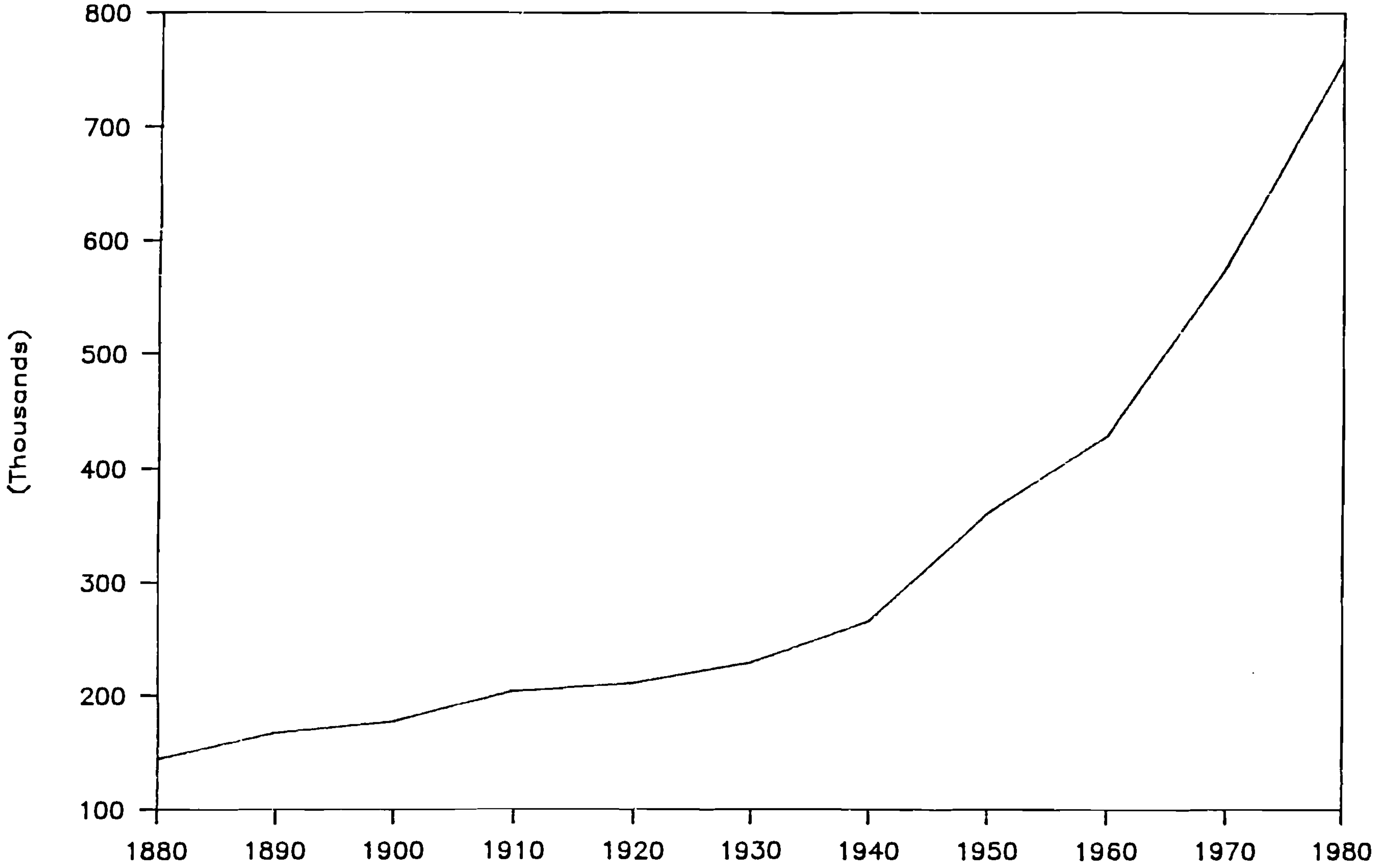

Fig. 5-1 Population of Dehra Dun District: 1880 - 1980

town numbered approximately twenty thousand persons. It was a military cantonment for several regiments of Gurkha troops and a favored settlement and retirement spot for many English colonial officials. In 1911 the town's inhabitants had nearly doubled to about 38,500. By this time the city had begun its role as a scientific and intellectual center for the colonial government. The Survey of India, the Forestry Department, and a number of other scientific arms of the Indian Government had established their headquarters here. By 1981 the total urban populace was 293,500. Today, in 1986, the total surpasses three hundred thousand.

Concentration of population within the metropolitan area has had a wide range of direct and indirect effects on the landscape and resources of the Doon valley. Urban demands for meat, milk, grains, drugs, fuelwood and charcoal, construction wood, lime, bricks, water, and other commodities rose steadily in the 1880-1940 period. The demand for these resources moved sharply upward between 1940 and the present day. The needs of the urban market encouraged expansion of arable land and clearing of forests and other vegetation in the district. Considerable evidence exists that these effects have extended well beyond the administrative boundaries of the district. As early as 1980, the district itself seems to have been importing foodstuffs to feed its population. The hinterland for Dehra Dun city and municipal region is far greater in extent than the confines of the Doon valley. The economic attraction of city markets pulled commodities and labour from hill areas in an expanding arc fifty or even one hundred kilometers or more from the city.

5.3 Transportation and Access

In 1829 district colonial administrators began construction of the main access road from Roorkee through the Siwaliks to Dehra Dun. By 1880 this was largely a "metalled" road, bridged and drained, and filled with cart traffic moving commodities in both directions. Throughout the century, the work of extending the intra-district road network continued. By the 1880s, virtually all villages had convenient access to a cartable road.

Construction of the Hardwar-Dehra railway, opened in 1880, afforded speedy and cheap access for both people and goods to the valley for the first time. Shortly thereafter, motor traffic on the main roads -- soon to be paved -- began in earnest. By the late 1920s, regular bus service from the plains had begun. These new forms of transportation superimposed upon the existing network of internal roads supplied a major impetus to the economic development of the district.

5.4 Expansion of Agriculture

Over the century between 1880 and 1980 the area of arable land has expanded from slightly more than 41,000 hectares to around 64,000 hectares in 1980, a 55% increase. As Fig. 5-2 shows, this has been a relatively slow, steady increase save for a sudden expansion between 1950 and 1960. In that decade 13,000 hectares of new land came under cultivation. Presumably this pulse resulted from government encouragement for agriculture

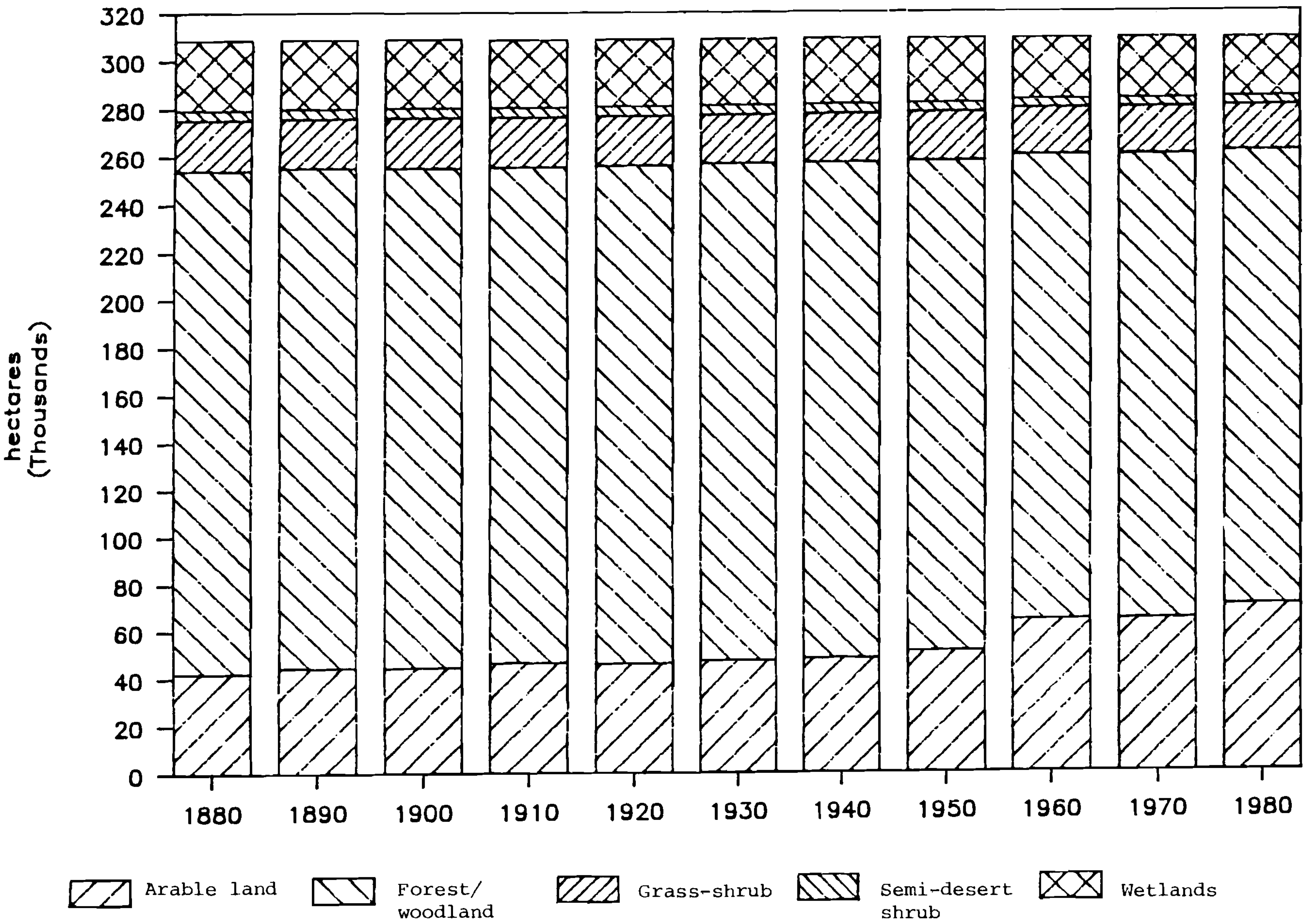

Fig. 5-2 Land Use of Dehra Dun District: 1880 - 1980

under the first Five Year Plan. A surge of new migrants to the district included some refugees from Pakistan after partition.

Crops grown have been primarily wheat -- though diminishing in importance -- followed by paddy rice, maize, barley, and millet. Sugar cane and small tea plantations are important cash crops. Fruits and vegetables for the urban markets round out the list.

Hilly terrain and difficult water supplies slowed conversion of land to agriculture. Often the only means of expansion for many farmers has been to terrace hillside lands with stone work -- an expensive and laborious process. Dry and porous soil makes rain-fed farming precarious and difficult. Expansion of arable land has frequently depended upon access to springs, streams or river-fed, small-scale, canal irrigation.

One of the largest canals, the Rajapur, dates from the pre-British period. British colonial officials built four of the remaining large riverine canals in the nineteenth century before 1880. Since that date, the government and private persons have invested in a number of smaller river and spring-fed canals or irrigation channels. The irrigated area has varied widely from season to season and year to year depending upon the rainfall and snowmelt of that year. In 1885, government-owned canals totalling 107 km in length irrigated about 5100 hectares of crop land. The total area watered from all sources has been considerably greater. Irrigated lands in the district have covered about one quarter of the total lands under cultivation (24.7% in 1901 and 27.6% of the cultivated area seventy years later).

Conversion of forest or scrub lands to agriculture, while significant, has not been a major source of environmental change in Dehra Dun District over the past century.

5.5 Changes in Vegetation

Changes in the vegetation cover of Dehra Dun District has been less than that for most other North Indian districts in the 1880 - 1980 period (See Fig. 5-2). Preliminary estimates show that the following vegetation categories* have suffered losses (upper set of figures) or gains (lower set of figures):

	Hectares	
Forest Woodlands	-27,721	(-16%)
Major Wetlands	- 4,607	(-21%)
Grass-Shrub	- 2,269	(-11%)
Semi-Desert Scrub	- 442	(-11%)
Total	-35,039	

*The number of categories (7) has been slightly expanded from the number (5) used in Fig. 5-2.

	Hectares	
Arable	+22,729	(+55%)
Human Use (Towns, roads, etc.)	+ 4,982	(426%)
Woods/Shrub Grass Mosaics	+ 7,382	(19%)
Total	+35,039	

The net effect of human actions over the past century has been to convert 35,039 hectares of the total area of 308,800 ha in the district from one vegetation category to another or from wild vegetation to a managed landscape.

Lands under the general classification of forest-woodland have shrunk by an estimated 27,700 hectares (-16%) since 1880. Conifers (chir, deodar, kail, spruce) show the greatest decline (22%). Losses in the broad-leaved temperate forests at 18.5% are less in percentage terms, but slightly more in number of hectares.

The estimated decline in swamp-marsh wetlands is 21%. This is the result of concerted investment in swamp drainage in the eastern part of the valley. Before as well as after 1880, the larger landholders, numbering many British settlers, drained swamps to reduce the risk of malaria. As the writer of the 1911 Gazetteer puts it: "The wide swamps which at one time covered so much of the [Eastern Doon] have entirely disappeared. . ." Clearly, wetland drainage has been a significant habitat alteration in the district.

Woods-shrub-grass mosaics increased by 19% over this period. This shift is probably a consequence of an ongoing process of forest and woodland degradation. Vegetation category shifts due to land conversion are not very dramatic. But it is clear from the available evidence that various forms of cutting, grazing and other human pressures on forests have substantially reduced the density and luxuriance of vegetation in the district. Slow thinning and degradation, rather than conversion to arable lands, has characterized change in the vegetation of the district.

Dehra Dun is a major timber collection point and market for the buoyant timber and fuel markets of the plain. Since 1880, if not before, Dehra Dun has continuously exported cut timber for sleepers, building scantlings and rafters. In 1970 the total timber exports from all sources were 10,000 metric tons. Fuelwood and charcoal have been until recent years another steady export from the district to the plains markets. Bamboos, thatching materials, and other forest products complete the list of materials taken from the district's woodlands.

5.6 Forest Reservation and Management*

The earliest settlements (more than 500 years ago) in the Doon valley were established on the slopes of the outer Himalayas and on the plateau in the valley defined by the Tons and Rispana rivers. These regions were well endowed with forest wealth which the people, largely farmers, used for satisfying their needs of fuel, fodder, structural timber and agricultural implements. Extensive agriculture was practised to produce food surpluses for an ever increasing population, and the forests were cleared for agricultural cultivation. Moreover, unrestrained forest cutting for profit during the brief Gorkha occupation (1803-14) left the forests in the vicinity of habitation in the valley devastated to a large extent (Tucker, 1982).

The entry of the British in 1814 did nothing, in the beginning, to improve the state of the forests. On the contrary, they introduced some drastic changes in the pattern of forest utilization which led to their further deterioration. Firstly, virgin sal forests were opened to commercial exploitation, and, secondly, the "zamindari" or land-lord system of land revenue was introduced which destroyed the community organizations in the villages. The forests were seen only as sources of revenue by the government and as a means of making quick profits by the zamindars, the new owners of the forested lands.

Large-scale clearfellings were carried out, and by the 1850's, sal tracts below the hills and in the valley were already cleared of marketable trees (Tucker 1982). In an effort to establish better control over the forest revenue and to ensure timber supplies for the newly introduced railway system, the Forest Department was established in 1855. It, however, was just a forest revenue collecting agency with a different name, and it did little to conserve or manage the forests.

During the 1870's (UPFD, 1979), it was realized that one of the important timber species being harvested, sal, was not regenerating naturally. The forestry system being practised was devoid of conservancy and consisted of heavy destruction and waste of forest resources. In order to introduce planned scientific management of forest resources in various parts of the then British India, the Indian Forest Act of 1878 was promulgated. This law defined several legal categories of forests, the most important of which was "reserved forests", which would be managed by the Forest Department for timber production and silvicultural improvement (Tucker, 1982).

Large areas of forests in the Doon valley were declared as reserved forests. Forestry activities were regulated according to prescriptions contained in a long-term plan of action, called "working plan", a system that is still practised today.

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*First five paragraphs were contributed by J.C. Nautiyal, Faculty of Forestry, University of Toronto, Canada.

Establishment of the central offices and institutes of the Forestry Department in Dehra Dun ensured that a large portion of the District's forest and woodlands came under official management. Therefore the forest records are full and relatively precise. The area devoted to officially designated reserved and protected forests has grown by 96% between circa 1880 and 1970:

Date	Dehra Dun Tahsil	Chakrata Tahsil	(Hectares) Total	% of Area
1877	77,000		77,000	24.9%
1901	77,002	36,778	108,779	35.2%
1950	77,287	36,518	108,805	35.2%
1961	76,082	39,089	115,171	37.3%
1971			150,803	48.8%

(Sources: Varun, 1979; Imp. Gaz. 1909; U.P. Forest Department Annual Administration Report, 1950-51, 1960-61.)

Passage of the 1878 Government of India Forest Act confirmed the status of the Dehra Dun government-managed forests. These comprised one-fourth of the lands in the district. By the turn of the century, incorporation of the Chakrata forests brought the proportion of reserved and protected forests to over one-third of the total area. This ratio remained stable until after Independence. The U.P. Zamindari Abolition and Land Reforms Act of 1950 gave the Forestry Department authority over private and village forests in the district. By 1971 nearly one-half the lands in the district were under professional forestry management and protection.

Placing such a large ratio of district lands under the protected forests category added a further impediment to the expansion of agriculture in the district. The fields and "village forest" lands of many villages in the district abutted the boundaries of government-protected forest tracts. Whatever market incentives might develop, they therefore could not cut and clear new fields beyond a certain well-defined limit.

Professional forest management may have limited, but it certainly did not halt, the deterioration of the forest, woodlands and wetlands of the district. Much unrestrained timber cutting had already taken place in Dehra Dun District between the assumption of British control and the demarcation of reserved forests in the late 1870s. Even after demarcation of the forests, acceptable standards for cutting and preservation were less stringent than those today. Descriptions of the first working plans of the late nineteenth century suggest much heavier cutting than might have been desirable for a sustained yield policy of the 1980s.

The British colonial forestry service expected to show a substantial profit on the extraction and processing of timber and other forest products from all its holdings. In the first decade of the twentieth century, Dehra Dun's average annual timber export to the plains was 6440 cubic metres (mostly sal for sleepers and building timbers). In the same period the Department licensed extraction of 27,552 cubic metres of fuelwood and charcoal and permitted cutting of 610,810 bamboos in the 77,000 hectares of the Doon forestry sector. Total average annual profits were 77,800 rupees.

Timber felled and sold by the department travelled to the plains by an intricate series of river passages. Individual logs floated down the Tons, Pabar and Jumna rivers to be caught by a boom. Thereafter the timbers went by raft down the Jumna river and the Western Jumna canal to a railhead near Delhi. Unexported timber enjoyed a ready market and rising prices at Dehra Dun municipality where a building boom followed the opening of the railway in 1900.

Extraction and sale of timber and other forest products through official channels was only one means of degradation. Private, individual cutting and gathering put additional pressure on private and on supposedly protected forest lands. Throughout the colonial period, the rural inhabitants of Dehra Dun district retained limited rights of access to government forests adjacent to their villages. Large areas of government forest were completely closed to grazing and gathering of fuelwood. But in certain demarcated areas, people could send in their herds for forage; they could take out dry fuel wood for personal and household consumption; they could lop trees for fodder and obtain torchwood and a limited amount of timber for building; and they could collect thatching grass and other forms of "minor forest produce" free of charge.

Before the early 1900s, these freely exercised village rights probably put less pressure on the forests than government-approved felling. However, growing urban demands for fuelwood and other forest products led to rising prices, making it profitable for villagers to cut more wood than needed for purely subsistence purposes. Despite various official control measures (including armed guards, arrests, and fines) larger numbers of rural inhabitants and their cattle have made greater demands on thinning woodlands and forest cover every decade. The sudden take-off of population in the district after 1947 has added a further dimension to licit and illicit cutting and gathering in the reserved forest lands. It appears that for many peasants, subsistence rather than merely supplemental income may be at stake in the forests.

5.7 Limestone Quarrying

Rising prices for building materials encouraged the Forest Department in 1904 to expropriate all private rights to the quarrying and processing of limestone. In 1908, 17,055 tons of lime left Dehra Dun by the railway. Laborers collected boulders bearing lime and placed them in large pits of about 30 cubic metres capacity. In these kilns, firewood burned steadily under about 10,000 kg of stones for a week. The end product was about

7500 kg of lime. The 1908 export of lime required an estimated 5000 to 6000 cubic metres of firewood for the kilns.

In 1911, four quarries were operating in the Doon Valley. That level of production changed very little until the State of Pakistan was created, and India had to develop its own sources of high quality limestone and marble. In 1980 there were about 100 quarry leaseholders in the Doon Valley, extracting 513 x 10^3, and 136 x 10^3 tonnes of limestone and marble, respectively, in that year (Bandyopadhyay and Shiva, 1985).

5.8 Animal Population

Livestock are obviously a source of agricultural productivity for the rural inhabitants of the district. Meat, dairy products, wool and hides are important sources of farm income. Dung for fuel or fertilizer is essential. Draft animals still are a major source for traction. At the same time, grazing animals make significant demands on vegetation. By and large, the district farmers do not cultivate forage crops for their livestock. Fallow lands, agricultural stubble, village commons, and forest and woodlands are the primary sources for animal forage. The Doon valley and hill animals have not been impressive for either size or productivity by plains district standards. The hill animals especially seem to have been uniformly small and scrawny. Cows were poor milk producers. But the hill bullocks were probably efficient for drawing ploughs and other farm tasks on the slopes of the terraced hillsides. It is also likely that they could survive on the scantier diet that hill and forest grazing supplied. Since 1947, the government has invested some resources in cattle and buffalo breeding. The size and the feeding requirements of these larger animals have risen accordingly.

The livestock population of Dehra Dun has grown at a steady pace (See Fig. 5-3). Between 1890 and 1966, total animals increased 89% from 168,000 to 315,000 head. More recent data for 1980 are not yet available but it seems unlikely that this trend has abated. Although impressive, this enhancement is much less than the 426% rise in human population for the century. Obviously the high proportion of urban dwellers in the district helps to explain the discrepancy. Nevertheless, both urbanites and the agricultural population depend upon animal resources. Between 1890 and 1966 the ratio of livestock to humans has varied from 99 head per one hundred humans in 1890 to a high of 124:100 in the 1908-1929 years, decreasing to 73:100 in 1966.

The composition of livestock herds has remained surprisingly constant over the seventy-six year period. Bovines (cattle, bullocks, and buffalo), sheep and goats constitute 98 to 99% of the district herds. Horses, not commonly employed in the region before the British annexation, remain unimportant. Bullocks continue to form 17 to 18% of the herds. Cattle, however, show a recent gain from 57 to 58% in the 1920s and 1930s to 62% of the total in 1966. Sheep and goats have lost proportionately.

The recorded enlargement in Dehra Dun's livestock has outpaced the expansion of land under cultivation. Arable land,

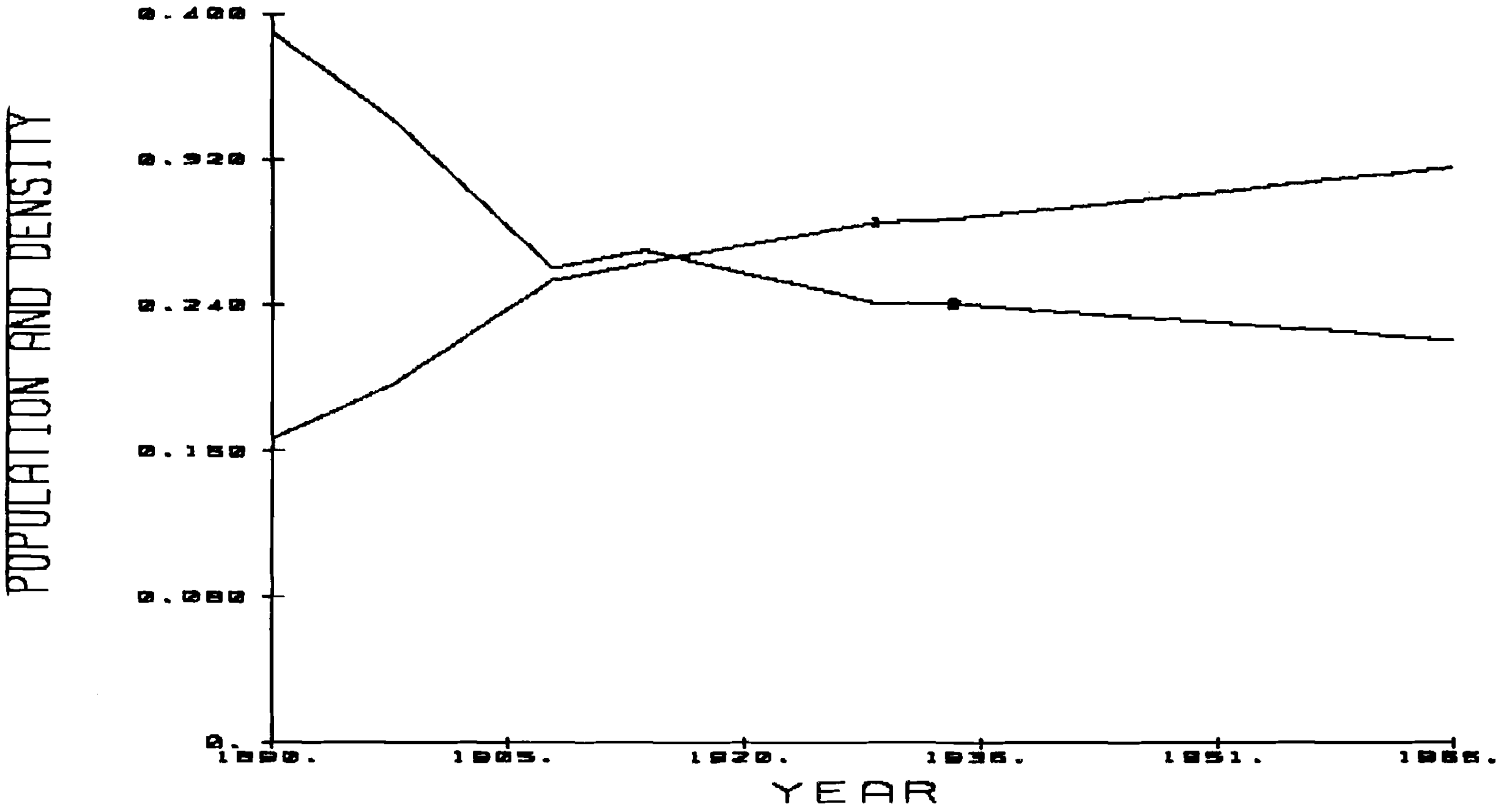

Fig. 5-3 Livestock population (in millions) (ascending curve) and population density (in hectares per annual (descending curve) in the Doon Valley between 1890 and 1966.

as mentioned above, grew by only 55% in the 1880 to 1980 period. We might therefore expect that somewhat greater pressure for scrub, woodland and forest grazing may be exerted now than in earlier years. Access to grass/shrub mosaics, wood-scrub and fallow lands has declined accordingly. The 1890 figure of 0.39 hectares per animal has dropped steadily to the 0.22 hectares per animal in 1966 (See Fig. 5-3). Cultivated forage crops and stall feeding do not seem to be common practices at present. Clearly for many farmers in the district, the only recourse has been the undergrowth, intermittent grasses and lopped branches of the district forests. Forestry department management of reserved forests placed a barrier between the peasant farmers of the district and their accustomed forage resources in the forests. Fodder for most of the year consisted of "grass carried in from the more precipitous hillsides by the women" and "leaves and straw" (1911 GAZ p. 36). Cattle owners rarely tried to store fodder, but "hillsides that were too steep for safe grazing acted as a natural reserve" (ibid). For four to five months before the summer rainy season, the hill villagers drive their cattle "up to the great forests on the higher hills: there they make a more or less permanent cattle station, not leaving it until the rains have well set in" (ibid).

In 1877-78 the department asserted that the prescriptive or customary rights of forest grazing held by farmers both in the Doon valley and in the hills was a privilege and not a right. Hereafter these rights were to be extended only to defined forest areas adjacent to each village. Grazing and access to the forests of the Eastern Siwalik ranges were banned altogether. This action seems to have put an end to most of the cattle stations for summer grazing in the forests. Continuing restrictions on access to more distant reserved forest blocks have forced more intensive, and one suspects, more damaging grazing on both private and reserved scrub and woodlands circumscribing each village. In its descriptions of individual villages, the 1911 gazetteer mentions the hardships caused the peasants by strict exclusion from many forest tracts.

Wild animals of all types have diminished in numbers as human and domestic animal populations have swollen. Hunting and the deterioration of habitat have combined to reduce the predators. Tigers, leopards, and the hyena were already reduced in numbers by the early twentieth century. Elephants were depleted by capture. The last known <u>khedah</u> was held in 1905. Deer herds -- sambhar, chital, and parha -- roamed in smaller herds in the early twentieth century because of "continuous destruction of game." Quail, duck, partridges, among other game birds were still prolific. Fish were still abundant, especially the large mahseer which could be readily netted by rural folk.

By the 1970s these animals were certainly far from abundant. A tiger census taken in 1973 found eleven animals surviving. Other animals suffered less drastic, but similar declines. The wildlife protection legislation of 1972 has prohibited taking of any animals in the district. Some restoration of populations may be expected in the reserved forests. But this has also reduced access to supplementary food supplies for the rural population. Fishing for mahseer is no longer common with the decline in numbers. Whether steady depletion of animal and bird numbers has had a deleterious effect on the ecosystems of the district is certainly a point that should be examined.

5.9 Man-land Ratios

The effects of one hundred years of economic development and growth in human numbers can be seen most dramatically in Fig. 5-4. The amount of arable land per person in the district -- both urban and rural -- has declined slowly but perceptibly over the century. From just under three-tenths of a hectare in 1880, the figure gradually dropped to just over one tenth of a hectare in 1980. This trend towards decreasing values supports the notion that the district has increasingly relied upon imported foodstuffs. Whether post-1950 investments in improved seeds, fertilizer and water have led to better yields thus compensating for this declining land ratio is not certain.

More startling is the trend in per-capita access to natural vegetation given by the upper curve in Fig. 5-4. In 1880 each person in the district had access to nearly 1.8 hectares of natural vegetation, which includes all the major types of vegetation cover, from wetlands to grasslands to forest areas. By 1980 this area had tumbled precipitously to just under four-tenths of a hectare per person.

The trend suggests that in at least one important sense, the population of the district has become impoverished. Rural folk can no longer readily and easily gather manifold products of grassland, shrub or woodland. Wild fruits, dyes, medicines, fuelwood, thatching materials, bamboo, honey, and game are either inaccessible or more costly in terms of time and energy for their collection. For the urban dweller, the availability of these products at low cost is no longer possible. Perhaps even more significantly, this unfavorable trend suggests that in each decade, the inhabitants of Dehra Dun have imposed greater pressure on the vegetation of the district. Degradation and depletion of the habitat is the inevitable result.

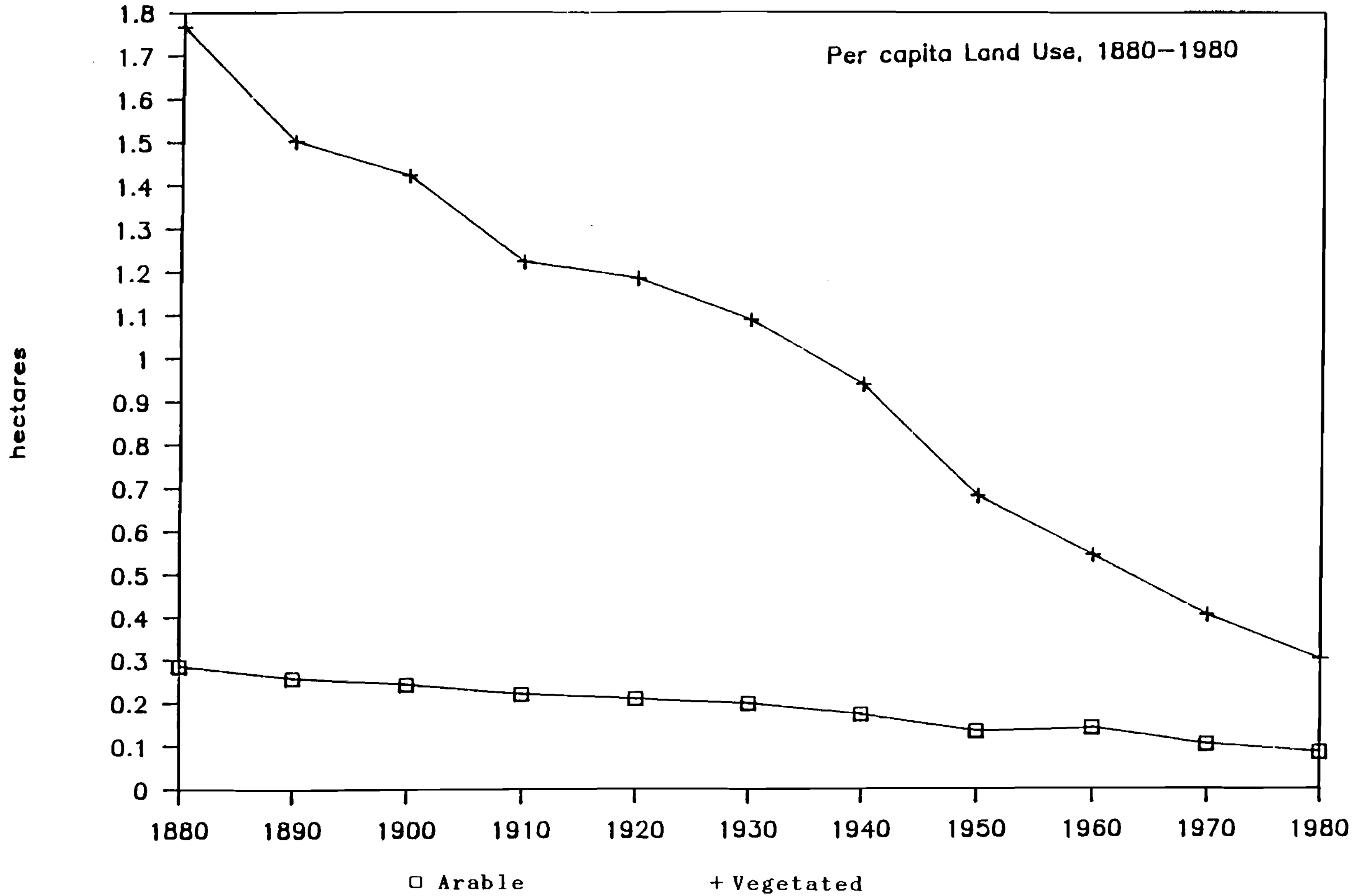

Fig. 5-4 The average area of arable land per person (lower curve); the average area of vegetated land per person (upper curve).

6. BASELINE REPORT: CURRENT CONDITIONS AND RECENT TRENDS

6.1 Introduction

The following baseline report of current conditions in the Doon Valley is preliminary. In some cases, the data banks were not made available to the Principal Investigators in time to meet the deadline for submission of the Phase I Report. In other cases, new measurement programs will have to be established under Phase II of the Project.

6.2 The Atmospheric Sector

6.2.1 Climate data sources

There are three climate observing stations in the valley: (1) Dehra Dun city; (2) the Forest Research Institute just to the west of the city, and (3) the Field Station of the Central Soil and Water Conservation Research and Training Institute - about 18 km to the west of the city). There is also an observing station in the hill town of Mussoorie overlooking the Valley. In addition, data are available from a "control" site, Roorkee, which lies to the south of the valley (about 65 km SSW of the City of Dehra Dun). Observations are made twice daily [0300 GMT (0830 LST) and 1200 GMT (1730 LST)] of the usual weather elements, including in particular maximum and minimum temperatures, precipitation amount, and instantaneous wind direction. In addition, pilot balloon observations are made at the Dehra Dun City station. The records go back many years, and climatological normals for the period 1931 to 1960 are published.

6.2.2 Recent trends in climate over India

The most important large-scale feature of the Indian climate is the southwest monsoon which in the Doon Valley, occurs generally between late June and mid-September (the rainy season). The remainder of the year is dry except for brief intervals of rain when weak disturbances cross the region from west to east.

There are significant year-to-year variations in the global atmospheric general circulation, particularly with respect to the behaviour of the monsoons. However, there is no evidence for any recent trends in India. For example, Padmanabhamurty has shown (see Volume 3 of this report) that there have been no statistically significant changes in annual rainfall in recent years.

6.2.3 Recent trends in the climate of the Doon Valley

Padmanabhamurty's study did not include rainfall data from the Doon Valley. However, a plot of the annual rainfall at the Forest Research Institute (Fig. 6-1) certainly does not support the idea of a change in rainfall locally in the Doon Valley. A careful statistical investigation of this time series as well as of 14 recent years of monthly rainfall amounts and temperatures at the Forest Research Institute has been undertaken by Fedorov

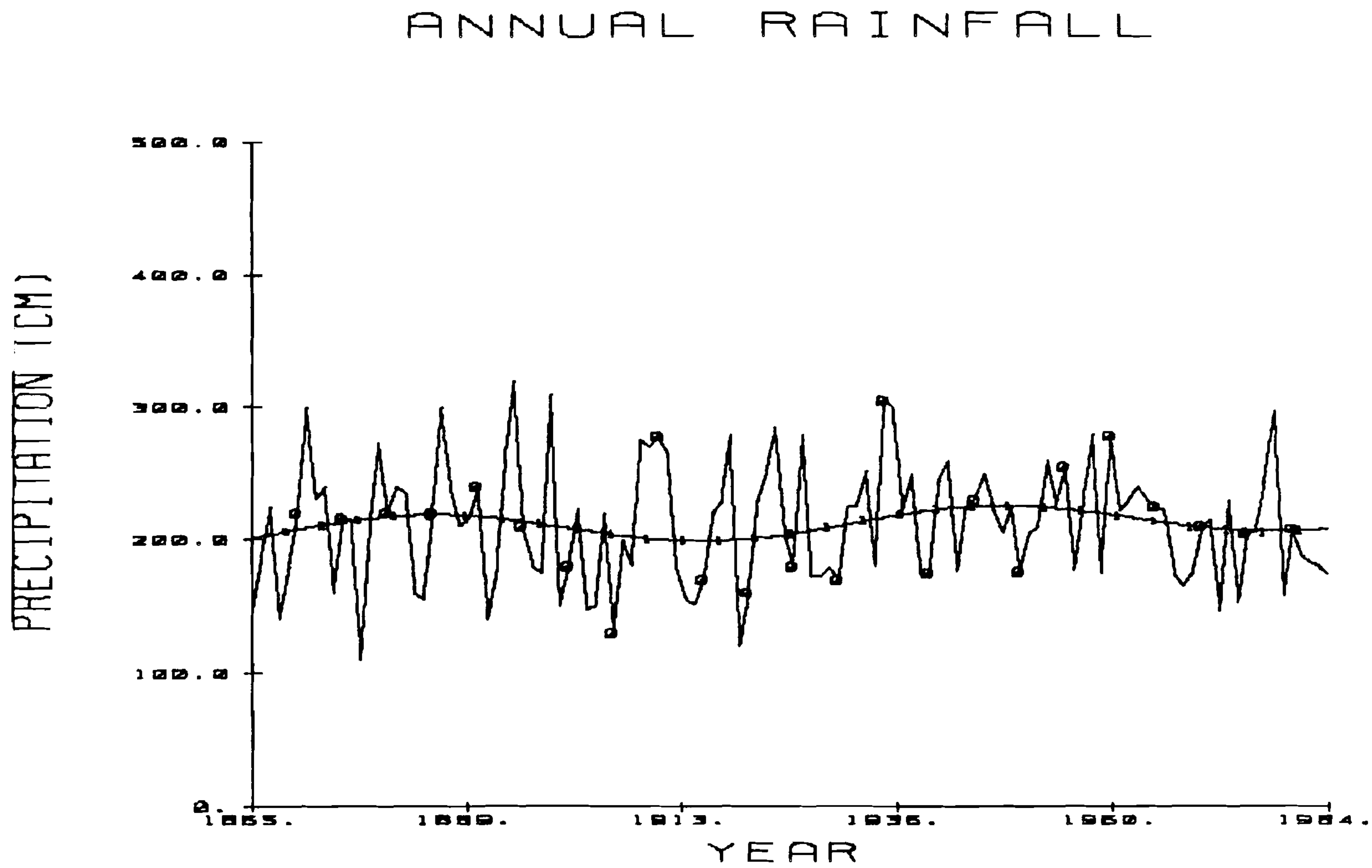

Fig. 6-1 Annual rainfall at the Forest Research Institute, Dehra Dun. A best-fitting curve is included.

and Lenko (see Volume 3 of this report). Again there is no evidence for any recent change in climate.

6.2.4 Evidence for mesometeorological wind circulations in the Doon Valley

Except during the summer monsoons, the topography appears to be generally favorable in the Doon Valley for the development of slope and valley winds, which would have a major effect on air quality in the area. Do the data provide any evidence to support this view?

The 30-year climatological summaries available to the Investigators include frequency distributions, by month of the year, of instantaneous wind directions at 0300 and 1200 GMT for Roorkee, Dehra Dun City and Mussoorie. Admittedly an instantaneous reading is not the best measure of wind; however, the long-term statistics clearly reveal the presence of a diurnal cycle in wind except during the monsoon season. Some illustrative results are given in Figs. 6-2a, b, c, which show:

-- At Roorkee, a "control" station out of the Valley, the prevailing wind is NW in January and SE in July. The frequency of calms is higher in January, particularly at 0300 GMT. (See Fig. 6-2a.)

-- At Dehra Dun City in January, there is a significant wind reversal in between 0300 GMT (prevailing wind N to NE) and 1200 GMT (prevailing wind SW to W). This effect is not so evident in July. (See Fig. 6-2b.)

-- At Mussoorie, a wind reversal occurs in January, as at Dehra Dun City, but the prevailing direction at 1200 GMT is S rather than SW to W (this may be due to very local differences in exposures). In July, the prevailing direction is S at both hours (in contrast to SE at Roorkee). (See Fig. 6-2c.)

In summary, the wind direction climatology at Roorkee is representative of conditions in the plains of Northern India. In the Doon Valley, there is good evidence even from this limited data set for a mesoscale wind field, as might also be expected. This has important implications for pollution control strategies, as will be elucidated in Section 7.2.

6.2.5 Temperature inversions in the Doon Valley

The vertical temperature structure in the Valley is an important consideration with respect to the dispersion of air pollutants. In particular, a temperature inversion (an increase of potential temperature with height) acts as a lid on upward diffusion of pollution.

There are no direct measurements of vertical temperature profiles in the Doon Valley, the nearest upper air station being at Delhi. However, a rough indication of local conditions may be obtained from a comparison of temperatures at Mussoorie with those in the Valley. (The difference in height between Mussoorie

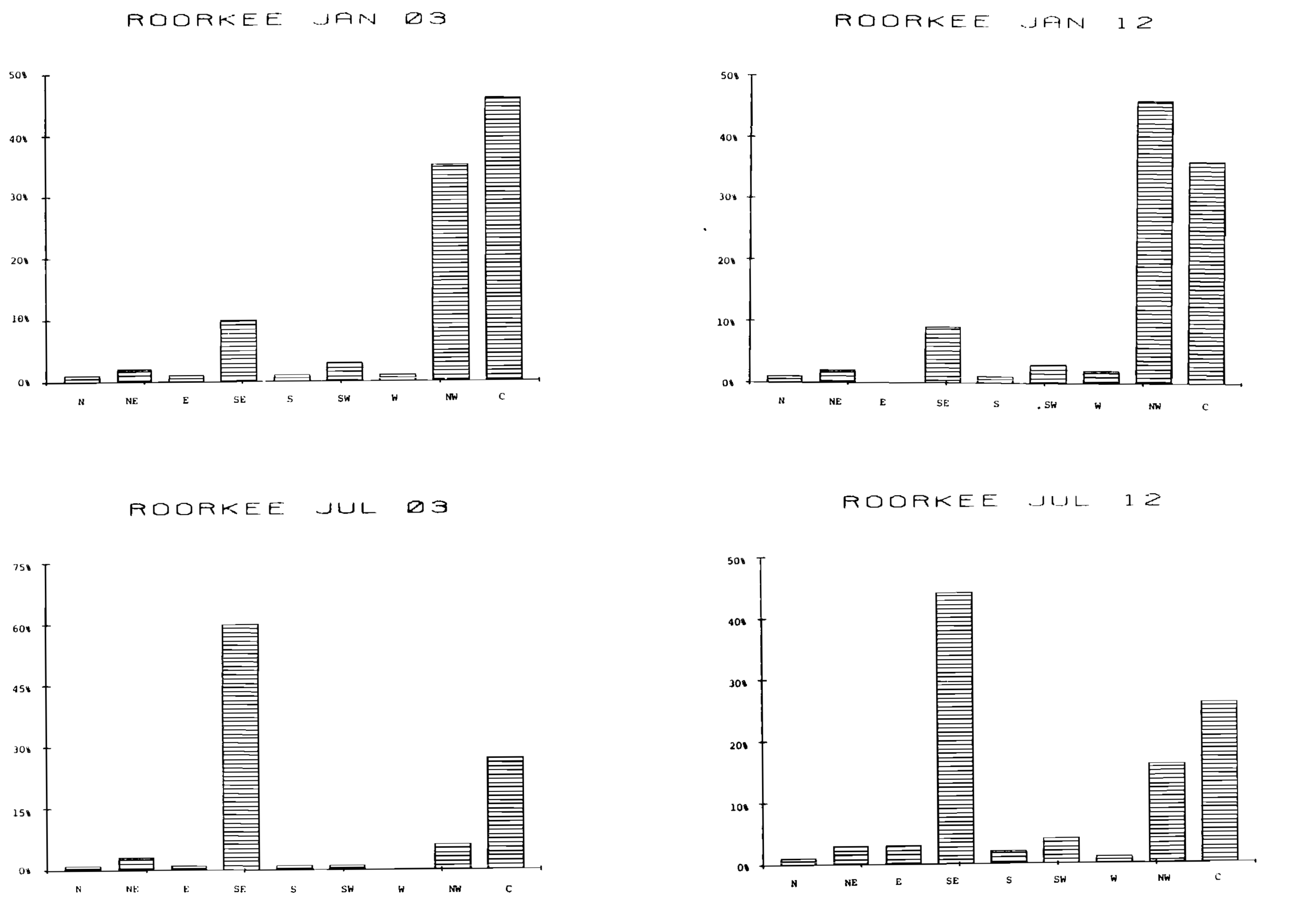

Fig. 6-2a Percentage frequencies of instantaneous wind directions at 0300GMT (0830LST) and 1200GMT (1730LST) in January and July for Roorkee.

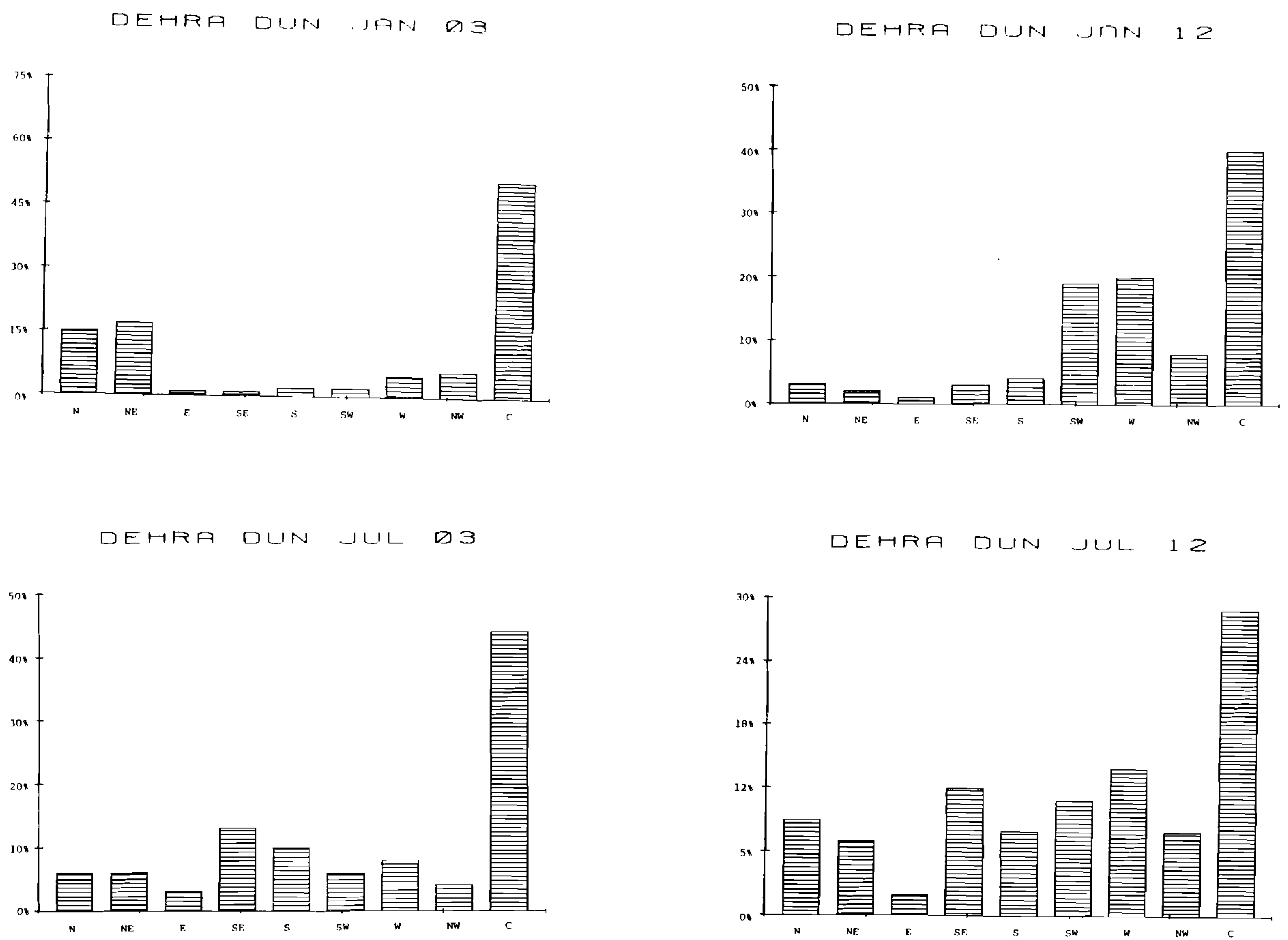

Fig. 6-2b Percentage frequencies of instantaneous wind directions at 0300GMT (0830LST) and 1200GMT (1730LST) in January and July for Dehra Dun.

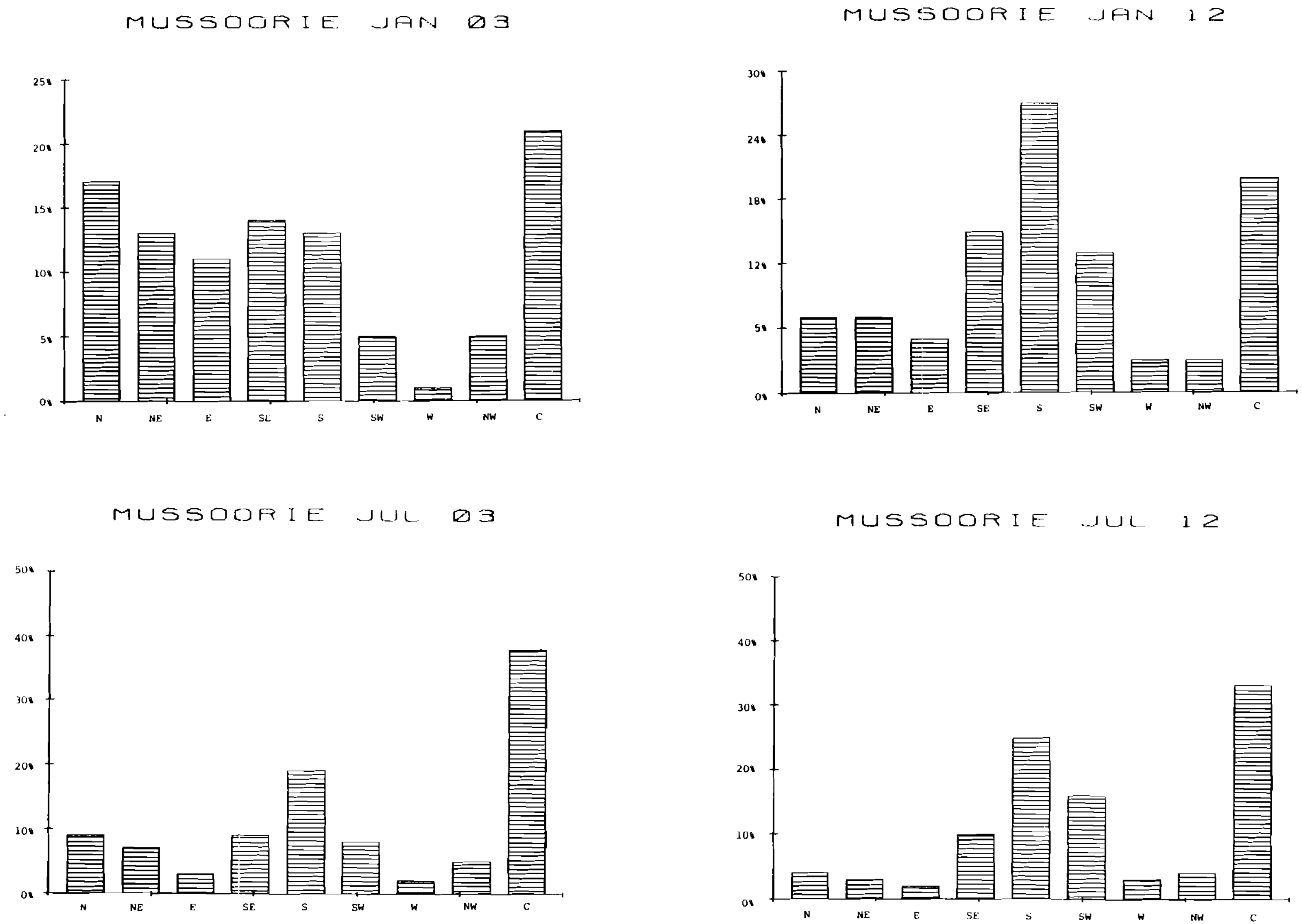

Fig. 6-2c Percentage frequencies of instantaneous wind directions at 0300GMT (0830LST) and 1200GMT (1730LST) in January and July for Mussoorie.

and Dehra Dun City is 1360m, so that 13.6°C (1°/100m) should be added to the Mussoorie temperatures to correct for adiabatic expansion and cooling, before comparing them with Dehra Dun city values.)

The results given in Fig. 6-3 should be considered as suggestive only. We have used climatological mean monthly temperatures, and there will in fact be a frequency distribution of temperature differences, some larger and some smaller than those shown in Fig. 6-3. In addition, we have assumed that the air is not saturated; when cloud and mist are present, the moist adiabatic lapse rate (0.6°C/100m) should be used. Nevertheless, Fig. 6-3 does suggest that temperature inversions may occur, thus limiting the dilution capacity of the mesometeorological valley system.

As an anecdotal footnote, one of the principal investigators (R.E. Munn) measured the temperature with a small digital thermometer exposed outside the left front window of a moving automobile at each 100 m of elevation between the city limits of Dehra Dun and Mussoorie. Heights were estimated from the readings of a small aneroid altimeter. The measurements were made between 1000 and 1100 LST on January 10, 1986. Skies were clear but there was a pall of smoke in the valley. The usual caveats apply to this data set:

-- Temperatures were no doubt rising with time, particularly on south-facing slopes. However, the increase would certainly not have been more than a couple of degrees per hour.

-- The twisting road was sometimes in sun and sometimes in shade, sometimes very near the edge of the slope and sometimes set back 20m or so.

In spite of these factors, the data displayed in Figure 6-4 suggest that an inversion was probably present in the valley on that occasion. Visually, there appeared to be an upper lid to the smoke pall at an elevation of about 700 m above the valley floor.

Continuing to observe the situation from a southward facing vantage point in Mussourie, wisps of smoke began to move up over the town at about 1145 LST, and by noon, the side of the valley was shrouded in fog (cloud), so that the trip back to Dehra Dun was in partial fog. It was therefore not appropriate to repeat the measurements on descent, and to average at each elevation, as is usually recommended.

Summarizing, on this single occasion at least, the valley did not have an impermeable lid; there was in fact considerable leakage of the pollution pall associated with upward-rising air over southward-facing slopes. In this connection, these observations suggest that air quality should be measured at the southern edge of Mussourie; it is possible that the import of pollutants into the hill town from the valley below could be significant.

Fig. 6-3 Differences in monthly mean potential temperatures between Dehra Dun City and Mussoorie. Lower curve-differences in daytime maxima; upper curve-differences in night-time minima.

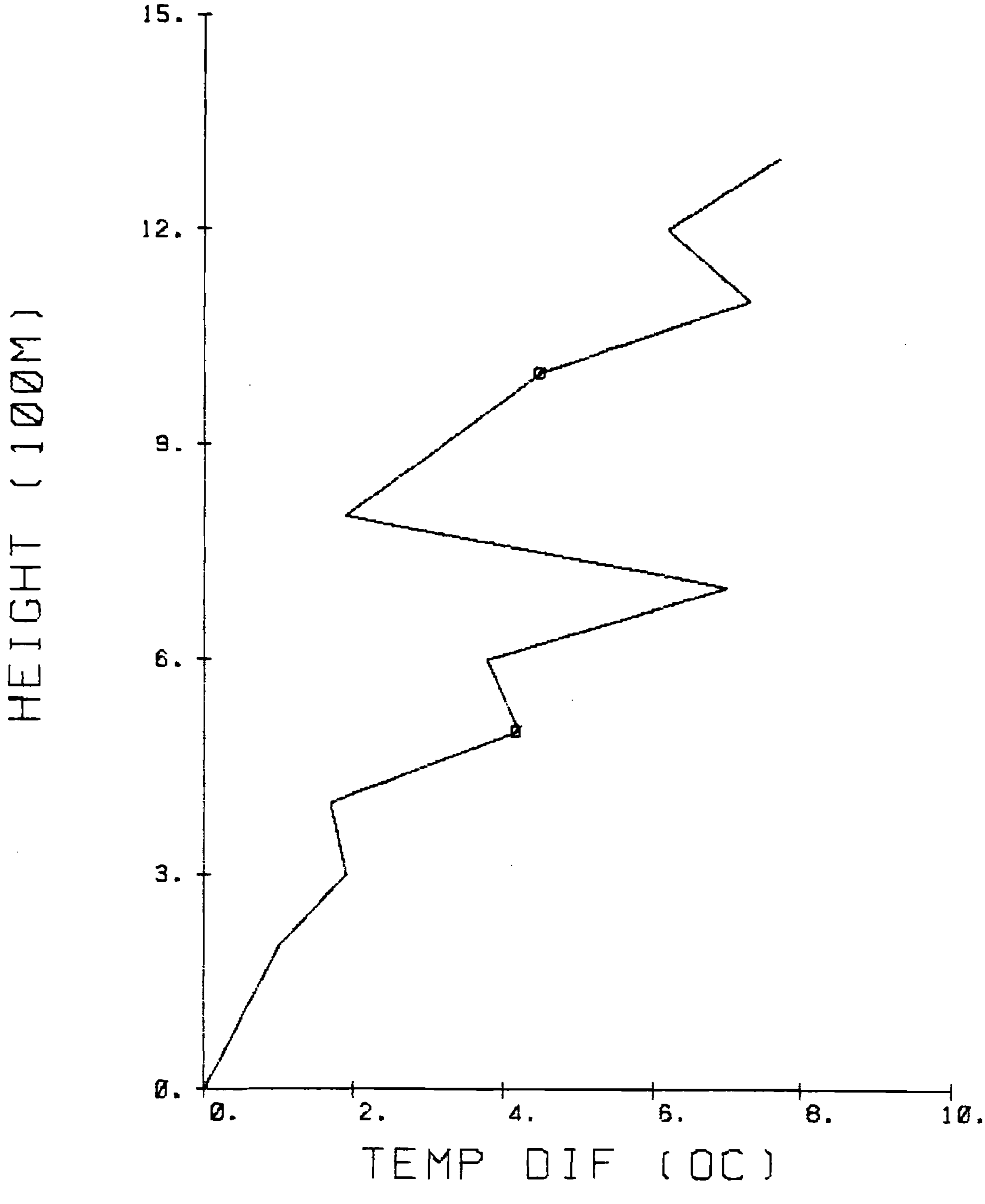

Fig. 6-4 Vertical profile of potential temperature between Dehra Dun and Mussoorie, 1000-1100 LST, 10 January 1986, obtained from an automobile moving up the hill. See text for caveats about the representativeness of this profile.

6.2.6 Air quality in the Doon Valley

Locations of the largest point sources of air pollution in the Doon Valley are shown in Fig. 6-5. These emitters are situated between Dehra Dun and Mussoorie. However, there are many smaller sources not only in the city but also in the surrounding rural areas. An air pollution emission inventory will have to be made during Phase II of the Project. Presently, the only information available is contained in an unpublished report dated September 1985. At the time of a site visit by a Central Board team on 19-21 August, 1985,

-- ARC Cement: particulate emissions from the stock exceeded the prescribed limit of 100 mg/Nm³ and there were many fugitive emissions.

-- M/s V.P. Carbide: the plant was not yet in production but it has an installed annual capacity of 21,000 tonnes of calcium carbide. Fabric pollution control filters were being installed.

-- M/s Aditya Chemicals Ltd.: particulate emissions were less than 50 mg/Nm³, well below prescribed air pollution control limits. The plant is producing about 10,000 tonnes per year of precipitated calcium carbonate.

-- Lime kilns: about 200 kilns are operating on both sides of Raipur Road near the Rispata river.

The only air quality measurements in the Valley were obtained close to point sources. For example, Bandyopadhyay et al. (1984) mention that measurements taken "near the Rispata bridge, and including sensitive areas like a residential children's school, revealed that the particulate matter in air was 350 micrograms per cubic meter" (8-hour averages). This area is close to the limestone kilns, which emit visible white dust. At a distance of 150 m from the kilns, concentrations of suspended particulate matter averaged over 8 hours are usually higher than 1000 micrograms per cubic meter (Shri D.P. Sharma, U.P. Pollution Control Board). One of the tasks to be undertaken during Phase II of the Project will be to establish a network of air quality monitoring stations at representative locations in the Valley.

One rough indicator of long-term pollution trends is visibility, particularly the frequencies of occurrences of haze and smoke (Munn, 1973). The measurements made at weather observing stations in the Doon Valley and vicinity will be examined for trends of this type as soon as the data become available to the principal investigators.

6.2.7 The Hydrologic Cycle

Rainfall climatologies are available from 3 stations in the valley, as well as from Mussoorie. As an additional piece of information, Moench and Bandyopadhyay (1985) mention that there is a rainshadow in the Aglar valley north of Mussoorie; rainfall measured at the village of Munglori in the Aglar valley during

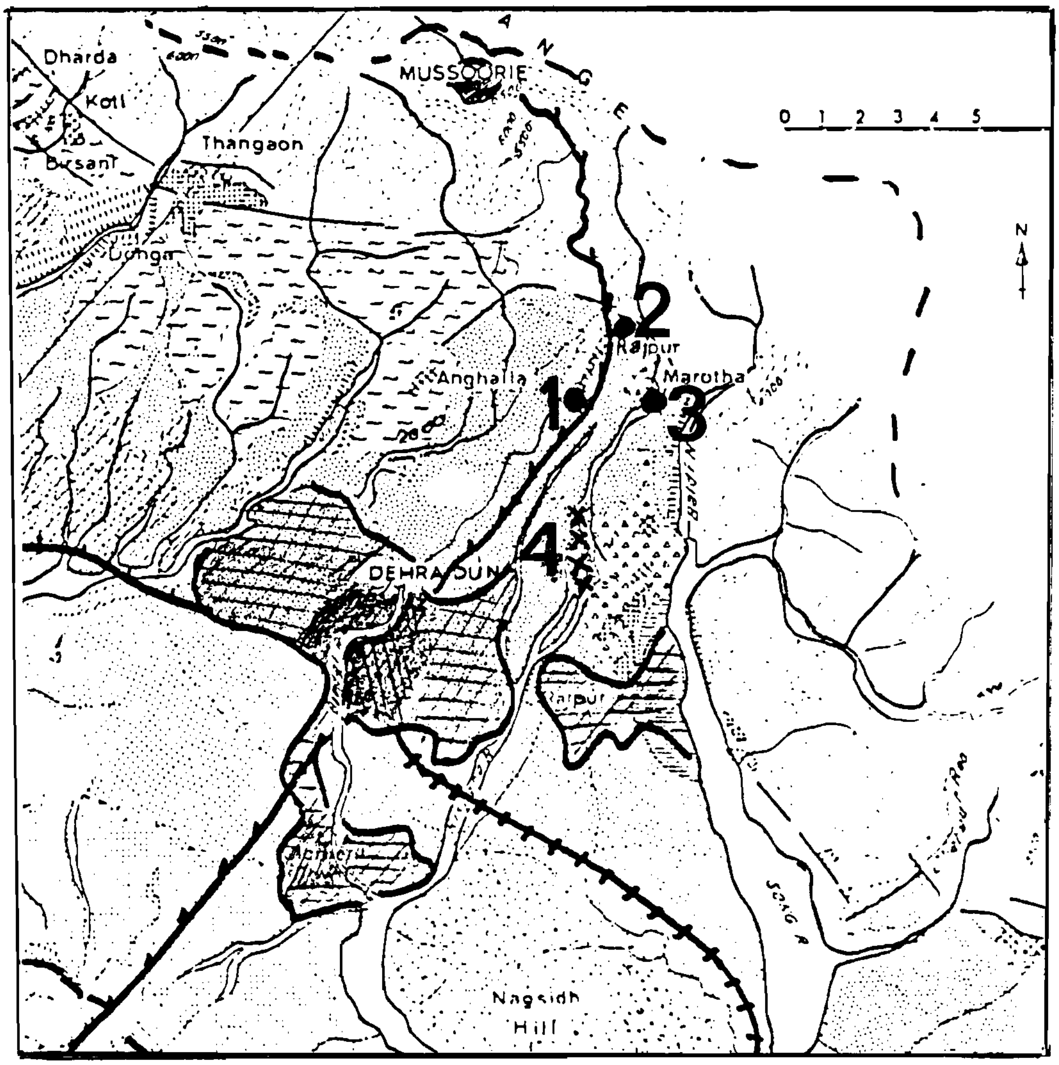

Fig. 6-5 Main point sources of air pollution in the Dehra Dun City-Mussoorie area.

1. ARC Cement Plant
2. UP Calcium Carbide
3. Adihaya Chemicals
4. Limestone Kilns

Railways

Main Roads

June-September 1984 totalled only 25% of that recorded at Mussoorie. So it is possible to obtain a rough engineering estimate of the water input to the Doon Valley system, including the year-to-year variability in rainfall; see Fig. 6-6 for an example of the type of climatological output that is available. From a knowledge of the temperature and humidity fields, a rather crude indirect estimate of evapotranspiration could also be made.

Some data on water storage and runoff have been collected by various national and state agencies. However, the information has not yet been obtained by the Principal Investigators in most cases. This part of the baseline report must therefore remain incomplete, and we are able to cite only the following:

a) Ground-water table in the vicinity of Dehra Dun

Roy (see Volume 3 of this Report) has mentioned that ground-water levels in Dehra Dun have reportedly lowered by about 15 m in the last decade. One of the tasks for Phase II of the IIASA study will be to undertake a careful statistical analysis of ground-water time series.

b) Peak discharges in 5 small watersheds in the Doon Valley

Babu and Narayana (1984) have studied peak discharges in 5 small watersheds in the Doon Valley using data for the years 1960-1983, and have developed a stochastic model for predicting the peaks. For one particular watershed, the actual and predicted peaks are shown in Fig. 6-7. As can be seen from the best fitting regression curve, an upward trend of 0.052 cubic metres per second per year in peak flow is obtained. This agrees with the general perception of Valley residents that peak run-off rates have been increasing in recent years.

6.3 Water Quality

Water quality is not a major public issue in the Doon Valley (see Section 3). For ease of reference, however, we cite three reports that mention water quality.

-- Singh (1983) - a Master's thesis at Jawaharlal Nehru University on water and sediment quality downstream from the Mussoorie phosphate mining area. Some typical results are shown in Table 6-1. The effect of the mines on sulphate, phosphate and calcium concentrations is detectable.

-- Katiyar et al. (1984) - A chemical analysis was undertaken of water quality near three mines and in the Baldi river. The results shown in Table 6-2 are consistent with those in Table 6-1. The sulphate and phosphate concentrations are elevated in the vicinity of untreated old mines.

-- FRI (1984) - A preliminary investigation is being undertaken of the chemical quality of Bijapur Canal water passing through the New Forest at Dehra Dun.

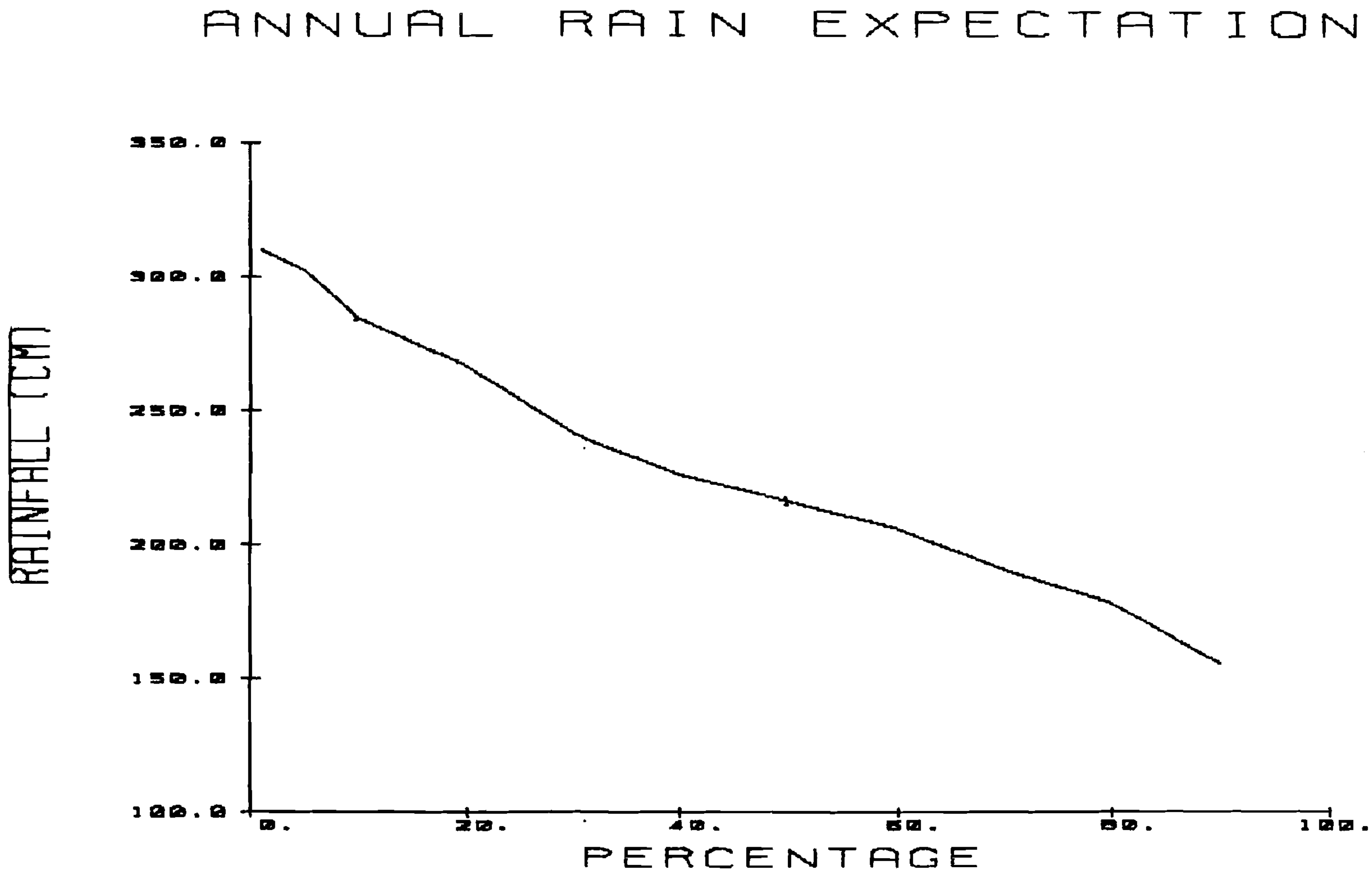

Fig. 6-6 Cumulative frequency distribution of annual rainfall amounts at the Forest Research Institute, Dehra Dun.

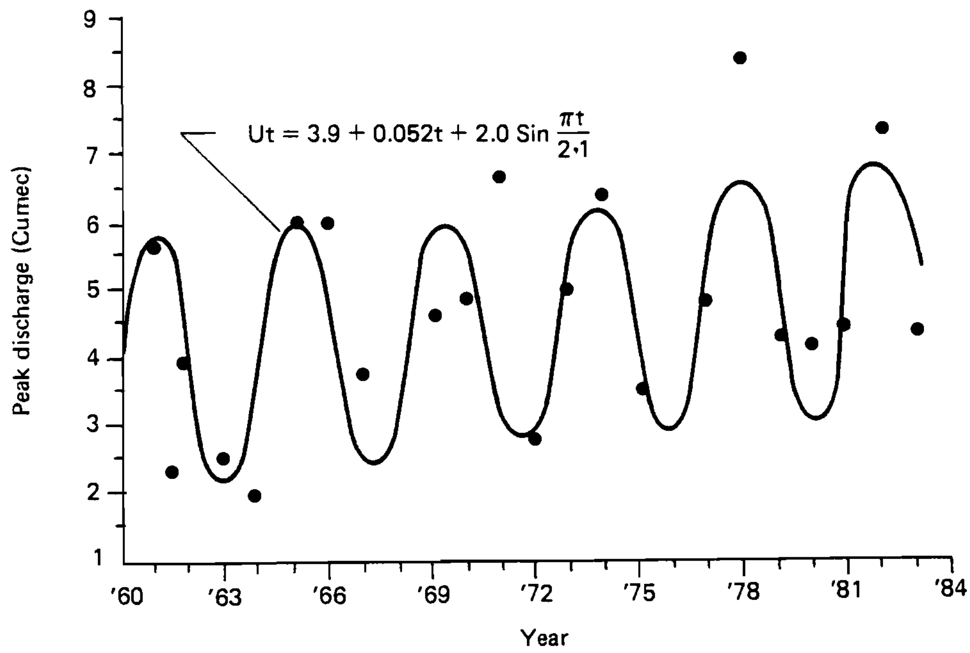

Fig. 6-7 Actual and estimated annual peak discharge in one particular watershed in the Doon Valley (Babu and Narayana, 1984).

Table 6-1: Some typical results from a study of water quality downstream of the Mussoorie phosphate mining area. Concentrations in ppm. (Singh, 1983)

Location	PH	Cl^-	F^-	HCO_3^-	SO_4^{--}	PO_4^{--}	Ca^{++}
1400 m upstream of mine discharge	8.1	4	1.3	173	265	0.48	21.5
100 m downstream of mine discharge	8.1	4	1.1	173	754	0.06	28.5
200 m downstream of mine discharge	8.1	4	1.3	145	577	0.36	150.0
Song Canal, Maldeota 17,400 m downstream	8.0	4	1.4	119	438	0.06	110.0
Tap water, Dehra Dun 33,400 m downstream	8.0	5	1.3	155	125	0.06	28.5

Table 6-2: Some results from a study of water quality in the vicinity of mining areas in the Doon Valley. Concentrations in ppm. (Katiyar et al., 1984)

Location	PH	HCO_3^-	SO_4^{--}	Ca^{++}
Treated old mine spoil (Jhandoonala)	8.2	143	108	51
Untreated old mine spoil (Dhandaula)	8.0	90	495	232
Untreated fresh mine spoil (Kali Rau)	8.0	130	370	182
Baldi river	8.0	140	172	66

6.4 The Forestry Sector*

6.4.1 Introduction

Forests of various types and variable densities cover about 1000 km^2, or nearly 50% of the area of the Doon valley. The forest resources of the valley are administered by the East and the West Dehradun Forest Divisions of the Siwalik Forest circle. There are no village or community forests in the valley. Therefore, leaving aside some negligible private or municipal treelands, practically all the forest in the valley is managed by the Uttar Pradesh State Forest Department. The forest distribution in the valley is shown in Fig. 6-8.

6.4.2 Description of the Forests

The Doon valley has been known for its excellent sal (*Shorea robusta*) forests. However, over the last few decades, the proportion of well stocked forests has been falling (Sharma & Sharma, 1983), and the present state of forests leaves much to be desired.

The forests in the three geographical regions within the valley are markedly different. The condition of vegetation in these three regions was assessed by using aerial photographs for the years 1975-77 (Sharma & Sharma, 1983). The approximate proportions of areas under different densities of forest cover (above 60%, 20 to 60%, below 20% and non-forest) are shown in Fig. 6-9.

The forest cover on the north-eastern slopes of the Siwalik was the best of all where about 56% of the land is covered with sal forests of high density (i.e., average crown cover of over 60%). In all, about two thirds of the region had some kind of forest cover. In contrast, the valley proper had less than 50% of its area under forest, and only one third of the region was under dense sal. Almost 8% of these flat lands had planted forests, raised mostly on poor and much degraded areas. The forest cover in the third region, the south-western slopes of the Himalayas, was found to be in a most pronounced state of degradation. Though technically 60% of the land had forest cover, only about 10% had dense forests. There were no sal forests in the region and the dense cover consisted of chir pine (*Pinus roxburghii*) and miscellaneous deciduous species. Almost 12% of the area was covered with scrub vegetation.

According to vegetation types, the forests in the Doon valley can be classified as sal (655 square km, or 64% of the total forest area), low-level miscellaneous (231 square km, or 23%), chir pine (2 square km, or 0.2%) and unworkable blanks (137 square km, or 13%).

On the basis of formal forest classification (Champion & Seth, 1968), the valley proper and the north-eastern slopes of

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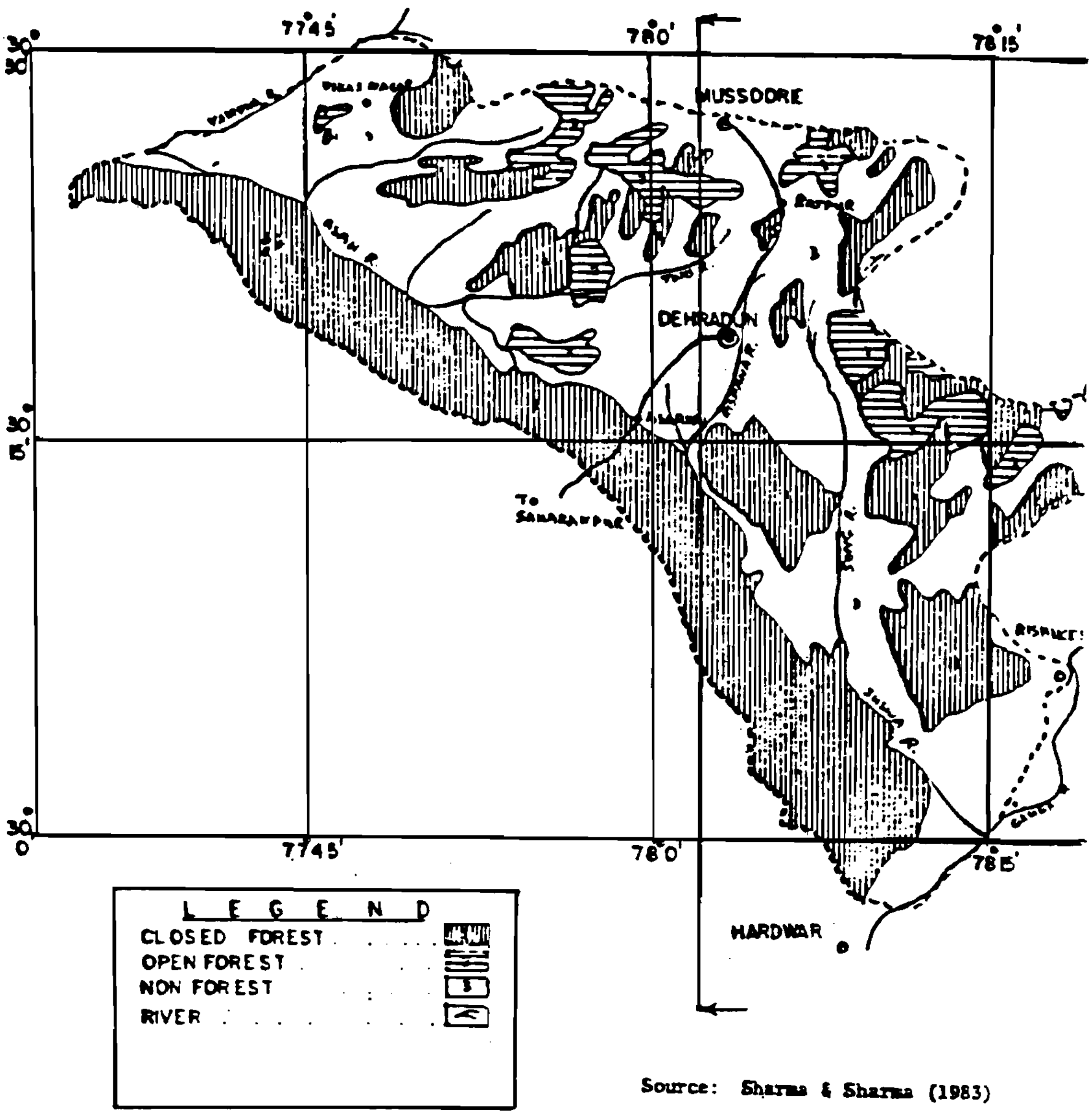


Source: Sharma & Sharma (1983)

Fig. 6-8 Vegetation Map of Doon Valley (Based on Land-Sat Imagery of the Year 1982)

Source: Sharma & Sharma (1983)

Fig. 6-9 Forest Cover in Three Regions of the Doon Valley the Siwaliks largely fall under "northern tropical moist deciduous" class of forests with sal as its predominant species.

As described earlier, forests growing on the slopes of the outer Himalayan range, reaching up to the Mussoorie ridge, are generally sparse and of poor quality. They are classified as "Himalayan subtropical scrub" within "Himalayan sub-tropical pine" class of forests. The dominant species among whatever overwood is left are chir pine and oak (Quercus incana). Shrubs cover large tracts of degraded land.

Certain small areas of forests in the valley proper, principally those on the river banks, fall under "khairsissoo primary seral" sub-type within "tropical dry deciduous" class of forests. The principal species in these forests, as the name implies, are sisham (Dalbergia sissoo) and khair (Acacia catechu).

Further information on the forests of the Doon Valley is given in Saxena (1972).

6.4.3 Recent Forestry Practices

Forestry working plans are generally for a period of 10 years and are reviewed and revised at the end of the period. The first working plan for the Dehradun forests was prepared by Fernandes in 1888. The plan currently being followed in the valley is the one prepared by Singh in 1980.

The objectives of management as laid out in the recent working plans are enumerated below:

1. To conserve, develop and extend the existing forest and vegetal cover for soil and water conservation;

2. To attain normal forests as far as possible (a normal forest permits nearly equal volumes to be harvested annually in perpetuity);

3. To improve the density of existing growing stock and increase the proportion of valuable timber species by planting;

4. To obtain sustained yield of commercial timber, fire-wood and other forest produce in perpetuity;

5. To meet the demand of forest produce under rights and concessions of the local people; and

6. To meet the present and future demands of industries for commercial timber, pulpwood and other raw material.

Though the objectives of forest management highlight the environmental and silvicultural aspects, in practice commercial utilization of the resource guides management practices in the valley like elsewhere in the region (Planning Commission, 1982 p.12).

The forests are grouped into different "working circles" (WC) depending upon the species, topography and other local factors. There is generally one set of prescriptions for areas within a given working circle. The latest working plan for Dehradun divides the forests into "Sal WC" (644 square km, or 63% of the total forest area), "Protection WC" (74 square km, or 7%), "Plantation WC" (85 square km, or 8%) and "Grazing WC" (11 square km, or 1%). There are two other working circles, namely, "Grazing Overlapping WC" (917 square km, or 90%) and "Khair Overlapping WC" (59 square km, or 6%), the jurisdictions of which superimpose over other distinct working circles.

Different management systems are applied to different working circles. Sal WC is currently managed under the "conversion to uniform" system. When natural regeneration did not follow fellings, the classical shelterwood compartment system was modified and the present system was evolved. Under this, areas are specially categorized according to the stage of regeneration. Fellings, in theory, are done only to facilitate regeneration. In practice, however, yield is obtained in almost all age groups. These forests have been suffering because of the lack of research into the problems of natural regeneration of sal, the inability of the administration to control grazing, lopping and thefts, and the temptation to raise plantations of fast growing species (UPFD, 1979).

The forests within the Protection WC are managed under the "protection system", where the objective is to conserve soil and water. No commercial exploitation is prescribed and the area is supposed to be protected from grazing, lopping and fire. In practice, however, the WC has very heavy incidence of biotic interference and there are no regeneration operations. Even though trees are not sold, they are often felled to meet the needs of local rightholders and concessionists.

"Clearfelling system" is practised in the areas under the Plantation WC. Large-scale afforestation through plantations was introduced in the early 1930's in the form of "taungya" (Stebbing, 1962, p.346). In this agro-forestry practice, sparsely vegetated areas and those supporting tree crops of low commercial value were clearfelled and planted with fast growing economical species. Agricultural crops like mustard and castor were grown between tree lines for 2 to 3 years. The choice of species has been dependent on the market and industrial demand as seen at the time of planting. For instance, earlier it was tun and semal for producing plywood and matchwood, but more recently there is a greater emphasis on planting pulpwood species such as hybrid eucalyptus and poplar. Other fast growing species which are favoured for planting are teak, khair, sisham and tropical pines. The tract is prepared for planting by removing all vestiges of past ground flora, sometimes using tractors and bulldozers.

The forests in the Miscellaneous WC are often worked under the "selection system". Trees are felled as and when they become mature and silviculturally available. In most cases the reason for not opting for a more concentrated system is the terrain condition. The areas in the Grazing WC are kept exclusively for grazing. Due to constant grazing and heavy lopping, much by the herds of nomadic gujjars, no improvement in pastures is possible. However, the bulk of the livestock in the valley is served through the Grazing Overlapping WC as it covers as much as 90% of the forest land. But here, grazing is somewhat regulated and only certain pre-specified forest blocks are opened to grazing during a given year. In practice, control of grazing is extremely difficult and the forests near villages are greatly damaged due to unauthorized grazing.

6.4.4 The Resulting Trends in the Doon Valley Forests

In recent years there has been a cumulative reduction in forest cover and crown density of natural forests. LANDSAT scenes for the years 1972 and 1982 (Sharma & Sharma, 1983) show that the forest cover in the valley decreased by 25% over a period of just 10 years. The reduction in dense forest (i.e., forests with average crown density of over 60%) during this period was as high as 33%. (See Fig. 6-10.)

This drastic change can be partially explained as due to lack of natural regeneration and transferring of forest land for settling displaced people. However, the main reasons are as follows:

(a) Planning of forestry activities exclusively for commercial objectives and ignoring the role of the forest in conserving soil and water;

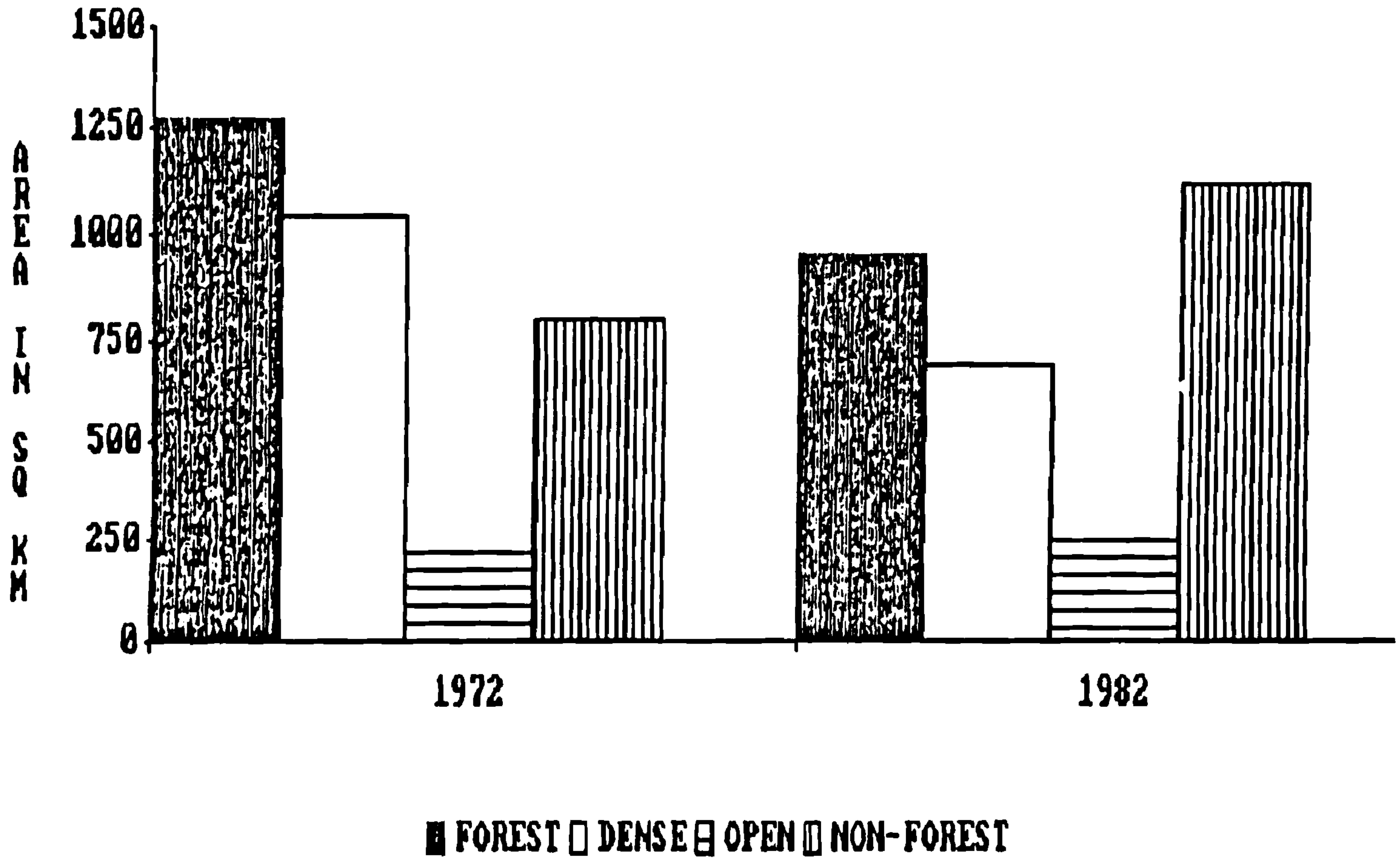
(b) A population explosion resulting in heavy demands for fuel and fodder which are often satisfied through unathorized means. The population of the Doon valley has almost doubled in the last 25 years (TCPD, 1982). This rate of growth is very high and if there is no significant attempt to stabilize the population soon, the demand for forest products in the valley may soon outstrip the maximum sustainable yield of the forests as in some other Himalayan areas (Nautiyal & Babor, 1985);

(c) The local demands for fuel and fodder have not been given due importance. This is evident from the fact that plantations of only industrial, and not of fuel or fodder, species have been raised;

(d) Adequate investments in undertaking soil and water conservation measures in the catchments of streams, over the eroded hills and in the areas around limestone quarries have not been made.

These causes of forest depletion can be overcome by linking forest planning with other socio-economic activities, and by adopting innovative approaches to the management of forests. If appropriate actions are taken in time, forestry can go a long way to stabilizing the ecosystem of the valley.

It must be emphasised that due to continuing high population density and other socio-economic factors, things can never go back to the days when village communities were living in stable equilibrium with the surrounding forests. This can be realized from the fact that all the village and other civil forests in the adjoining districts of Garhwal and Nainital have either disappeared or have become unproductive (UPFD, 1979). Despite defective planning and faulty execution by the Forest Department



Source: Sharma & Sharma (1983)

Fig. 6-10 Forest cover in Doon Valley

under severe odds, only the forests controlled by the Department have survived. The Forest Department in Dehradun, with a radically different approach towards forest management, and with cooperation of the local people, may still be able to contribute to improvement of the ecosystem of the Doon valley if a rational population policy aimed at stabilization of the population at a future date and integrated development are planned and executed.

6.5 Soil Erosion

The limestone quarries have caused serious soil erosion, particularly in the area between Mussoorie and Dehra Dun (see Fig. 6-5). At present, the quarries and the areas affected by their waste disposal cover about 6.5% of the above-mentioned area (DOE, 1984). It is difficult to estimate the accuracy of this figure but officially, the leasehold area covers 14 km^2, about 80% of which was formerly forested.

7. SOME RECOMMENDED SECTORAL ENGINEERING APPROACHES

7.1 Introduction

The development of a comprehensive environmental management strategy will have to take account of a large number of interactive issues and socio-economic conditions. Within the framework of a systems approach, various kinds of modules will have to be joined together with a number of feedback loops.

This idea was elaborated in Section 4. Here it should be emphasized that the inner working parts of individual modules are rather complex, and in many cases we have only a qualitative notion of their "circuit diagrams." Nevertheless, some of them are sufficiently well understood that state-of-the-art environmental engineering techniques could be applied immediately to effect significant sectoral improvements in the state of the environment. These cases will be considered in this Section, although two points should be made at the outset:

1. Although the inner structure of a module may be understood in principle, the site-specific data sets required to operate an appropriate management scheme may be incomplete. In such cases, e.g., air pollution, recommendations on data needs will be given.

2. The various modules are inter-connected. For example, regional air pollution increases when population increases but may decrease if new technology is applied. However, once a working model of the air pollution box is developed, it will be possible to ask a number of "What if?" questions with respect to possible changes in the inputs from other modules.

7.2 Air Pollution

There are several ways to control air pollution (Munn and Rodhe, 1985):

1. Reduction in emissions through, for example,

    -- gradual replacement of old industrial plants by new ones;

    -- gradual replacement of old vehicles by new ones;

    -- installation of stack-cleaning equipment, such as filters and precipitators;

2. Construction of tall chimneys and/or increasing the exit velocities and temperatures of chimneys; (These were common solution in the 1960s before the effects of long-range transport of pollutants were realized.)

3. Intermittent emission control (reducing emissions during atmospheric episode conditions);

4. Optimal location of industrial units (avoiding sites where atmospheric dispersion is poor; spacing of point sources in such a way that pollution "hot spots" are avoided; separating residential/agricultural areas from industrial establishments through green belts; etc.).

No single approach is best, and an optimum management strategy uses a range of methods for controlling air pollution. In recent years, many air pollution control authorities have been renamed air management authorities, reflecting a shift in emphasis.

The information needed to operate a regional air pollution control program includes the following:

1. A set of air quality standards is required for the main gaseous and particulate pollutants.

Note: (a) The standards must be supported by scientific research reports (as published by the World Health Organization, for example) indicating that effects on health or vegetation are possible if the standards are exceeded.

(b) Annual, daily and hourly standards are required.

(c) There ought to be a process that will permit industry and the public to comment formally on new proposals for air quality standards.

2. An emission inventory of both point and diffuse area sources is needed, for pollutants for which air quality standards have been set.

Note: (a) The inventories should include information on both locations and strengths of emissions. Engineering estimates of strengths can be obtained from a knowledge of the industrial processes involved, using so-called "emission factors" (see various air pollution handbooks).

(b) The inventories should include information on typical variations that occur diurnally, weekly and annually. (As an example, domestic cooking sources in the Doon Valley are highest from 7 to 9 pm, with a secondary peak near sunrise, while brush burning is a seasonal phenomenon occurring mainly in late summer after harvesting.)

(c) At present, it is not possible to estimate the relative contributions of various sectors (industrial, transportation, urban, agricultural) to the total pollution loading of the valley or even of the City of

Dehra Dun. This information is required in order to set priorities on control strategies.

(d) The most detailed survey has to be done for the area between Dehra Dun City and Mussorie (see Fig. 6.5).

3. For major classes of emitters, information should be compiled on the cost, cost-effectiveness and practicality of introducing pollution controls.

4. Information on the mesometeorology of the Valley is required.

Note: (a) Not only the distribution of emitters but also the wind field is important in determining regional pollution potential.

(b) A model of the wind field will have to be developed based on currently available climatological data and some additional field measurements, particularly with respect to inversion heights and intensities.

(c) Using the source inventory and the wind field model, predictions can be made of regional air quality, including both space and time variations.

5. Air quality measurements must be made in the Valley on a regular basis.

Note: (a) These measurements are required:

(1) to determine whether air quality standards are being met.

(2) to estimate long-term trends in air quality;

(3) for comparisons of model predictions with observed values.

With the information listed above, it will be possible to simulate the effects of various industrial development strategies, e.g., comparing alternate sites for new industries, transportation corridors, etc. Here it should be mentioned that air quality management is a long-term activity requiring collaboration rather than confrontation between regulators and those being regulated, and supported by scientific data that are open to public scrutiny. Air quality in the Doon Valley cannot be changed very much in a day or a year, but progress will be accomplished by a series of many small and often imperceptible steps forward.

Finally, mention should be made of the various possible mathematical models that could be applied to estimate the dispersion from multiple sources in the Doon Valley. The models range from a simple input-output model to very complex representations of the 3-dimensional terrain and wind fields. As the models become more complex, so do the input data requirements, and it is often desirable to begin with a rather simple model. Also it should be mentioned that the most appropriate model depends on the use to which it will be put, e.g., land-use planning vs. intermittent emission control.

The contribution by M. Piringer in Volume 3 provides a description of various kinds of multiple-source air pollution models, and defines the input data needs of each.

Air pollution abatement in the City of Dehra Dun.

Without waiting to establish a monitoring network and a multiple-source air pollution model, several measures could be taken to improve air quality in the City of Dehra Dun:

(1) compulsory servicing of public and private transport units, with respect to air pollution emissions (see Section 3).

(2) paving of the shoulders of downtown streets (see contribution by R. Tilak, in Volume 3).

(3) organization of traffic-free zones in the most crowded areas of the city.

(4) Open green spaces should be increased to 20% of the total lawn area, instead of 6.5% as provided by the Master Plan (DOE, 1984).

7.3 The Hydrologic Cycle*

7.3.1 The hydrologic paradox

A major issue for the Doon Valley is certainly that of water conservation. As pointed out by Singh (1973): "Paradoxically, the valley though located in a high rainfall area, faces acute shortage of water during the dry seasons." On average, the water-table is about 6.4 m higher in summer than in winter.

The situation is becoming more serious because the annual hydrologic cycle has been changing in recent years (less storage; higher runoff during the monsoon; decreasing supply of water during the dry seasons). Added to this is the fact that there are increasing withdrawals of water by industrial, agricultural and domestic users.

*Use of the word cycle is not strictly correct because the Valley is not a closed system - water is imported through atmospheric transport and deposition, and is exported by river transport and evaporation and atmospheric transport.

The increase in summer runoff is a self-perpetuating spiral because of the increasing soil erosion that it causes. [Soil is lost in the Doon Valley at a rate of about 50-55 tons per hour during the monsoon season, according to Saxena and Verma (1981).]

In these circumstances, a two-pronged water resource management strategy should be elaborated:

(1) engineering measures to reduce summer runoff rates and the resulting soil erosion; and

(2) medium- to long-term development of an operational hydrologic model.

7.3.2 Engineering measures to reduce soil erosion

The approaches recommended by the Central Soil and Water Conservation Research and Training Institute to reduce summer runoff rates are very practical, and the program should be accelerated, with slightly better coordination among the various parties involved. Some of the techniques being used include:

-- Prevention of cutting trees and of excessive grazing, particularly on slopes;

-- Afforestation; (There are several excellent programs for tree-planting, by volunteers as well as by commercial and government agencies.)

-- Debris stabilization downstream of quarries. This is achieved through construction of terraces and gabions and the planting of grasses and shrubs. (An example of the great effectiveness of such measures is shown in Table 7-1.) For very steep slopes, special engineering works must be constructed to prevent landslides (Sastry et al., 1981);

-- Significant reduction in the number of new roads being constructed on the slopes. Bridle paths rather than gravel roads are being recommended to connect remote villages to main roads;

-- Bunding (construction of earthen levees) along the boundaries of small watersheds, reducing runoff by up to 85% (Sastry and Narayana, 1984);

-- Banning of farming on steep slopes; [See Table 7-2 for an example of the effect of slope steepness on soil loss (tonnes/ha) at two locations in India (Singh et al., 1981). There is a considerable increase in soil loss with increasing slope.] In this connection, the Planning Commission in the Seventh Five Year Plan has recommended that: "Cultivation of Agricultural crops in areas with above 15 degree slopes should be stopped, and these areas should be planted with five F's (food, fodder fuel, fertilizers and fibre) trees" (Bahuguna, 1986).

Table 7-1: Volume and weight of debris deposited on the Dehra Dun - Sahastradhara road before and after gabions were constructed on the slopes above the road (Katiyar et al., 1984)

	Quantity of debris on the road			
	Before treatment (1983-84)		After treatment (1984-85)	
	Volume (cu. metres)	Weight (metric tons)	Volume	Weight
Debris and small boulders	8758	17516	2100*	4200*
Blasting boulders	8757	17514	Nil	Nil

*This debris came through two drainage channels from untreated sub-watersheds.

Table 7-2: The effect of slope on soil loss at two sites in India (Singh et al., 1981)

A. Rehmankhera (near Lucknow) (average for years 1961 to 1976)

Slope	0.5%	1.5%	3.0%
Soil loss (tonnes/ha)	4.2	6.7	12.7

B. Kharagpur (average for years 1964-1968)

Slope	2%	3.5%	5%
Soil loss (tonnes/ha)	9.1	12.2	15.8

-- Levelling of existing fields. This measure significantly reduces runoff and soil erosion.

Many of these ideas are included in the Master Plan, Regulated Area, Dehra Dun (TCPD, 1982) but the list contained therein is worth repeating:

-- planting of vegetation along river banks to reduce soil erosion;

-- construction of reservoirs in the upper reaches of rivers to help store surplus water;

-- banning the removal of boulders, sand and gravel from river beds (such removals accelerate water flows during monsoons);

-- rehabilitation of mining areas to reduce soil erosion;

-- construction of embankments in areas vulnerable to floods;

-- banning construction on or near small rivulets; blockages in these water courses affect other areas.

These very practical measures are to be encouraged.

7.3.3 The development of an operational hydrologic model

A working model of the hydrologic cycle in the Doon Valley would be useful for long-term water resource management. (See contribution by S. Kaden in Volume 3 of this Report.) At present, it is not clear whether the drop in water table is due to an increasing amplitude of the annual runoff cycle, or is due to the increasing number of tube wells being sunk in the valley.

The geomorphology of the region is well known (Nossin, 1971; Singh, 1973), and quite a bit of information is available on groundwater (Singh, 1973; see for example, Fig. 7-1) and on rainfall. However, runoff during peak monsoon cloudbursts (when a significant fraction of the annual total occurs) will be difficult to measure, as indeed will also be the estimation of evapotranspiration from the rugged slopes of the Valley. One of the Principal Investigators (R.E. Munn) once carried out a field study of evapotranspiration in the Marmot Creek watershed of the Canadian Rocky Mountains. The conclusion reached was that evapotranspiration estimates in such rugged terrain were too uncertain to be useful for water resource management purposes (Storr et al., 1970).

7.4 Groundwater Utilization and Storage in Dehra Dun City

As mentioned by Roy (see Volume 3 of this Report), "Groundwater levels in Dehra Dun City have reportedly lowered by about 15 m in the last 7 years or so." Roy suggests some engineering measures that could be taken to alleviate the problem, noting that existing tubewells tap more or less the same aquifers at depths of about 120-140 m, and that more and more wells are being built in a rather haphazard manner:

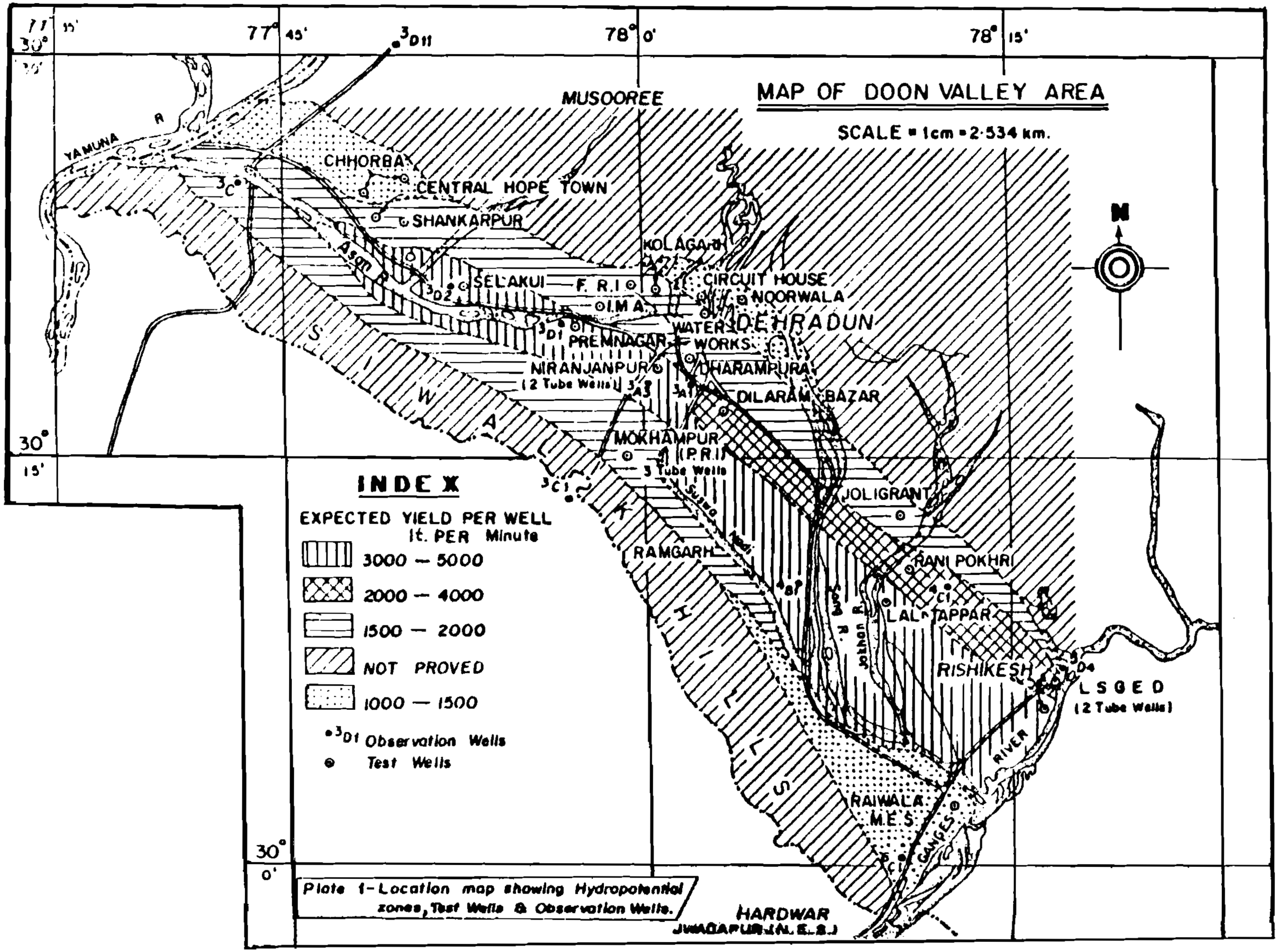


Fig. 7-1 Expected yield per well (litres per minute) in the Doon Valley, based on a survey carried out between 1960 and 1967 by the Exploratory Tubewells Organization, Government of India (Singh, 1973)

1. Future tubewell development should be controlled so that new wells are properly spaced (with respect to the existing network of wells) and properly designed to tap deeper aquifers in a staggered manner.

2. A "nest" of properly spaced tubewells should be constructed along the terraces of Tons Nadi in the Jhajra sector beyond Premnagar, and the water should be piped into Dehra Dun.

3. In order to implement these suggestions, a detailed assessment of groundwater resources and location of existing wells will have to be carried out.

4. Finally, industries that have the potential for causing groundwater pollution should not be allowed to locate in the valley unless appropriate treatment facilities are included in the engineering design plans. Groundwater is such an essential regional resource that no chances should be taken that it might become depleted or polluted. If a water pollution source is removed, a river will purify itself very quickly but groundwater may remain polluted for many years.

In Volume 3 of this Report, S. Kaden recommends that feasibility studies be carried out with a view to constructing underground water storage systems. These do not require high capital investment and have negligible evaporation losses compared to those from surface water reservoirs. The engineering techniques that could be used to store water underground are well known (see Asano, 1985).

7.5 Land Reclamation

Flash floods are continually changing the water courses in the Doon Valley. As river beds dry up and new ones are formed, areas of gravel and sand are exposed, with only a thin layer, if any, of topsoil. Scientists at the Central Soil and Water Conservation Research and Training Institute, Dehra Dun have demonstrated the effectiveness of a number of practical measures for reclaiming these areas for agricultural purposes (Singh et al., 1981; Saxena and Verma, 1981; Sastray and Narayana, 1984):

-- Improvement in the retention of soil moisture through deep pitting and replacement of excavated gravel with good soil, although it should be mentioned that this process is rather costly; (Fruit trees can then be grown successfully.)

-- Runoff storage in farm ponds for subsequent irrigation of crops;

-- Optimization of crop-rotation techniques;

-- Planting of babar grass to stabilize bunds;

-- Planting of trees (eucalyptus in particular) and babar grass on riverbed lands; the resulting green matter produced can help meet the fuel, fodder and fibre requirements of the villagers.

Technology transfer to the farmers in the Doon Valley, through demonstration plots, field extension courses, special publications, etc. is an important element of the Central Soil and Water Conservation Research and Training Institute.

8. CONCLUSIONS AND GENERAL RECOMMENDATIONS

At the outset it should be emphasized that there should not be a distinction between "polluting" and "non-polluting" industries, since the difference between these two "categories of industry" is just determined by the degree to which society is willing to pay for "cleaning-up" these so-called "polluting industries" by investing in technical facilities. One would extremely limit industrialization if all efforts were to be concentrated on "non-polluting" industries, e.g., assembly of electronic products. And examples exist where even these "non-polluting" electronic industries have polluted the environment, e.g., groundwater in the United States (California) through the production of integrated circuits and micro-chips.

In this context, the Phase I study has considered qualitatively an array of industrial development strategies that might be appropriate for the Doon Valley. Three of these strategies are worthy of further assessment, using modern methods of computer simulation:

1. Decentralized industrialization (employment and income generation in rural areas through sales of processed agricultural products)

2. Centralized (non-polluting) processing of agricultural products such as fruits and vegetables, wood and other forest products, as well as meat, hides and skins (this would generate rural income through increased demand for agricultural productss and would provide employment plus income in urban areas).

3. Development of educational and research facilities in the industrial field and therefore in coordination and cooperation with (high technology) industry. This would generate additional employment oppurtunities in urban centers like Dehra Dun. At the same time, such activities would provide properly skilled labor and supervisors for industry and would broaden the industry-related basic research.

Although the data available to the investigators in Phase I have been rather limited, there are clear signs of environmental deterioration in the Valley. (Industry may not be the major cause of this downward trend in some cases.) So industrial development strategies other than the three listed above would be more difficult and more costly to implement.

Evidence of declining environmental quality is to be found in:

1. A recent drop in the water-table in the vicinity of Dehra Dun during the dry season.

2. Visible scarring of the valley slopes due to limestone quarrying, with resultant soil erosion and decreasing forest cover.

3. Poor air quality, particularly in the Dehra Dun - Mussoorie pocket, where limestone kilns are emitting large clouds of white particles.

4. Deforestation due to the wood-processing industry and increased firewood demand.

5. Declines in the numbers of valued species of birds, animals and fish.

A major cause for this decline in environmental quality is the increasing population of people and livestock in the Valley. For example, growth rate of the Dehra Dun urban agglomeration between 1971 and 1981 was 44%, which was higher than the national average (DOE, 1984).

The principal factors that could be identified as causing the environmental deterioration are:

-- limestone quarrying

-- limestone burning (cottage industry)

-- limestone processing (chemical industry)

-- other industrial activities (e.g., sugar refining)

-- transportation

-- population increases, particularly migration into the Dehra Dun agglomeration, leading to:

  a. deforestation

  b. intensified agrculture/animal husbandry

  c. increased domestic consumption of water

Industrial development of the Doon Valley requires a thorough understanding of the <u>carrying capacity</u> of the region. As was suggested in Fig. 4-3, however, <u>carrying capacity</u> is not a fixed quantity but depends on:

-- the levels of environmental quality deemed to be acceptable by society;

-- the lifestyle expectations (incomes, food, shelter, education, etc.) of society;

-- the investments (local, regional, national) that society is prepared to make on environmental protection and pollution control equipment;

-- externalities such as new technologies, changes in world trade patterns, etc.

From the point of view of carrying capacity, the most limiting factor for further industrial development in the Doon

Valley is the current lack of water during the dry season. Although monsoon rains are very large, most of the water evaporates or is lost as runoff. The highest priority should therefore be given to water management. In particular, there is need to design engineering works that will improve the water storage capacity of the Valley. These facilities must be based on understanding, monitoring and modelling the hydrologic cycle. Several practical suggestions for improving the hydrologic carrying capacity of the watershed are as follows:

-- Control of future tubewell development (e.g., staggering of wells to tap different aquifers);

-- Construction of underground water storage systems;

-- Discouragement of plans to locate water-intensive industries in the Valley.

-- Reduction of monsoon runoff, e.g., through afforestation.

Other carrying capacity factors that limit development in the Valley include:

-- Human and livestock populations; (By improving environmental and economic conditions, planners may encourage immigration, severely taxing the carrying capacity of the region.)

-- The poor assimilative capacity of the Valley atmosphere, during the dry seasons, placing an upper limit on the pollution that can be emitted if air quality standards are to be met;

-- Availability of arable lands;

-- Milk and fuel wood; (These products cannot be imported economically into the Valley, and thus there is an upper limit to the population that can be sustained unless improved or alternative technologies are used.)

-- Livestock populations; (If stall feeding were introduced, the forestry carrying capacity of the Valley would be increased with respect to this factor.)

-- Economic factors such as transport costs to distant markets and within urban areas, energy costs, availability of raw materials, waste disposal facilities, etc.

In all of these cases, carrying capacity/sustainability studies need to be undertaken, based on a system approach, in which appropriate simulation models are adapted and calibrated for use in the Valley.

In particular, there is a clear need for the development of an air quality management strategy. Industry is presently a major offender in the industrial area north of Dehra Dun City. However, the relative contribution of industrial sources to the general air pollution loading of the Valley is not known. Some of the concrete steps that need to be taken, are given in the Work Plan for Phase II.

Turning now to the broader topic of environmental management (including the management of impacts not caused by industry), a number of important ideas were developed at the Advisory Committee meeting March 3-5, 1986.

First, the conceptual frameworks given in Figs. 4-1, 4-2 and 4-3 may be helpful. Secondly, the practical measures discussed in Section 7 for reducing monsoon runoff and soil erosion should be promoted. Many of these ideas have already been implemented to a certain extent but consideration might be given to providing additional encouragement. Local enthusiasm to help solve the environmental problems of the Valley is very high; this pool of good will is an important resource for the future. Thirdly further attention should be given to long-term programs that would reduce migration into the cities. Some possibilities include:

-- Food processing. This is recommended because it makes use of locally available fruit and vegetables, and can be undertaken in the countryside.

-- Cottage industries (handicrafts, furniture, etc.). These industries have the advantage that they are generally non-polluting.

-- Education and research.

-- High-technology industry. It should be noted, however, that other areas in India may be better situated in this regard, and it will be important to try to find a specific niche for the Doon Valley.

Finally, some suggestions made by a forestry subgroup at the Advisory Committee Meeting should be mentioned:

(a) Afforestation of village lands and outer Himalaya lands should be accelerated. There is the prospect that most of the reserve forest land in the Doon Valley will be included in a national park. Thus there may be a rapid increase in demand for firewood from other areas, amplified by the ever growing population. Fuel wood requirements may simply not be sufficient. Targets must be set on species, locations and management criteria. For this program to work, stall feeding of animals needs to be commenced in order to reduce grazing losses. In determining location, it will be important to select villages where the people are likely to be receptive. It will also be helpful to check the comparative productivity efficiencies (the fodder/milk ratios) of buffalo and cows. (Buffalo do not graze and therefore are preferable to cows in terms of forest management.) It is understood that some FAO demonstration forests exist in India; these may serve as examples.

(b) Agro-forestry projects incorporating recycling of organic fertilizers and provision of fuelwood to villages should be enlarged. Tree species to be considered include:

(1) for fodder- Macaranga peltata, Grawia, Robinia

(2) for nitrogen fixation- Acacia, Ailanthus, Celtis australis

(c) Development of a leather business (tanning and processing) would remove some pressure from animal grazing, particularly among older animals. Then wattle (Acacia) plantations should be encouraged to produce tannin (for curing hides) as well as for fuel wood. (Rural Technology Institute, Wardha, Maharashtra; Central Leather Research Institute, Madras; State Industry Development Corporation, Lucknow). The leather-processing industry is non-polluting, and the tanning industry can be designed to be non-polluting.

(d) In the implementation of forestry projects, women should be trained and involved because they are often the active members of society in collecting firewood and fodder, and have a vested interest in forest management.

(e) Industrial opportunities exist in the forest sector that ought to be exploited:

-- charcoal production by rural workers for consumption by urban low-income population

-- manufacture of energy-efficient stoves, a decentralized small-scale industry

-- production of carbonated waste material.

9. A WORK PLAN FOR PHASE II

9.1 Introduction

While Phase I attempted to make a qualitative assessment of the environmental situation in the Doon Valley, the second phase will provide more quantitative information, particularly with respect to the various options available for industrial development. According to UNIDO, the parties involved in the second project phase are likely to be:

as financial sources	- UNIDO and possibly the GDR government - the Government of India
as executing agency	- UNIDO
as sub-contractor	- IIASA
as project counterpart	- Department of Environment, Government of India
as Indian expertise	- Indian Environmental Core Group, Jawaharlal Nehru University, Central Pollution Control Institute, Hardwar, Meteorological Department, GDR, etc.

Phase II is likely to last about 18 months; policy recommendations that are more quantitative than was possible in Phase I can be expected after the first 6 months.

The proposed work plan for Phase II will comprise the following elements:

1. Work to be carried out by IIASA (including collaborative studies in the GDR on water management)
   a. activities during first 6 months
   b. activities during the remaining Phase II period
2. Work to be carried out by the Indian Government
   a. expected counterpart inputs for 1a and 1b
   b. independent activities for obtaining long-term statistical information
   c. activities for building-up a national environmental core group and monitoring system
3. Work to be carried out by other bodies, with respect to environmental management of the Doon Valley, but not related directly to industrial development.

In this connection, the Indian Core and Support Groups and IIASA should play a coordinating role to ensure program integration.

It is strongly recommended that serious efforts be made to ensure that all of the studies discussed below are carried out.

9.2 Air Quality Management

Air quality management studies should be given high priority in Phase II. The evidence presented in Section 6.2 supports the idea that the assimilative capacity of the valley is often greatly reduced. The following studies should therefore be undertaken:

9.2.1 Climatological analyses

Historical time series of twice-daily observations from the five climatological stations in the area and of pilot balloon observations from the Dehra Dun City station should be analyzed in the usual ways for spatial wind and temperature patterns. These patterns are needed in order to develop appropriate air pollution models.

Responsibility: IIASA

Timing: First 6 months of contract

9.2.2 Establishment of continuously recording meteorological stations

Three continuously recording meteorological stations should be established:

-- at the Field Station of the Central Soil and Water Conservation R. and T. Institute;

-- at a location 200 m above the valley floor (to detect temperature inversions);

-- at Mussoorie.

Hourly wind and temperature observations should be taken at these stations, as well as 24-hour high volume sampler measurements. Data from these stations are essential inputs into the air pollution models.

Responsibility: Indian Meteorological Department

Timing: As soon as possible

9.2.3 Infrared temperature measurements

As pointed out by Dobesch (see Volume 3 of this Report), it may be possible to use remotely-sensed and other infrared imagery to obtain snapshots of the variations in ground temperature throughout the Valley. This is not an easy task, of course. It will require first, the use of complex algorithms to remove the effects of horizontal variations in vegetation biomass, surface roughness, etc. and second, ground-truth observations at several points in the Valley.

The approach is promising, and the desired output is certainly important; given the variations in surface temperature across a region, it is possible to infer the wind patterns and thus the air pollution field. It is recommended that the Indian Institute of Remote Sensing be invited to undertake the study. In this connection, Dr. Dobesch is of the opinion that in order to calibrate the system, more detailed information on land use will be required than is currently available at IIASA.

Responsibility: Indian Institute of Remote Sensing with Dr. Dobesch as advisor

Timing: Over full contract period

9.2.4 A short-term meteorological field program

A 4-week field campaign should be undertaken. This should be scheduled for the dry season, preferably October or November, and should include:

(a) Measurements of the inversion structure over the centre of the valley, obtained with a minisonde or an acoustic radar (Kumar et al., 1986).

(b) Automobile temperature traverses through the valley --particularly in the western sector, where the promontory Lachhiwala may block the ventilation of the valley.

Responsibility: IIASA plus Indian Department of the Environment and Prof. B. Padmanabhamurty, JNU

Timing: First priority in October-November, second priority in April-May

9.2.5 Air pollution observations

In addition to the high-volume sampler observations mentioned in Section 9.2.2 above, a portable monitoring station should be used to obtain hourly measurements of the range of pollutants for which air quality standards exist. Measurements need not be made during the monsoon season. These data are needed for comparison with model predictions.

Responsibility: Indian Department of the Environment and Pollution Control Research Institute, Hardwar

Timing: As soon as possible

9.2.6 Emission inventory

An emission inventory should be carried out as soon as possible. This should include:

-- locations of all industrial chimneys, and provisional estimates of emissions (mass per unit time).

- -- locations of significant transportation line sources, and provisional estimates of emissions as a function of time of day and day of the week.
- -- locations of significant domestic area sources, and provisional estimates of emissions as a function of time of day, day of the week and season.
- -- locations of significant rural area sources, e.g., burning of agricultural wastes, as a function of season.

Responsibility: Pollution Control Research Institute, Hardwar

Timing: As soon as possible

9.2.7. Development of mesoscale multiple-source air pollution models

As suggested as a first step by Piringer (see Volume 3 of this Report), a simple air pollution box model should be adapted for use in the Doon Valley. This would provide estimates of areally averaged concentrations for the main pollutants but would not give any information on hot spots.

The box model could be adapted from one already existing at the Central Institute for Meteorology and Geodynamics in Vienna, and it could become operational shortly after an emission inventory (see Subsection 9.2.6) became available.

Responsiblity: IIASA/Central Institute for Meteorology and Geodynamics

Timing: First 6 months

As a second step, a Gaussian multiple-source plume model adapted to valley situations should be applied to the Doon Valley. This work could be undertaken at the Central Institute for Meteorology and Dynamics, including training (1 month) in the use of the model by an Indian scientist.

Responsibility: IIASA/Central Institute for Meteorology and Dynamics

Timing: Second 6 months

There remain two important tasks that could not be undertaken until late 1987 after the data mentioned in Subsection 8.2.1 to 8.2.6 are collected and analyzed:

- -- Episode modelling
- -- Calibration of the box and multiple-source models on the basis of observed values.

Responsibility: IIASA/Central Institute for Meteorology and Geodynamics

Timing: Final 6 months of contract

9.2.8 Economic studies of the cost-effectiveness of various pollution control strategies

The multiple-source air pollution models will give an idea of how to maximize air quality for given air pollution emissions. However, there is need for an associated economic submodel that could be used to determine the costs of the resulting control strategies.

Responsibility: IIASA

Timing: Final 6 months

9.3 Water Management Studies

The contribution of S. Kaden in Volume 3 of this Report forms the basis for the following proposals with respect to Phase II water management studies. During the meeting of the Advisory Committee, it became clear that if engineering measures were not taken, ground-water would probably be the most serious limiting factor for further industrial development in the Doon Valley. The following recommendations therefore must be given very high priority. It is proposed that most of the work will be done by a separate contract between UNIDO and Dr. Kaden in the Institute for Water Management (IWM), Berlin, GDR. Some preliminary discussions have already taken place.

9.3.1 Preliminary survey and collection of additional data

As a first step, all relevant data on geography, hydrology, hydrogeology, etc. will have to be collected and analyzed. This will require a 2-week visit to the Doon Valley by Dr. Kaden. In particular, there is a need for flow rates of the Ganga and Yamuna rivers.

The survey will provide guidance on whether additional short-term field observations are necessary during the monsoon and/or the dry periods.

Responsibility: IIASA, IWM

Timing: First 6 months

9.3.2 Water balance model

A general water balance model of the Doon Valley, covering all relevant subprocesses of the hydrological cycle should be developed for monthly mean values.

Precipitation patterns are well known. For evapotranspiration, semi-empirical models may be applied based on available geographical and climatological information. To describe the distribution of total runoff into surface runoff, infiltration, baseflow, etc., simple conceptual models (with lumped parameters) can be used.

Responsibility: IIASA/IWM, GDR

Timing: First 12 months

9.3.3 Groundwater flow model

A groundwater flow model for the Doon gravel should be developed. This model should consider distributed parameters, the interrelationship between surface water and groundwater, and time-dependent recharge. In view of the lack of data, a simple finite-difference flow model is recommended.

Calculations with this model would increase our knowledge of water resources processes and could be used for designing monitoring and exploration programs. Such programs should be started as soon as possible in order to gain a better understanding of the functioning of the system.

An improved groundwater flow model could help in the design of a controlled system of groundwater extractions, including design scheduling of artificial groundwater recharge. This model could be used operationally for control of groundwater extraction rates and the design of new installations.

Responsibility: IIASA/IWM, GDR

Timing: First 12 months

9.3.4 Water management modeling

Depending on the success of the process modeling mentioned above, a more management-oriented planning model should be developed in 1987 as a tool to find rational strategies for long-term development. The model should be capable of dealing with:

-- controversy among different water users, socioeconomic development and environmental quality,

-- multiple criteria for evaluating strategies in cases where some of the criteria can not be evaluated quantitatively,

-- uncertainties and the stochastic character of system input (e.g. precipitation).

To meet these requirements, a model should be developed that combines a multi-criteria analysis for planning periods of more than one year with stochastic simulations of system behaviour using monthly time steps. The model should be highly interactive and user-friendly. Computer color graphics should be used for the visual display of results. If these features are not included, decision makers will not use the system.

Responsibility: IIASA/IWM, GDR

Timing: Final 6 months

9.4 Studies Relating to Regional Management

At the Advisory Committee Meeting on 3-5 March 1986, a subgroup elaborated the conceptual regional assessment and land-use management frameworks as described in Section 4. These ideas need to be refined in several ways:

-- through presentation of the frameworks to the Indian Core and Support Groups and to representatives of research and public bodies in the Doon Valley;

-- through elaboration of a manageable matrix on activities - VECs-VDCs-VACs (see Section 4.5);

-- through practical use by the Core Group and other bodies concerned with the promotion of better regional management in the Doon Valley.

If the various issues in the Doon Valley of concern to the local residents and to the government of India can be viewed within a comprehensive ecological framework, the task of land-use management will be greatly simplified.

In addition to these general remarks, there is a clear need for detailed studies of the ecological sustainability of the Doon Valley for various development goals and life styles. This work will require inputs from the sectoral studies, e.g., in air quality, groundwater and forest management, but these inputs will need to be coordinated in order that they can be pieced together later.

Particular attention should be given to studies in which the consequences of alternative industrial development pathways are compared. These studies will have to include economic analyses because in principle, the pollution emissions from any given industrial enterprise can be made as small as desired -- but at a price which in some cases may be too high.

Some of the alternative industrial development pathways that might be examined include the following:

1. Major industrial development, using state-of-the-art pollution control technologies;

2. The creation of a technopolis providing incentives to non-polluting high technology factories, supported by an increasing number of colleges and research institutes.

3. Major wilderness and recreation development, creation of a national park and discouragement of new industries from locating in the the Valley.

These three pathways are of course extreme cases that are not likely to be realized. But an analysis of the possible outcomes should provide helpful guidance with respect to long-range industrial planning for the Valley. Other more detailed analyses will also be necessary, e.g., to determine whether a very few limestone quarries (5-10) under strict government control could be operated in an environmentally acceptable way.

Responsibility: IIASA

Timing: 18 months

9.5 Forest Management

At the Advisory Committee Meeting on 3-5 March 1986, a subgroup made a number of important recommendations with respect to the forestry sector. This is a critical sector with respect to the carrying capacity of the Valley, particularly if a national park is created in the Forest Reserve area of the Siwaliks, removing a significant supply of fuelwood. Some of the general proposals are given in Section 8. Other recommendations falling directly within the framework of Phase II of the Doon Valley Study are as follows:

9.5.1 Forest growth models

There is need for one or more forest growth models, whose outputs would be used as inputs into forest carrying capacity supply-demand models. Suitable model frameworks already exist but they need to be adapted so that their space and time resolutions are appropriate for the supply-demand models. One such model that should be applied is described by Kairiukstis in his contribution to Volume 3.

Responsibility: IIASA

Timing: 12 months

9.5.2 Forest carrying capacity models

Because the carrying capacity of the forests is crucial to the future of the Doon Valley, the development of appropriate forest carrying capacity models should be given high priority. Section 4.7 outlined the work that should be undertaken, beginning with a linear programming model, to be followed by the development of a dynamic non-linear model. Another approach that should also be applied is described by Kairiukstis in his contribution to Volume 3.

The task will not be easy. In this connection it should be emphasized that the goal is to provide practical assistance in managing the forests, and is not to build a bigger and bigger model.

Responsibility: IIASA, with Prof. Nautiyal as advisor

Timing: 18 months

9.6 Computer-Oriented Activities

If the quantitative assessments described above are to be applied in a policy framework, they must be in user-friendly form. IIASA has had long experience with decision-support systems, and it is proposed to develop an integrated system of software tools to make the scientific basis for development planning and impact assessment directly available to planners, policy and decision makers. Using concepts of artificial intelligence coupled with more traditional methods of applied systems analysis (e.g., operations research, mathematical statistics) these tools are designed to provide easy and direct access to scientific evidence, and allow the efficient use of formal methods of analysis and information management by technical and non-technical users.

On the basis of experience gathered during Phase I, and the detailed discussions during the Advisory Committee Meeting, 3-5 March 1986, the following six directions should be emphasized in Phase II:

1. Preparation of operational atmospheric, hydrological and land-use models for the Doon Valley. These models must include the most essential features of industrial development impacts, and must be compatible with available data. Both simulation and optimization models have to be prepared. The latter ones will be essential for optimal allocation of industries and for analysis of various policies in forestry, land-use and water management. More information on models to be used in Phase II can be found in Volume III in papers by K. Fedra, S. Kaden, L. Kairiukstis and M. Piringer.

2. The integrated set of software tools will form the core of a computer-based Environmental Assessment of Industrial Development for the Doon Valley. It will be based on methodologies developed at IIASA and will fully exploit modern computer technology.

   The study will concentrate on the integration of established techniques of environmental impact assessment, simulation modeling, data base management, operations research methodology, statistical methods of data analysis and model calibration, analysis of models under uncertainty, optimization techniques and modern computer technology including interactive color graphics and techniques of Artificial Intelligence.

   The basic idea is to draw together the components of a comprehensive assessment, such as the background data, descriptive and normative models for the analysis of what-if questions and the design of management alternatives, and decision-support methods.

   The basic functions of the system include:

   -- providing background information on the status quo and likely development options;

-- design and analysis of feasible development policies (optimization of individual activities, designing/optimizing sets of coordinated activities) and their environmental implications and consequences;

-- and finally, the comparative evaluation of development alternatives and decision support (policy analysis).

To facilitate the access to complex computer models for the more casual user, and for more experimental and explorative use, it appears necessary to build much of the accumulated knowledge of the subject areas into the user interface for the models. Thus, the interface will have to incorporate software that is capable of assisting any non-expert user to select, set up, run, and interpret specialized software. By providing a coherent user interface that makes interactions between different models, their data bases, and auxiliary software for display and analysis transparent for the user, a more experimental and educational style of computer use can be employed, allowing for easy exploration of alternative development policies and strategies in actual planning situations or for training purposes.

Conceptually, the main elements of the system are:

-- an Intelligent User Interface, which provides access to the systems' workings for the user. This interface must be attractive, easy to understand and use, and to a certain extent provide the translation between natural language and human style of thinking to the machine level and back. This interface must also provide a largely menu-driven conversational guide to the system's usage (dialog-menu system), and a number of display and report generation styles, including color graphics and linguistic interpretation of numerical data (symbolic/graphical display system);

-- the Information System, which includes the system's Knowledge and Data Bases as well as the Inference and Data Base Management Systems, which not only summarize application- and implementation-specific information, but also contain the most important and useful domain-specific knowledge;

-- the Model System, which consists of a set of models (Simulation, Optimization), which describe individual processes that are elements of a problem situation, perform risk and sensitivity analyses on the relationship between control and management options and criteria for evaluation, or optimize plans and policies in terms of their control variables given information about the user's goals and preferences according to some specified model of the system's workings and rules for evaluation.

-- the Decision Support System, which assists in the interpretation and multi-objective evaluation of modeling results, and provides tools for the selection of optimal alternatives with interactively defined preferences and aspirations.

-- Model Calibration and Testing Module, which enables models to be adapted to available data, defines the most significant gaps in the data, scans the essential endogenous parameters and input variables.

Recognizing the open-ended nature of such a project, we propose a well-structured cooperative effort that takes advantage of the large volume of scientific software already available. A modular design philosophy enables us to develop individual building blocks, which are valuable products in their own right, in the various phases of the project, and interface and integrate them in a framework which, above all, has to be flexible and easily modifiable with growing experience of use. Using an open architecture concept, the demonstration prototype can be constructed at relatively low cost and with only incremental effort.

The modular system will be structured around a major regional development model based on concepts of systems dynamics and rule-based simulation.

This model will be augmented by a decision-support module for discrete multi-criteria optimization, i.e., the selection of preferred alternatives from a set of feasible options, generated through scenario analysis.

This decision-oriented top-level will be connected to selected sectoral simulation and optimization models (e.g., individual industries, air quality, water resources, and possibly also forestry, agriculture, urban development, etc.). These models can either be used directly or they can provide input (aggregated parameters) to the top level.

Both levels of models will be supported by data bases, which again can be used directly as an interactive information system.

The above system will be complemented by the less detailed System of Ecological Forecasting (SEF), the first version of which was already tested in Phase I. The final version of SEF will be used for training activities.

It is obvious that the quality of the final results will be determined by the quality of the models mentioned above and by the reliability of the input data.

Basic software techniques for user interface design and systems integration, and an operational prototype of such an interactive software system will be available for demonstration at the very beginning of Phase II (See Volume 2).

The transfer of this software to India will be simplified significantly if according to earlier plans, the Central Pollution Control Institute in Hardwar were to acquire the corresponding equipment (SUN 3/160C).

3. Statistical methods will be one of the main tools in data analysis and model fitting. Therefore, the necessary set of programmes has to be prepared and transferred to the Indian Core Group. Statistical methods will also be used to construct optimal monitoring networks.

4. As has been emphasized many times, reliable data are crucial to the assessment. So data collection and improvement of the data bank will continue in Phase II.

5. The training component is of great importance in this Project, especially with respect to computer-oriented activities. It is planned that Indian collaborators will visit IIASA several times in Phase II (the total length of these visits has to be at least 6 months).

6. To ensure transfer of the most essential software, it is recommended that in the budget for Phase II, funds be included to purchase an IBM PC-AT or equivalent IBM compatible computer.

9.7 Related Studies (coordinated but not funded by the Project)

9.7.1 Input-Output Studies

As suggested in the contribution by Parikh in Volume 3 of this Report, input-output studies of energy and materials are urgently needed in order to estimate the ecological sustainability of the Doon Valley and of Dehra Dun City.

Input-output studies of energy

For different sectors in the Doon Valley having different energy consumption patterns, the energy flows need to be worked out. Referring to Parikh's contribution in Volume 3, her Fig. 2 is a schematic representation with respect to the agricultural sector. Numerical values need to be estimated, and similar flow charts should be developed for the industrial, transportation and urban sectors. Various sorts of aggregation could then be undertaken as appropriate for particular scenario studies.

Responsibility: To be decided

Timing: Long-term

Input-output studies of materials

Following the ideas of Moench and Bandyopadhyay (1985) and in parallel with the input-output studies of energy, the material flows in the Doon Valley need to be worked out. Special consideration will have to be given to estimating the conversion rates to waste products and their disposal.

Responsibility: To be decided

Timing: Long-term

9.7.2 Environmental Histories

The results given in Section 4 demonstrate the contribution that an historian can make to the preparation of a land-use management plan or an environmental impact assessment. It is therefore recommended that one or two young Indian historians be sponsored at Duke University to work with Professor John Richards learning the basics of this new science. The historians would then become available to assist the Indian Core Group in the Doon Valley and elsewhere. This would strengthen greatly the capability of the Core Group to sponsor studies of baseline conditions in areas of interest.

Specifically, the research centered at Duke University would elaborate the ideas contained in Section 4 along the following lines:

1. Expansion of the data base used in Section 4 to include the entire hinterland of Dehra Dun municipality. This will require a preliminary study to define the area in neighboring districts having intensive economic and other relations with the Dehra Dun population. Portions of districts such as Tehri Garhwal and other Kumaon hill districts must certainly be considered. Time series similar to those for Dehra Dun district can be developed for a larger economic and ecological region. If sufficient care is used, these time series can be pushed back to as early as 1860 or even 1840.

2. Systematic and detailed research in the available records of the Forestry Department. This will provide rich information on the history of the forestry sector of Dehra Dun valley, and of the larger economic and ecological region. These data should help shape projections and estimates of longterm sustainability of the forestry sector. For example, it is possible to obtain year-by-year figures for fuelwood, timber, minor forest products, and other productive uses of the Doon forests. It is possible to follow detailed working plans on a plot-by-plot basis to determine the degree of change in the composition of the forest at twenty to thirty year intervals. In essence, this will be a

process of retrospective monitoring for the forestry sector of the district.

3. Close scrutiny of irrigation department, municipal, and other records to undertake retrospective monitoring of water supplies for human use, agriculture and industry.

4. Further detailed research on changes in the domestic and wild animal populations and their relationship to environmental degradation.

5. Detailed retrospective monitoring of limestone production and its demands and pressures upon the natural resources of the valley. It should be possible to collate annual time series data for raw material inputs and for lime outputs.

6. Detailed retrospective study of transportation, migration and circulation patterns for the period under review.

7. Meshing of documentary evidence and other data with land-use information available from satellite imagery for the Doon valley and its hinterland. It is especially important to obtain a clear and reliable land-use profile for the mid-1980s in order to work backward in time. At the same time, such an interface will help achieve a corrected, or at least corroborated, portrait of current land-use.

Responsibility: Prof. J. Richards supported externally plus some local currency

Timing: 18 months

9.7.3 Climate Change Studies

9.7.3.1 Analysis of climatological time series

Time series of daily climatological observations for the three valley stations, as well as for the hill station (Mussoorie) and the control station (Roorkee) were not available at IIASA in Phase I. It is recommended that very long (30 to 60 yr) time series for these stations be acquired and analysed for evidence of recent changes in local climate. The elements to be examined are:

-- Precipitation

-- Temperature

-- Diurnal range in temperature (a decrease in the range would indicate an increase in haze and smoke.)

-- Visibility and frequencies of occurrence of various obstructions to visibility.

A search should also be made for crop-yield data, which might give a good indication of climatic trends. See contribution by Dobesch in Volume 3 of this Report.

Responsibility: IIASA

Timing: 18 months

9.7.3.2 Investigation of the local impacts of global climate change over the next fifty years

There is general agreement that the earth will warm during the next 50 years due to the increasing concentrations of carbon dioxide, methane and other "greenhouse" gases. The global warming is expected to average about 2°C but there will be large variations from region to region. In areas such as the Doon Valley where there is considerable smoke and haze, long-term trends in concentrations of suspended particulate matter will also have to be considered in the assessment of climate warming.

Numerical models of the atmospheric general circulation are being used in several countries to simulate the effect of a doubling of greenhouse gases. The outputs of these models are mean values, for each grid square (360 km x 360 km) on the earth, of temperature and precipitation, as well as frequency distributions of daily values. Although the spatial resolution of these models is subject to many uncertainties, the models do give at least a first estimate of how the climate might change in the next 50 years. Planners should not assume that present climate will continue.

For Phase II of the Doon Valley assessment, it is proposed to acquire a set of climatological frequency distributions for a CO_2-warmed earth, specifically for the grid square containing Dehra Dun. These distributions can be obtained from one of the large computing centres producing three-dimensional atmospheric general circulation simulations. The data would be used to investigate the possible impacts on the Doon Valley of global climate warming. The output would contain practical advice for planners, who should not assume that present climate will continue. The study could also lead to some useful sensitivity analyses of biosphere sustainability to such changes (see, for example, Antonovsky and Korzukkin, 1986).

Responsibility: IIASA

Timing: 18 months

9.7.4 Studies of Valued Ecosystem Indicators (VICs)

As suggested by several persons, there is need to quantify the effects of human disturbances on selected valued ecosystem indicators (VEIs) in the Doon Valley. The output would be a model that could be calibrated with historical data on population densities, habitat availability and related factors and that could be used to provide estimates of the impacts of various proposed land transformation schemes on the VEIs.

One such VEI is the game fish Mahseer, which is disappearing from the rivers and streams of the Doon Valley (see contribution by Tilak in Volume 3). Other recommended VEIs are the major game birds (pheasant, partridge, quail), which are particularly sensitive to disturbances in ground cover. A proposal to undertake a study of gamebirds has been made by P.J. Garson (University of Newcastle upon Tyne) (personal communications). This kind of work should be supported.

Responsibility: Prof. P.J. Garson supported externally

Timing: Long-term

9.8 Some Recommendations to the Doon Valley Core Group

1. It is recommended that Phase II of the Doon Valley study be undertaken, the work plan being that given above. Recognizing that the proposals contained in Section 9.7 do not fit into the UNIDO framework, it is recommended that the Indian Core Group, UNIDO and IIASA support efforts to seek alternate sponsors in such cases.

2. Early in the course of Phase II, a 3-day meeting should be held in the Doon Valley to present the results of the Phase I study, and to seek the collaboration of the local people involved. People to be invited to the meeting should include members of the Core and Support Groups to the Doon Valley Study, as well as representatives of local organizations interested in sustainable ecological and economic redevelopment of the Valley.

3. It is recommended that the Pollution Control Research Institute in Hardwar be commissioned to undertake:

   (a) air pollution monitoring in the Doon Valley;

   (b) a preliminary inventory of emission sources.

   The Pollution Control Research Institute is already receiving technical assistance through UNIDO/UNDP to develop a pollution monitoring capability, and the Institute has been appointed to the group supporting the Indian Core Group of the IIASA study. State-of-the-art sampling and analysis equipment is available, and the Institute could play an important role in the air pollution studies planned for Phase II. In this connection, the sampling strategy (siting of stations, sampling periods, etc.) should be designed to meet the needs of the air pollution meteorologists and modellers. It is therefore recommended that a small Air Pollution Working Party be established, consisting of:

   Dr. B. Padmanabhamurti from the Core Group (Chairman)

Dr. B.B. Lal, Pollution Control Research Institute

Drs. R.E. Munn and V. Fedorov, International Institute for Applied Systems Analysis

Dr. M. Piringer, University of Vienna

4. The Indian Institute of Remote Sensing in Dehra Dun provides a unique facility for monitoring land-use and environmental changes in the Doon Valley. That Institute should be asked to play a major role in documenting present and future trends in the valley.

5. Data Base Management

   In order to ensure an orderly information base for all parties to use, the following elements need to be assembled, collated and stored for easy access:

   -- Recent aerial photography and satellite imagery-scale 1:50,000 or better. (Indian Institute of Remote Sensing).

   -- Integrated land resource survey information on geology, topography, soils, vegetation, climate, and land use, using existing information and survey program where possible. (Central Soil and Water Conservation Research and Training Institute; National Institute of Hydrology; Wadia Institute of Geology; J. Nehru University).

   -- Relevant forestry reports, documents and data bases, including forestry growth, age and composition data (U.P. Forest Department; Forest Research Institute).

   -- Preparation of computer map files of the above, permitting various kinds of overlays. One example of the striking visual displays that could be obtained is given in a Canada Forestry Service report, "Using Ecological Resouce Inventory" (Holland, 1984).

6. A representative of the Uttar Pradash Forestry Department should be invited to join the Doon Valley Core Group.

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APPENDIX 1

ADVISORY COMMITTEE MEETING ON THE IIASA/UNIDO PHASE I OF THE ENVIRONMENTAL ASSESSMENT OF THE DOON VALLEY, INDIA

March 3-5, 1986
IIASA, Laxenburg, Austria

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APPENDIX 2

LIST OF PERSONS CONSULTED IN INDIA REGARDING THE DOON VALLEY ASSESSMENT

Drs. Munn and/or Fedorov have consulted the following persons in India with respect to the Doon Valley assessment.

The Core Group for the Doon Valley IIASA/UNIDO Study

- Dr. S. Maudgal, Department of the Environment (Coordinator)
  New Delhi
- Prof. P.S. Ramakrishnan, Jawaharlal Nehru University
  New Delhi
- Prof. B. Padmanabhamurti, Jawaharlal Nehru University
  New Delhi
- Shri Sreenivasan, Jawaharlal Nehru University
  New Delhi
- Dr. V.V. Dhruva Narayana, Central Soil and Water
  Conservation Research and Training Institute
  Dehra Dun
- Lt. Col. P. Mishra and Prof. M.D. Shedha
  Indian Institute of Remote Sensing
  Dehra Dun
- Dr. (Mrs.) N. Bhat, Department of the Environment
  New Delhi

The Support Group for the Doon Valley IIASA/UNIDO Study

- Dr. C.K. Gosh, Indian Meteorological Department
  New Delhi
- Dr. S. Chandra, Director, National Institute of Hydrology
  Roorkee
- Mr. B.B. Lal, Pollution Control Research Institute
  Hardiwar
- Shri A. Khurama, District Magistrate
  Dehra Dun
- Shri A. Kaushal, Nehru Yuvak Kendra
  Dehra Dun
- Mr. S.Talmar, Director, Ministry of Industries
  New Delhi
- Dr. R.V. Singh, President, Forest Research Institute
  Dehra Dun

Others

- Dr. A. Agarwal
  Centre for Sciences and Environment
  New Delhi

- Dr. J. Bandyopadhyay, Doon Valley Ecosystem Study
  Indian Institute of Management
  Bangalore

- Dr. Bhandari, Deputy Director, Central Building
  Research Institute
  Roorkee

- Dr. A.K. Biswas, Consultant to UNEP on water projects
  in India

- Dr. S.N. Chaudhury, Pollution Control Research Institute
  Hardwar

- Dr. S.K. Das, Director, Indian Meteorological Department
  New Delhi

- Dr. R. Dayal, Forest Research Institute
  Dehra Dun

- A.K. Gupta, Pollution Control Research Institute
  Hardwar

- Dr. G. Van Ittersum, FAO and Wildlife Institute of India
  Dehra Dun

- H.C. Jain, Pollution Control Research Institute
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- Prof. A.K. Roy, Indian Institute of Remote Sensing
  Dehra Dun

- Shri Sesham, Secretary, Department of the Environment
  New Delhi

- Dr. J.B.Sale, FAO and Wildlife Institute of India
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- Dr. V. Shiva, Doon Valley Ecosystem Study

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- B.K. Subba Rao, Forest Research Institute
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- Dr. N. Subramanyam, Central Water Commission
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- R. Swaminathan, Pollution Control Research Institute
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APPENDIX 3

PROGRESS MADE WITHIN PHASE I WITH RESPECT TO SUPPORTING STRUCTURES IN INDIA, TRAINING OF INDIAN NATIONAL COUNTERPARTS AND INITIATION OF THE ENVIRONMENTAL DATA BANK FOR THE DOON VALLEY

1. Establishment of Supporting Structure in India

The Core Group and the Support Group for the Doon Valley IIASA/UNIDO Study were established in November, 1985.

The Core Group is a multidisciplinary scientific team comprising professionals in environmental sciences, socio-economics, meteorology, hydrology, forestry management, and computing. A list of its members is given in Appendix 2.

The members of the Group made essential contributions to the data collection process and to a better understanding of the problems related to assessment of the environmental impacts of industrial development in the Doon Valley. They also contributed to Volume III of this report.

In Phase II, the Group will be responsible for forming alternative concepts of industrial development in the Doon Valley, together with IIASA's team.

One of the major activities of the Group in Phase II will be to transfer the methodology and software tools developed by the Project and to disseminate results in India.

The objectives of the Support Group are to describe the major socioeconomical and environmental problems in the Doon Valley to the research teams, and to organize public and legislative support for the measures to improve environmental conditions that the Project will recommend.

The members of the IIASA's team are highly appreciative of the effective help of the Support Group members in organizing their field trips. The list of members of the Group is given in Appendix 2.

2. Training of the Indian National Counterpart

The training component of the Project was mainly oriented to computer-related activities.

The two sets of training programmes, "Interactive System for Design and Analysis of Simulation Experiments (ISSE)" and "System of Ecological Forecasting (SEF)" were transferred to the Indian Core Group. SEF is mainly for training purposes, but can be used for a preliminary assessment of the impacts of industrial and agricultural development on the environment. ISSE consists of two parts, PLAN and SYS. PLAN is the program for constructing optimal multifactor experiments on computers and SYS provides the tools for corresponding statistical analyses. Further details are given in Volume III. The first versions of ISSE and SEF were transferred during the field visit of Prof. V. Fedorov (November-December, 1985). The final versions of these software were handed over to Mr. Sreenivasan (Indian Core Group member responsible for studies related to the software component of the Project) during his visit to IIASA. Both systems were demonstrated to a number of Indian representatives, including Dr. S. Maudgal (Director of the Department of Environment, Government of India), B.B. Lal (Director of the Pollution Control Institute, Hardwar), and members of the Indian Core Group visiting the Advisory Committee Meeting (March, 1986, IIASA); they positively evaluated these systems.

Mr. S. Sreenivasan spent about three weeks at IIASA working with the members of the Project and other IIASA scientists. He participated in the preparation of various alternative scenarios of industrial development in the Doon Valley. Together with the Project's computer assistant, M. Lenko, he analyzed the majority of these scenarios on IIASA's VAX 11-780. They mainly worked with SEF and ISSE. Mr. Sreenivasan also participated in improving the Data Bank for the Doon Valley. In other words, participation in the computer- oriented activities was the prime component of his stay at IIASA.

During the Advisory Committee Meeting (March, 1986) for representatives of the Indian Core Group (see the list of names in Appendix 2) two seminars devoted to the software activities were organized at IIASA.

In the first seminar, ISSE and SEF were extensively discussed with a subsequent demonstration of their possibilities. In the second seminar, Dr. K. Fedra (Leader of the IIASA's Project on "Advanced Computer Applications") gave a lecture devoted to modern computerized approaches in decision making and demonstrated a prototype of the "Integrated System for Development Planning and Impact Assessment", which was proposed for implementing Phase II of the Project (for details, see Volume III).

The training activities included the following lectures delivered by Prof. R.E. Munn during his field visit to India:

- Environmental Impact Assessment (Central Water Commission)

- Assessment of Industrial Development Impact in the Doon Valley (JNU)

In the summer of 1986, the Young Scientist Summer Program will take place at IIASA. Details and invitations were sent to India (Department of Environment, Government of India and the Pollution Control Institute, Hardwar).

3. Initiation of the Environmental Data Bank for the Doon Valley

The technical details of the data bank are given in Volume II, together with some sample printouts. The data consist of two main blocks:

- Statistical data block comprising various aspects of the Doon Valley geography, environment, economics, land-use, and demography.

- Block of digitized maps, which will be used in the interactive decision-making support system.

In Phase II it is planned to extend sections related to the meteorology and hydrology of the Doon Valley (see Chapter 8, this volume, and the contributions by Fedra, Kaden, and Piringer, Volume II).

It must be emphasized that this data bank could be of interest to other research groups and subsequent studies beyond the Project, providing for them a test ground for new approaches in environmental assessment.

4. Guidelines for Establishing a National Environmental Monitoring Network

Dr. S. Maudgal and his colleagues in the Government of India (Department of the Environment, Meteorological Department, etc.) are well aware of the need to ensure uniformity in the design of environmental monitoring networks, particularly with respect to:

- Siting criteria.

- Instrumentation.

- Periodic field inspections and calibrations.

- Quality control.

- Management of large data banks.

- User accessibility.

Guidelines for operating specific types of networks are available from WMO, WHO, and other international bodies. Where applicable, these guidelines are being followed by the appropriate departments, agencies, and institutes in India.

The only advice that can be offered is therefore the following:

(1) As in many other countries, the responsibility for collecting environmental data is shared amongst several bodies. As a result, methods of storing and accessing information are not uniform, creating problems for the

user. It is recommended that possible ways of overcoming this situation should be considered.

(2) UNEP has established a facility in Geneva called GRID (Global Resource Information Data Base). Although still in an early stage of development, GRID will ultimately provide environmental data, ordered by geographic location and synthesized to answer specific questions posed by environmental managers. As is no doubt the case already, the Government of India should follow carefully the development of GRID, and should seek to ensure compatibility between GRID and its national environmental data management systems.

APPENDIX 4

LIST OF RELEVANT LOCAL, STATE AND NATIONAL STANDARDS, GUIDELINES AND REGULATIONS

The information in this Appendix is incomplete. However, it does seem to be sufficient to demonstrate that there is adequate statutory authority to solve most of the problems existing in the Doon Valley on a case-by-case basis. In addition, as is mentioned in Section 3, citizen groups have the possibility of taking class actions to the courts (Ramamurthy, 1985).

Karajagi (1985) has summarized the main environmental regulations that apply in India as follows:

Regulations	Objectives
1. Air (Prevention & Control of Pollution) Act, 1981	This act provides for prevention, control and abatement of air pollution through Pollution Control Boards.
2. Forest (Conservation) Act, 1980	State Governments have to obtain approval from Government of India before converting forest lands to non-forest lands.
3. Water (Prevention and Control of Pollution) Act, 1977	Act providing for collection of a tax on water from certain industries so as to augment the resources of Central and State Boards for Prevention and Control of Pollution.
4. Insecticides (Amendment) Act, 1977	To regulate the import, manufacture, sale, transport, distribution and use of insecticides.
5. Water (Prevention and Control of Pollution) Act, 1974	This act envisages establishment of Boards for Prevention and Control of Water Pollution so as to maintain and restore wholesomeness of water.
6. Wild Life (Protection) Act, 1972	This act provides for the protection of wild animals and birds and for establishing sanctuaries, National Parks, Game Reserves and closed areas.*

*Facilities for big game shooting in the Dehra Dun District (except for protected species such as tiger and leopard) are provided in the Jhabrawala and Barkot forest blocks through permits obtainable from the Chief Wild Life Warden, Uttar Pradash (Varun, 1979).

7.	Insecticides Act, 1968	To regulate the use of insecticides to prevent risk to human beings or animasl.
8.	Indian Forest Act, 1927 and various State Acts	To protect the forests

Specifically relating to Uttar Pradesh State, an Act known as "Uttar Pradesh Rural and Hill Areas Tree Protection Act, 1976 (U.P. Act No. 45, year 1976) controls the felling of trees in all rural and hilly areas of Uttar Pradesh, including the Doon Valley.

In the book, "India's Environment" (Bandyopadhyay et al., eds., 1985, pp. 247--309), several authors discuss the efficacy of environmental regulations in India. The general view in that book seems to be that the regulations are sometimes inconsistent with one another, and are difficult to implement. These criticisms are not unique to India but are voiced by citizen groups around the world. However, there is no doubt that other countries have much to learn from India. The recent Supreme Court decision on Doon Valley quarrying, including payment of legal costs of the citizen group involved, is without precedent in most industrialized countries.

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AN ASSESSMENT OF ENVIRONMENTAL IMPACTS OF INDUSTRIAL DEVELOPMENT

With Special Reference to the Doon Valley, India

Phase I

VOLUME II

SOFTWARE AND DATA

International Institute for Applied Systems Analysis
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UNIDO Contract No. 85/82 (US/GLO/85/039)

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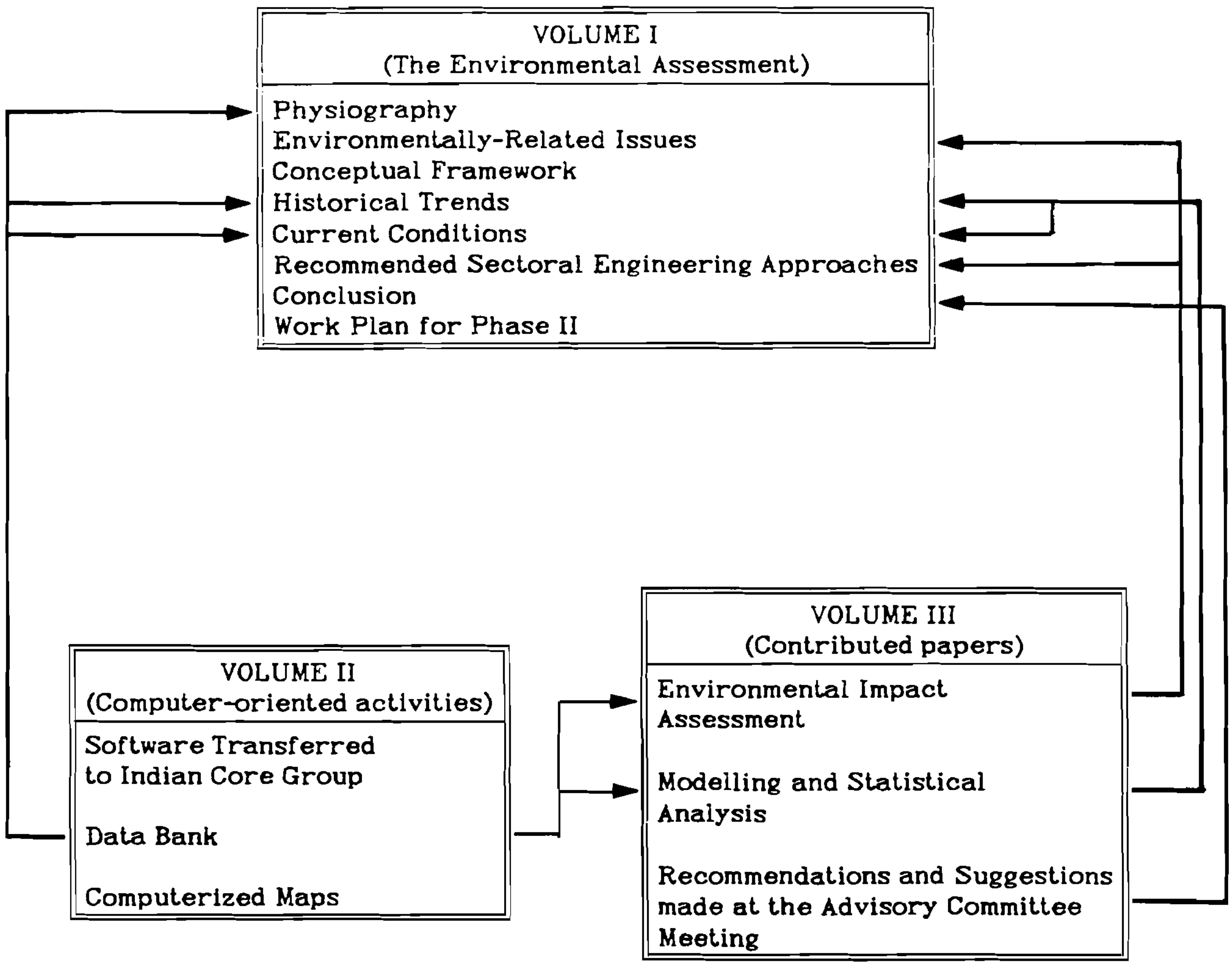
THE STRUCTURE OF THE REPORT



FOREWORD

The present report (Phase I) contains three parts.

Volume I covers a conceptual framework for environmental impact assessment of the Doon Valley, a description of present environmental conditions and past trends in the region, and a comprehensive work program and recommendations for Phase II of the project. To a great extent, Volume I summarizes the main findings of Phase I of the Project, reserving the presentation of details for the two other volumes.

Volume III contains a collection of contributed papers which were presented at the Advisory Committee Meeting (March 1986, IIASA) and some proposals on future activities made by participants of this meeting. Some of the papers are rather general but the majority of them are devoted to specific aspects of the environmental assessment of the Doon Valley and supplement Volume I.

The present volume (Volume II) is devoted to computer-oriented results of Phase I, including a data bank. The potential users should be equipped with elementary computer knowledge: this volume contains tools (more accurately, the instructions on how to use them) but not any final results.

CONTENTS

I SOFTWARE TRANSFERRED TO THE INDIAN CORE-GROUP

PREFACE

The main efforts of the project during Phase II will be directed towards quantitation of ideas and hypotheses on environmental conditions in Doon Valley.

A number of models comprising various aspects of environmental dynamics are planned to adjust to Doon Valley's specific features. It is evident that models of different levels of detailedness will be necessary in order to analyze all possible alternatives for development of the region. Some of them can describe or (more accurately) simulate general tendencies in the valley, say, its average erosion or average soil productivity. Others can give more detailed results, such as dynamics of space distribution of pollutants or an admissible water management policy.

To appropriately handle this variety of models, it will be necessary to have a special software. Here we will apply the existing methodology based on statistical ideas, usually referred to as "Analysis and Design of Simulation Experiments." (See, for example, Fedorov, 1983; Fedorov, Korostelev, Leonov, 1984; Naylor, 1971.)

Part 1 contains a short introduction to the subject and a manual with a simple example.

Part 2 is a short description of the "System of Ecological Forecasting" (SEF). This system can be used to analyze changes in environmental characteristics of geographically and economically homogeneous areas. In terms of references, SEF is planned to be a component of the project's training activities.

Part 3 contains the most essential information from the Data Bank and a short description of computerized versions of Doon Valley maps.

1 INTERACTIVE SYSTEM FOR DESIGN AND ANALYSIS OF SIMULATION EXPERIMENTS

User's Guide

S. Leonov, V. Fedorov

VNIISI - IIASA

1. Introduction

Computers make it possible to construct and run complicated mathematical models of complex systems (e.g., economic systems, ecological systems) which involve hundreds of inputs and equations. The links between the different variables (inputs and outputs) and equations in these models are usually very difficult to follow, and this is complicated by the fact that the models are continuously being updated and improved by the incorporation of new mathematical features. Sometimes models consist of modules (elements) prepared by different researchers, and this is one reason why mathematical models (or, more accurately, their computerized versions) occasionally become "mysterious" even to their authors. Analytical techniques prove to be practically useless in analyzing the properties of these models. Since it is not possible to obtain the required results in this way, it is natural to try another approach: one possibility is to carry out simulation experiments with the mathematical models themselves.

The question of the effectiveness of these experiments and whether the chosen model adequately describes the empirical data arises at the very beginning of the research. To study this, "models" of the models are often constructed. In what follows the terms ***secondary model*** and ***primary model*** will be used in an attempt to avoid confusion.

The construction of secondary models can also be stimulated by the fact that the primary models are frequently too detailed for the specific investigations that the researcher wishes to perform. For instance, to describe the behavior of a primary model over a relatively small range of input values, it might be sufficient to use a polynomial approximation of the model. One attractive feature of this approximation is that it then becomes possible to develop fast real-time interactive software. This type of software can be extremely useful to decision makers because it allows them to scan a lot of variants in a relatively short time.

The types of problems that can be solved are indicated in Figures 1-3. Figure 1 illustrates the possibility of testing or refining the primary model by applying the secondary model to initial data. Figure 2 explains the possibility of combined analysis of two systems. Figure 3 illustrates how primary models can be compared through approximation by the same secondary model.

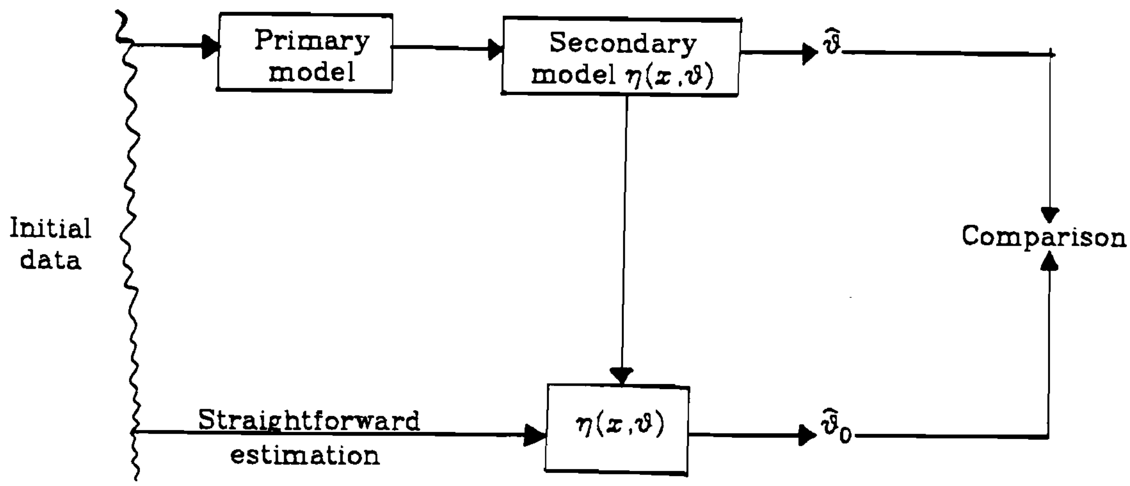


Figure 1 Testing a primary model by applying a secondary model to initial data.

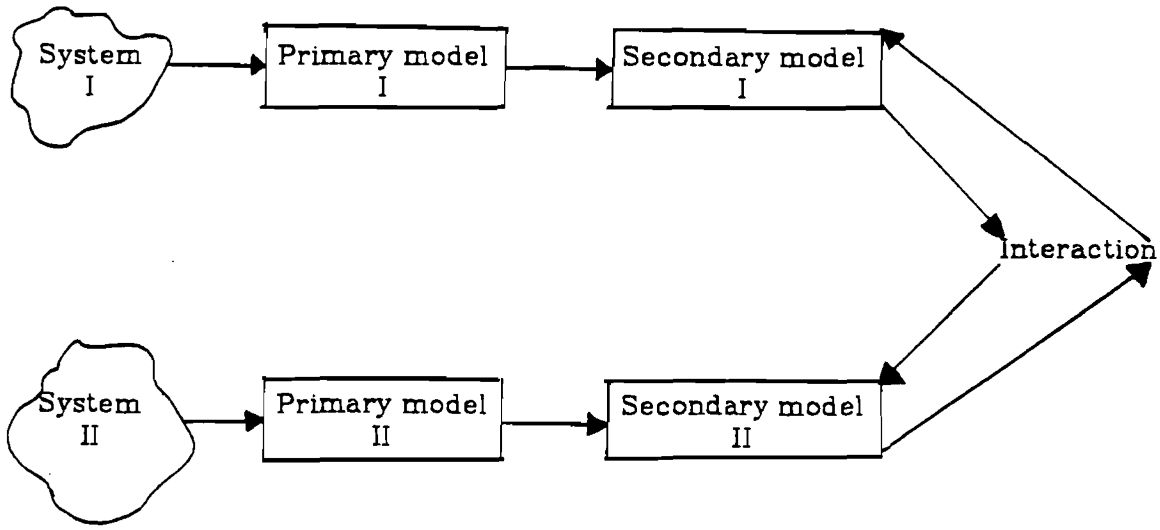


Figure 2 The combined analysis of two systems.

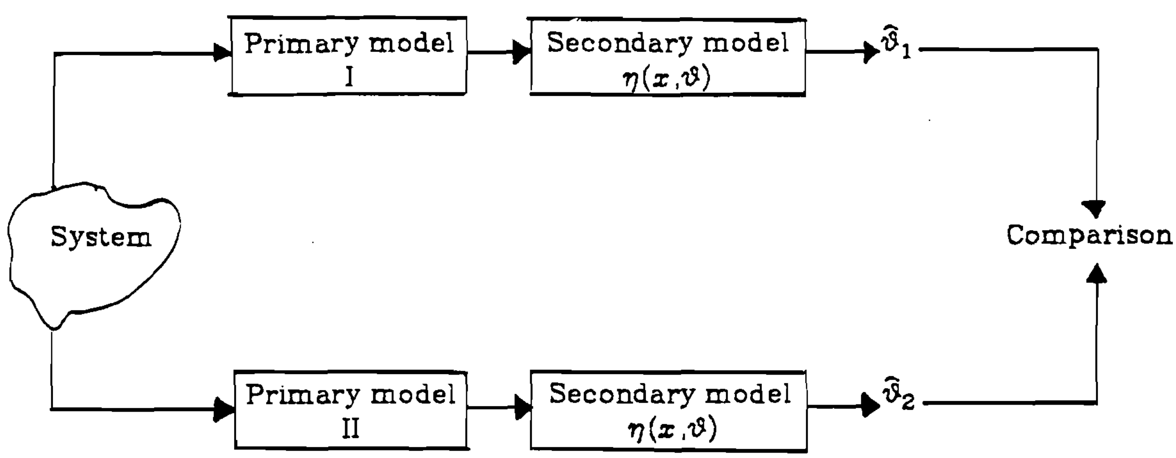


Figure 3 Comparison of primary models through approximation by the same secondary model.

2. Structure of the Interactive System

The current version of the system contains two main programs: PLAN (intended for construction of experimental design) and SYS (intended for data analysis). These programs are indpendent of each other and are linked only through input - output files of data. It is necessary to point out that the treatment of any specific primary model requires an exchange module. This module makes it possible to repeatedly call the primary model varying input data. It must be mentioned also that some potentialities notforeseen in the system may be assigned to the exchange module.

3. Construction of Experimental Design

While investigating the primary model, it is assumed that input variables x (factors or independent variables) are separated into groups according to: first, prior information on their nature, and second, the expected degree of their influence on dependent variable(s) Y . The factors are usually separated into the following groups:

(a) Scenario and exogenuous variables;

(b) Parameters of the model whose values are obtained on the stage of identification;

(c) Variables known with "small" random errors; they may often be considered as random ones.

The program PLAN can generate designs of different types for variables from different groups:

- orthogonal design
  - (i) two-level design $X=\{X_{ij}\}$; $X_{ij}=+1,-1$; X is Hadamard matrix, $N=4k$, k is an integer number ($X^TX=NI_N$, I_N - Identity matrix);
  - (ii) three-level design $X=\{X_{ij}\}$, $X_{ij}=+1,0,-1$; X is conference matrix, $N=4k+2$ ($X^TX=(N-1)I_N$)

  In this version the following numbers of experiments for orthogonal design are possible:

  4, 8, 12, 16, 20, 24, 32, 40, 44, 48, 52, 60, 64, 68;
  6, 14, 18, 26, 30, 38, 42, 54, 62.

  The orthogonal design is recommended for group i if a detailed investigation for the factors from i is required;
- random design with two- and multi-level independent variation of factors (usually used for the factors from group b);
- random design with simultaneous variation of all factors of the group (may be applied for block analysis);
- random design with continuous law of distribution: uniform and normal (may be applied for those factors which are known up to small random error).

The criterion for design construction is the correlation coefficient of column vectors of X - matrix : the columns must have as small a correlation as possible. The design may also be generated (for some groups) in a purely random manner.

There are two variants of the application of generated design $X=\{X_{ij}\}$:

(i) X - matrix is written (row by row) into the auxiliary file HELP.DAT for application in the exchange module and further analysis of simulation experiment;

(ii) the levels of factors may be set in the real scale: mean values and scale of variation are chosen by the user. The design in the real scale is obtained with the help of the evident formula: $FN_{ij}=AMD_j*(1+ALF_k*X_{ij}), i=1,N$. Here the j-th factor belongs to the chosen group k ; ALF_k is a scale of variation for group k ; AMD_j is a mean value of the j-th factor. The matrix $FN=\{FN_{ij}\}$ is stored (row by row) in the file HELP.DAT .

4. Analysis of Experiments

The aim of the simulation analysis is the construction of a secondary model of the form:

$$y=g(x)=a_0+a_1f_1(x)+\cdots+a_kf_k(x), \quad (1)$$

where y is a response function (dependent variable); $a_0,a_1,\ldots,a_k$ are parameters to be estimated (regression coefficients); $f_1,\ldots,f_k$ are known functions depending on x - vector of input variables.

Since k is usually large, one of the main problems of experimental analysis is the screening of significant factors. The following is the statement of the problem: input data is set -

$$\begin{matrix} x_{1,1} & x_{1,2} & \cdots & x_{1,m} \\ x_{2,1} & x_{2,2} & \cdots & x_{2,m} \\ \cdots & \cdots & \cdots & \cdots \\ x_{N,1} & x_{N,2} & \cdots & x_{N,m} \end{matrix}$$

where N is a number of observations and m is a number of variables. One variable is taken as a response and is denoted by Y . Then k functions $f_1,f_2,\ldots,f_k$, depending on the rest of the variables, are chosen. (They may be constructed with the help of some transformations - the set of the most usable transformations is provided by the program.) That is the final step in the formulation of the problem. Screening experiments can now be carried out.

Here we shall enumerate the possibilities of the program:

(1) Input variables can be separated into groups with the help of an identification vector; variables from only one group are analysed simultaneously, but the identification vector may be changed, and the groups easily rearranged.

(2) It is possible to make transformations of factors, include their interactions, and take any variable as a response.

(3) The program provides the stepwise regression procedure (subroutine STPRG): factors may be included into regression or deleted from the equation (Efroymson, 1962). This program for screening significant factors is based on the subroutines from SSP - package (1970). Some modifications of these subroutines have been carried out for the implementation of interactive regime. Interpretation of input and output information in this module will cause no difficulties for a user familiar with the SSP - package.

(4) A user may obtain both statistics analogous to SSP - subroutines and some additional information, for instance, a correlation matrix of regression coefficients and a detailed analysis of residuals.

(5) If a secondary model is used for interpolation or extrapolation (subroutine FORECAST), values of input variables (predictors) are chosen by the user and the standard errors of the prognoses are calculated.

(6) A heuristic method of random permutations (subroutine STRAN) for testing significance of entered variables is provided by the program. (See Fedorov et al, 1984.)

Program SYS utilises 3 files: SYSIN.DAT and SYSOUT.DAT for input and output information respectively, and an auxiliary file SYSST.OUT for intermediate information.

REFERENCES

Efroymson, M.A. 1962. Multiple Regression Analysis, in ***Mathematical Methods for Digital Computers***, A. Ralston, H. Wilf (eds). New York: Wiley.

Fedorov, V. 1983. Analysis and Design of Simulation Experiments for the Approximation of Models. WP - 83 -71 . Laxenburg, Austria: International Institute for Applied Systems Analysis.

Fedorov, V., A. Korostelev, S. Leonov. 1984. Analysis and Design of Simulation Experiments with Linear Approximation Models. WP - 84 - 74 . Laxenburg, Austria: International Institute for Applied Systems Analysis.

Naylor, T.M. 1971. Computer Simulation Experiments with Models of Economic Systems. John Wiley and Sons, N.Y., London.

System/360 Scientific Subroutine Package, Version 3, Programmer's Manual. 1970. New York: IBM, Technical Publications Department.

Instructions for program PLAN.

Information on the terminal, variable(s) for input	Comments
1. A NUMBER OF GROUPS AND A NUMBER OF FACTORS ? (KG,M)	KG - a number of groups for experimental design, M - total number of factors.
2. FACTOR IDENTIFICATION ? (IN(i), i=1,M)	IN(i) (i=1,M) - an index of a group to which factor i belongs.
3. A NUMBER OF GROUPS FOR CORRELATION ANALYSIS, INCLUDING ORT.GROUP ? (MCOR)	MCOR - a number of groups for which correlation analysis is executed (including orthogonal group)

Message 4 appears, if KG > MCOR .

4. THEIR INDEXES ? (NCOR(i), i=1,MCOR)	NCOR(i) - indexes of the groups for which corr. analysis is executed.
5. WITH ORTHOGONAL DESIGN: YES - 1, NO - 0 ? (II)	II=1 - with orthogonal design, II=0 - without orthogonal design

Messages 6 - 8 appear if II=1 .

6. ORTHOGONAL GROUP ? (NORT)	NORT - an index of the group with orthogonal design.
7. A CODE FOR ORTHOGONAL DESIGN: 2 - TWO-LEVEL DESIGN (N IS 4-TUPLE), 3 - THREE-LEVEL DESIGN (N IS 2-TUPLE) (NX)	NX=2 - two-level (+1, -1) design is constructed, NX=3 - three-level (+1, 0, -1) design is constructed.
8. DESIRABLE N ? (N) (possible N appear on terminal)	If NX=2, N has the form: N=4k, k - integer If NX=3, N has the form: N=4k+2.

(Caution: N must be greater than 3 and less than 69 !!!)

9. GROUP CODES : 1 - SIMULTANEOUS VARIATION, 2 - TWO-LEVEL VARIATION, 3 - MULTILEVEL VARIATION, 4 - UNIFORM DISTRIBUTION, 5 - NORMAL DISTRIBUTION (IG(i), i=1,KG).	IG(i) - a code for experimental design for group i: 1 - two-level (+1, -1) simultaneous variation for all factors belonging to group i; 2 - two-level (+1,-1) independent variation; 3 - multilevel independent variation (see <10>); 4 - factors from group i have uniform distribution (see <13>); 5 - factors from group i have normal distribution (see <14>).

Messages 10-12 appear for each group with IG(i)=3.

10. GROUP i. A NUMBER OF LEVELS ? (LEV(i))	LEV(i) - a number of levels for group i.
11. LEVELS ? (V(l,i), l=1,LEV(i))	V(l,i) - values of levels.
12. PROBABILITIES ? (P(l,i), l=1,LEV(i))	P(l,i) - corresponding probabilities.

Message 13 appears for each group with IG(i)=4.

13. GROUP j , INTERVAL OF VARIATION - (-A,A). YOUR *A* ?	Factors from group j are uniformly distributed on (-A, A).

Message 14 appears for each group with IG(i)=5.

14. GROUP 1, MEAN = 0, STANDARD DEVIATION ? (BNOR(1))	Factors from group 1 are normally distributed, BNOR(1) - standard deviation.

Message 15 appears if II=0 (see <5>).

15. MINIMAL AND MAXIMAL NUMBERS OF EXPERIMENTS ? (NN, NMAX)	NN, NMAX - minimal and maximal numbers of experiments are arbitrary (no orthogonal design)
16. DO YOU NEED TO WORK WITH THE VECTOR OF MEANS ? (JWR)	JWR=1 - see <17-18>. JWR=0 - see <19>.

Messages 17-18 appear if JWR=1. In that case the levels of factors are chosen by the user and set in the real scale (see introduction)

17. GROUP COEFFICIENTS ? (ALF(i), i=1,KG)	ALF(i) - group coefficients.
18. VECTOR OF MEANS ? (AMD(j), j=1,M)	AMD(j) - vector of means.

(In that case the value FN(i,j) of factor j in i-th experiment equals to:

FN(i,j) = AMD(j) * (1 + ALF(k)*X(i,j)),

here X(i,j) - constructed design, k - an index of the group to which factor j belongs).

19. TO THE BEGINNING - 1, TO THE END - 0 ? (IBN)	IBN=1 - go to <1>, IBN=0 - STOP.

Instructions for program SYS (Analysis of the simulation experiment)

Information on the terminal, variable(s) for input	Comments
1.NUMBER OF OBSERVATIONS ? (N)	N - total number of observations under analysis
2.TOTAL NUMBER OF VARIABLES ?	MTOT - total number of variables (factors)
3.IDENTIFICATION VECTOR ? (IDNTF(i),i=1,MTOT) Caution: format - 10I1 !!!	Variable i belongs to block IDNTF(i)
4. A VARIABLE NUMBER AND SCALE ? (KSCAL, SCAL) TO STOP INPUT - TYPE 0 0	Scaling of variable KSCAL is made: X(KSCAL)::= X(KSCAL) * SCAL
5. BLOCK FOR ANALYSIS ? (NBL)	Variables from block NBL will be analysed

(Caution: total number of variables in the block, including transformations and interactions, must be less than 60 !!!)

6. TRANSFORMATION OF INDEPENDENT VARIABLES: YES - 1, NO - 0 ?	ITR=1 - see <7>, ITR=0 - goto <8>.

Message 7 appears if ITR=1.

7. TABLE OF TRANSFORMATIONS:

1. X::= X*X	5. X::= LN(X)
2. X::= Sqrt(X)	6. X::= 1/X
3. X::= ABS(X)	7. X::= Arctg(X)
4. X::= Exp(X)	

INPUT: VARIABLE NO., TRANS. NO. (KT, NUMTR)	A new independent variable X(new) is created: variable KT is transformed (it must belong to block NBL !!!),

	transformation NUMTR is carried out, IDNTF(new)::= NBL.
8. DEPENDENT VARIABLE ? (NUMDEP)	NUMDEP - dependent variable (response function)
9. WITH INTERACTIONS: YES - 1, NO - 0 ? (INTER)	INTER=1 - if variables i,j belong to block NBL, a new indpendent variable is created: X(new)::= X(i)*X(j)
10. STEPWISE ANALYSIS: EFROYMSON PROCEDURE - 0, WITH PERMUTATIONS - 1,, ANALYSIS AND FORECAST - 2, END OF TASK - 3, ANOTHER OPTION - 4 (IAN)	IAN=0 - Efroymson procedure is executed (see STPRG - instructions); IAN=1 - stepwise regression with permutations is executed (see STRAN - instructions), it is recommended after STPRG ; IAN=2 - forecasting is executed (see FORECAST - instructions), caution: it must be used just after STPRG !!! IAN=3 - Stop, IAN=4 - go to <11>
11. INNOVATION OF IDENTIFICATION VECTOR: NO INNOVATION, NEW ATTEMPT - 0 PARTIAL INNOVATION - 1 TOTAL INNOVATION - 2 ANOTHER OPTION - 3 (I11)	I11=0 - go to <5> (new block may beanalysed) I11=1 - go to <12> (identif. vector may be changed) I11=2 - go to <3> (total innovation of identif. vector) I11=3 - go to <10>

Message 12 appears if I11=1.

12. INPUT: VARIABLE AND NEW BLOCK NUMBER ? (TO STOP INPUT - TYPE 0 0) (KK, NEWBL)	Partial innovation of identification vector: if 0 < KK < MTOT, then IDNTF(KK)=NEWBL if KK=0, go to <8> .

Instructions for subroutine STPRG - Efroymson procedure

! Information on the terminal, ! variable(s) for input !	! Comments !
1. OUTPUT OF CORRELATION MATRIX: YES - 1, NO - 0 (KOUT)	KOUT=1 - correlation matrix is written into file SYSOUT.DAT
2. CODES (IDX(i), i=1,M) (Caution: format - 10 I1 !!!!)	Input of codes for stepwise regression: IDX(i)=0 - free variable, IDX(i)=1 - variable i is forced into regression equation; IDX(i)=2 - variable i is deleted from regression. IDX(M)=3 - variable M is dependent variable.

Total number of independent variables in the analysed block (transformations and interactions are included) equals to M-1 .

3. INFORMATION ON THIS STEP: PRINT - 1, NO - 0 (NOUT)	NOUT=1 - information is stored in the file SYSOUT.DAT
4. FORWARD PROCEDURE - 0, STOP - 1, DELETING PROCEDURE- 2 (NSTOP)	NSTOP=0 - next step of stepwise regression is carried out; NSTOP=1 - end of stepwise procedure (see <6>); NSTOP=2 - deleting procedure is executed (see <5>).
5. DELETING PROCEDURE (No input !!!)	Information on deleting procedure appears on the terminal (see test example)
6. TO TYPE TABLE OF RESIDUALS: YES - 1, NO -0 (NR)	NR=1 - table of residuals is written on the terminal and stored in the file SYSOUT.DAT .

Instructions for subroutine FORECAST - analysis and forecast

```
 ------------------------------           ----------
! Information on the terminal, !         ! Comments !
!  variable(s) for input       !          ----------
 ------------------------------


1. FORECASTING: YES - 0, NO - 1      IFORE=0 - forecast is executed (see <2> ),
      (IFORE)                        IFORE=1 - end of subroutine.

     Message 2 appears for all variables from block NBL (only for
       basic variables - not for transformations and interactions)

2. INPUT: VALUE OF VARIABLE          D(j) - a value of variable j for
      j ?  (D(j))                         for forecast.

3. NEW ATTEMPT - 0, TO STOP - 1 ?    IATT=0 - forecast is made in the
      (IATT)                          new point ( go to  <2> );
                                     IATT=1 - end of subroutine.
```

Instructions for subroutine STRAN - stepwise regression with permutations

```
 ------------------------------           ----------
! Information on the terminal, !         ! Comments !
!  variable(s) for input       !          ----------
 ------------------------------


1. NUMBER OF PERMUTATIONS AND         LMAX - number of permutations
   AND MAX. NUMBER OF STEPS ?          on each step,
     (LMAX, NMAX)                     NMAX - maximal number of steps in
                                       stepwise regression procedure
                                      (NMAX must be less or equal to  M-1  -
                                        a number of independent variables)

2. NUMBER OF INTERVALS AND            NDIV - a number of intervals,
   SCALE FOR A HISTOGRAM ?            SMS - a scale for a histogram
    (NDIV, SMS)

    Histograms for several statistics are constructed: T - Student's,
     F - Fisher's, SS - proportion of the sum of squares reduced on
     the given step. When LMAX is not too large ( LMAX < 100  ), it is
     recommended to use NDIV = 5 - 10, SMS = 1.
    Caution: the following inequalities must be satisfied -
                LMAX < 300 ,    2 < NDIV < 50 .

3. PROGRAM CODE: 0 - FROM             MD=0 - stepwise regession is executed
   THE 1-st STEP, 1 - NOT             from the 1-st step (no forced variables)
   FROM THE 1-st STEP ?  (MD)         MD=1 - some variables are forced into regression -
                                       see  < 4,5 >.

     Messages 4,5 appear if  MD = 1.

4. TOTAL NUMBER OF FORCED             MX1 - a number of variables forced
    VARIABLES ?  ( MX1 )                into regression equation.

5. THEIR INDEXES ?                    NV(i) - indexes of forced variables.
   ( NV(i), i=1,MX1)

6. TOTAL NUMBER OF DELETED            MDEL - total number of deleted
    VAIABLES ?  (MDEL)                       variables.

     Message 7 appears if  MDEL > 0  .

7. THEIR INDEXES ?                    MDL(i) - indexes of deleted variables .
```

(MDL(i), i=1,MDEL)

8. TO WRITE T - HISTOGRAM : YES - 1, NO - 0 ? (JJT)	JJT=1 - information on T-statistic appears on the terminal and is stored in the file SYSOUT.DAT

Analogous messages appear also for F- and SS- statistics.

9. TO CONTINUE - 1, TO STOP - 0 (JKJ)	JKJ=1 - next step of stepwise procedure is carried out (go to (8)); JKJ=0 - end of subroutine.

Example of one session with program SYS: output file 'SYSOUT.DAT' with some comments

```
************************************************************

        SYSTEM FOR SIMULATION ANALYSIS, OCT 24,1985

   NUMBER OF OBSERVATIONS  ?
 12
```

Number of observations is 12.

```
   TOTAL NUMBER OF VARIABLES  ?
 31
```

Total number of variables is 31.

```
   IDENTIFICATION VECTOR :
  1  1  1  1  1  1  1  2  2  2  2  2  2  2  2  3  3  3  3  3
  3  3  3  4  4  4  4  4  4  4  5
```

Identification vector can separate variables into a given number of blocks. Analysis can be done independently for any of these groups.

```
************************************************************

   BLOCK FOR ANALYSIS ?
     CAUTION: TOTAL NUMBER OF VARIABLES IN THE BLOCK
     (INCLUDING TRANSFORMATIONS AND INTERACTIONS)
     MUST BE LESS THAN 60
 1
```

The influence of the first block on response function is analyzed on this stage.

```
        TABLE OF TRANSFORMATIONS
   1.   X:==X*X            5.   X:==LN(X)
   2.   X:==SQRT(ABS(X))   6.   X:==1/X
   3.   X:==ABS(X)         7.   X:==ARCTG(X)
   4.   X:==EXP(X)

 INPUT: VARIABLE NO,  TRANSFORMATION NO.
 COMMENT: IF YOU WANT TO STOP INPUT , PRESS    0 0
 1  4
```

Transformation number 4 (exp(x)) is made with the firs variable: X(32)=exp(X(1)),   32=M+1   M is total numbe of variables.

```
 0  0

     DEPENDENT VARIABLE  ?
 31
```

Variable 31 is the response function.

```
   WITH INTERACTIONS  ? ( YES - 1, NO - 0)
 0
```

Interactions are not included here.

```
 A NUMBER OF OBSERVATIONS      12

             TABLE OF VARIABLES
        FORMAL VARIABLE   1  REAL VARIABLE   1
        FORMAL VARIABLE   2  REAL VARIABLE   2
        FORMAL VARIABLE   3  REAL VARIABLE   3
        FORMAL VARIABLE   4  REAL VARIABLE   4
        FORMAL VARIABLE   5  REAL VARIABLE   5
        FORMAL VARIABLE   6  REAL VARIABLE   6
        FORMAL VARIABLE   7  REAL VARIABLE   7
        FORMAL VARIABLE   8  REAL VARIABLE  32
```

Variables which are to be analyzed on this stage.

Transformation of variable X(1) (X(32)) is also included in the first block.

```
 ********** STEPWISE PROCEDURE **********
VARIABLE     MEAN      STANDARD
   NO.                 DEVIATION
    1       0.           1.04447
    2       0.           1.04447
    3       0.           1.04447
    4       0.           1.04447
    5       0.           1.04447
    6       0.           1.04447
    7       0.           1.04447
    8       1.54308      1.22746
    9       2.16667     22.90561
```

Beginning of screening analysis.

Means and standard deviations of variables.

The response function here is the ninth variable.

```
CORRELATION MATRIX
ROW  1
   1.00000    0.00000   -0.00000    0.00000   -0.00000   -0.00000    0.00000    1.00000    0.24066
ROW  2
   0.00000    1.00000   -0.00000    0.00000   -0.00000   -0.00000    0.00000   -0.00000    0.37999
ROW  3
  -0.00000   -0.00000    1.00000   -0.00000   -0.00000   -0.00000   -0.00000    0.         0.41799
ROW  4
   0.00000    0.00000   -0.00000    1.00000    0.00000    0.00000    0.00000    0.00000    0.45852
ROW  5
  -0.00000   -0.00000   -0.00000    0.00000    1.00000    0.00000    0.00000    0.00000    0.42305
ROW  6
  -0.00000   -0.00000   -0.00000    0.00000    0.00000    1.00000   -0.00000    0.         0.44332
ROW  7
   0.00000    0.00000   -0.00000    0.00000    0.00000   -0.00000    1.00000    0.00000    0.08360
ROW  8
   1.00000   -0.00000    0.         0.00000    0.00000    0.         0.00000    1.00000    0.24066
ROW  9
   0.24066    0.37999    0.41799    0.45852    0.42305    0.44332    0.08360    0.24066    1.00000
```

Correlation matrix of input variables and response function. The part of this matrix is the identity matrix due to orthogonality of the design.
The last line is the correlation of the response with input variables.

```
NUMBER OF SELECTION    1
CODES
 0  0  0  0  0  0  0  0
```

All variables are free (no forced, no deleted).

```
 *****************  STEP  1  *****************
VARIABLE ENTERED..... 4
SUM OF SQUARES REDUCED IN THIS STEP....     1213.370
PROPORTION REDUCED IN THIS STEP........        0.210
CUMULATIVE SUM OF SQUARES REDUCED......     1213.370
CUMULATIVE PPOPORTION REDUCED..........        0.210  OF     5771.334
   MULTIPLE CORRELATION COEFFICIENT...    0.459
   F-VALUE FOR ANALYSIS OF VARIANCE...    2.662
   STANDARD ERROR OF ESTIMATE.........   21.349
 VARIABLE         REG. COEFF.      ERROR          T-VALUE
     4            10.05556         6.16304          1.632
  INTERCEPT        2.16667
-------------------------
```

Regression analysis after the first step.

```
 *****************  STEP  6  *****************
VARIABLE ENTERED..... 1
SUM OF SQUARES REDUCED IN THIS STEP....      334.259
PROPORTION REDUCED IN THIS STEP........        0.058
CUMULATIVE SUM OF SQUARES REDUCED......     5556.482
CUMULATIVE PPOPORTION REDUCED..........        0.963  OF     5771.334
   MULTIPLE CORRELATION COEFFICIENT...    0.981
   F-VALUE FOR ANALYSIS OF VARIANCE...   21.552
   STANDARD ERROR OF ESTIMATE.........    6.555
 VARIABLE         REG. COEFF.      ERROR          T-VALUE
     4            10.05556         1.89232          5.314
     6             9.72222         1.89232          5.138
     5             9.27778         1.89232          4.903
     3             9.16667         1.89232          4.844
     2             8.33333         1.89232          4.404
     1             5.27778         1.89232          2.789
  INTERCEPT        2.16667
-------------------------
```

Regression analysis after 6 steps. Six variables from the first block are entered.

Multiple correlation coefficient (0.981) is large enough. Student's T-statistics show possible significance of variables 1-6.
(Caution: distribution of T-value does not coincide with classical Student's distribution!)

```
 ***** END ***** STEPWISE PROCEDURE ***** END *****
```

End of the first stage of screening analysis.

```
    BLOCK FOR ANALYSIS ?
      CAUTION: TOTAL NUMBER OF VARIABLES IN THE BLOCK
      (INCLUDING TRANSFORMATIONS AND INTERACTIONS)
      MUST BE LESS THAN 60
 2
```

Now the influence of the second block is included.

```
      DEPENDENT VARIABLE  ?
 31
```

```
   WITH INTERACTIONS  ? ( YES - 1, NO - 0)
 1
```

Interactions of variables from the second block are included.

```
 A NUMBER OF OBSERVATIONS       12

             TABLE OF VARIABLES
         FORMAL VARIABLE   1  REAL VARIABLE   8
         FORMAL VARIABLE   2  REAL VARIABLE   9
         FORMAL VARIABLE   3  REAL VARIABLE  10
         FORMAL VARIABLE   4  REAL VARIABLE  11
         FORMAL VARIABLE   5  REAL VARIABLE  12
         FORMAL VARIABLE   6  REAL VARIABLE  13
         FORMAL VARIABLE   7  REAL VARIABLE  14
         FORMAL VARIABLE   8  REAL VARIABLE  15
         FORMAL VARIABLE   9  INTERACTION OF VARIABLES   8  AND   9
         FORMAL VARIABLE  10  INTERACTION OF VARIABLES   8  AND  10
         FORMAL VARIABLE  11  INTERACTION OF VARIABLES   8  AND  11
         FORMAL VARIABLE  12  INTERACTION OF VARIABLES   8  AND  12
         FORMAL VARIABLE  13  INTERACTION OF VARIABLES   8  AND  13
         FORMAL VARIABLE  14  INTERACTION OF VARIABLES   8  AND  14
         FORMAL VARIABLE  15  INTERACTION OF VARIABLES   8  AND  15
         FORMAL VARIABLE  16  INTERACTION OF VARIABLES   9  AND  10
         FORMAL VARIABLE  17  INTERACTION OF VARIABLES   9  AND  11
         FORMAL VARIABLE  18  INTERACTION OF VARIABLES   9  AND  12
         FORMAL VARIABLE  19  INTERACTION OF VARIABLES   9  AND  13
         FORMAL VARIABLE  20  INTERACTION OF VARIABLES   9  AND  14
         FORMAL VARIABLE  21  INTERACTION OF VARIABLES   9  AND  15
         FORMAL VARIABLE  22  INTERACTION OF VARIABLES  10  AND  11
         FORMAL VARIABLE  23  INTERACTION OF VARIABLES  10  AND  12
         FORMAL VARIABLE  24  INTERACTION OF VARIABLES  10  AND  13
         FORMAL VARIABLE  25  INTERACTION OF VARIABLES  10  AND  14
         FORMAL VARIABLE  26  INTERACTION OF VARIABLES  10  AND  15
         FORMAL VARIABLE  27  INTERACTION OF VARIABLES  11  AND  12
         FORMAL VARIABLE  28  INTERACTION OF VARIABLES  11  AND  13
         FORMAL VARIABLE  29  INTERACTION OF VARIABLES  11  AND  14
         FORMAL VARIABLE  30  INTERACTION OF VARIABLES  11  AND  15
         FORMAL VARIABLE  31  INTERACTION OF VARIABLES  12  AND  13
         FORMAL VARIABLE  32  INTERACTION OF VARIABLES  12  AND  14
         FORMAL VARIABLE  33  INTERACTION OF VARIABLES  12  AND  15
         FORMAL VARIABLE  34  INTERACTION OF VARIABLES  13  AND  14
         FORMAL VARIABLE  35  INTERACTION OF VARIABLES  13  AND  15
         FORMAL VARIABLE  36  INTERACTION OF VARIABLES  14  AND  15
```

Formal and real indexes of variables here differ from each other.

```
 ********** STEPWISE PROCEDURE **********
VARIABLE     MEAN     STANDARD
  NO.                 DEVIATION
   1       0.16667     1.02986
   2       0.          1.04447
   3       0.66667     0.77850
   4       0.          1.04447
   5       0.          1.04447
   6      -0.33333     0.98473
   7      -0.33333     0.98473
   8       0.          1.04447
   9      -0.16667     1.02986
  10       0.16667     1.02986
  11      -0.16667     1.02986
  12      -0.16667     1.02986
  13       0.16667     1.02986
  14       0.16667     1.02986
  15      -0.16667     1.02986
  16       0.33333     0.98473
  17       0.          1.04447
  18       0.33333     0.98473
  19      -0.33333     0.98473
  20       0.          1.04447
  21       0.          1.04447
  22       0.          1.04447
  23       0.          1.04447
  24       0.          1.04447
  25      -0.33333     0.98473
```

```
   26       0.          1.04447
   27       0.          1.04447
   28       0.          1.04447
   29       0.          1.04447
   30       0.          1.04447
   31      -0.33333     0.98473
   32      -0.33333     0.98473
   33       0.          1.04447
   34       0.          1.04447
   35      -0.33333     0.98473
   36       0.          1.04447
   37       2.16667    22.90561
NUMBER OF SELECTION    1
CODES
 0  0  0  1  1  0  0  0  0  0
 0  0  0  0  0  0  0  0  0  0
 0  0  0  0  0  0  0  0  0  0
 0  0  0  0  0  0
```

Formal variables 4, 5 (real variables 11, 12) are forced into regression.

```
 ****************  STEP  2  ****************
VARIABLE ENTERED..... 5
SUM OF SQUARES REDUCED IN THIS STEP....      715.593
PROPORTION REDUCED IN THIS STEP........        0.124
CUMULATIVE SUM OF SQUARES REDUCED......     3766.298
CUMULATIVE PPOPORTION REDUCED..........        0.653  OF     5771.334
   MULTIPLE CORRELATION COEFFICIENT...    0.808
   F-VALUE FOR ANALYSIS OF VARIANCE...    8.453
   STANDARD ERROR OF ESTIMATE.........   14.926
 VARIABLE        REG. COEFF.      ERROR         T-VALUE
      4          15.94445        4.30873         3.700
      5           7.72222        4.30873         1.792
  INTERCEPT       2.16667
--------------------------
 ***** END ***** STEPWISE PROCEDURE ***** END *****
```

They explain 65.3% of variance. That is why variables 1 - 12 are to be analyzed together.

```
    IDENTIFICATION VECTOR :
   1  1  1  1  1  1  1  1  1  1  1  1  2  2  2  2  2  2  2  2
   2  2  2  2  2  2  2  2  2  2  3
```

New identification vector: variables 1 - 12 are in the first block.

```
************************************************************

    BLOCK FOR ANALYSIS ?
      CAUTION: TOTAL NUMBER OF VARIABLES IN THE BLOCK
      (INCLUDING TRANSFORMATIONS AND INTERACTIONS)
      MUST BE LESS THAN 60
 1

      DEPENDENT VARIABLE  ?
 31

    WITH INTERACTIONS  ? ( YES - 1, NO - 0)
 0
 A NUMBER OF OBSERVATIONS       12

              TABLE OF VARIABLES
         FORMAL VARIABLE   1  REAL VARIABLE   1
         FORMAL VARIABLE   2  REAL VARIABLE   2
         FORMAL VARIABLE   3  REAL VARIABLE   3
         FORMAL VARIABLE   4  REAL VARIABLE   4
         FORMAL VARIABLE   5  REAL VARIABLE   5
         FORMAL VARIABLE   6  REAL VARIABLE   6
         FORMAL VARIABLE   7  REAL VARIABLE   7
         FORMAL VARIABLE   8  REAL VARIABLE   8
         FORMAL VARIABLE   9  REAL VARIABLE   9
         FORMAL VARIABLE  10  REAL VARIABLE  10
         FORMAL VARIABLE  11  REAL VARIABLE  11
         FORMAL VARIABLE  12  REAL VARIABLE  12

 ********** STEPWISE PROCEDURE **********
VARIABLE     MEAN     STANDARD
```

```
   NO.              DEVIATION
    1      0.          1.04447
    2      0.          1.04447
    3      0.          1.04447
    4      0.          1.04447
    5      0.          1.04447
    6      0.          1.04447
    7      0.          1.04447
    8      0.16667     1.02986
    9      0.          1.04447
   10      0.66667     0.77850
   11      0.          1.04447
   12      0.          1.04447
   13      2.16667    22.90561
NUMBER OF SELECTION    1
CODES
 0  0  0  0  0  0  2  2  2  2
 0  0
```

Variables 7 - 10 are deleted from equation.

```
 *****************  STEP  8  *****************
VARIABLE ENTERED.....12
SUM OF SQUARES REDUCED IN THIS STEP....        56.004
PROPORTION REDUCED IN THIS STEP........         0.010
CUMULATIVE SUM OF SQUARES REDUCED......      5710.720
CUMULATIVE PPOPORTION REDUCED..........         0.989  OF      5771.334
   MULTIPLE CORRELATION COEFFICIENT...    0.995
   F-VALUE FOR ANALYSIS OF VARIANCE...   35.330
   STANDARD ERROR OF ESTIMATE.........    4.495
 VARIABLE         REG. COEFF.       ERROR           T-VALUE
    11             5.03509         1.99695           2.521
     6             8.73100         1.42766           6.116
     4             7.38597         1.63050           4.530
     5             6.60819         1.63050           4.053
     3             8.47953         1.51792           5.586
     2             6.65497         1.45837           4.563
     1             3.59942         1.45837           2.468
    12             2.97368         1.78613           1.665
  INTERCEPT        2.16667
-------------------------
```

Eight variables explain 98.9 % of variance, but they essentially differ in significance (see T-values). Therefore it is naturally to suggest that deleting some of them will not deteriorate approximation (secondary) model essentially.

```
 ********* DELETING PROCEDURE *********

 *****************  STEP  7  *****************
VARIABLE ENTERED..... 1
SUM OF SQUARES REDUCED IN THIS STEP....       142.091
PROPORTION REDUCED IN THIS STEP........         0.025
CUMULATIVE SUM OF SQUARES REDUCED......      5654.715
CUMULATIVE PPOPORTION REDUCED..........         0.980  OF      5771.334
   MULTIPLE CORRELATION COEFFICIENT...    0.990
   F-VALUE FOR ANALYSIS OF VARIANCE...   27.708
   STANDARD ERROR OF ESTIMATE.........    5.400
 VARIABLE         REG. COEFF.       ERROR           T-VALUE
    11             4.29167         2.33806           1.836
     6             9.72222         1.55871           6.237
     4             8.62500         1.74269           4.949
     5             7.84722         1.74269           4.503
     3             7.73611         1.74269           4.439
     2             6.90278         1.74269           3.961
     1             3.84722         1.74269           2.208
  INTERCEPT        2.16667
-------------------------
```

```
 ********* DELETING PROCEDURE *********

 *****************  STEP  6  *****************
VARIABLE ENTERED..... 1
SUM OF SQUARES REDUCED IN THIS STEP....       334.259
PROPORTION REDUCED IN THIS STEP........         0.058
```

```
CUMULATIVE SUM OF SQUARES REDUCED......      5556.483
CUMULATIVE PPOPORTION REDUCED..........         0.963  OF      5771.334
   MULTIPLE CORRELATION COEFFICIENT...    0.981
   F-VALUE FOR ANALYSIS OF VARIANCE...   21.552
   STANDARD ERROR OF ESTIMATE.........    6.555
 VARIABLE        REG. COEFF.      ERROR          T-VALUE
     4           10.05556        1.89232          5.314
     6            9.72222        1.89232          5.138
     5            9.27778        1.89232          4.903
     3            9.16667        1.89232          4.844
     2            8.33333        1.89232          4.404
     1            5.27778        1.89232          2.789
  INTERCEPT       2.16667
-------------------------
 ***** END ***** STEPWISE PROCEDURE ***** END *****
```

Two variables (11, 12) are deleted from regression without essential increasing of the sum of squares. The most significant variables are variables 1 - 6.

Here is the listing of subroutine FORECAST.

```
                                   *** MODEL ANALYSIS AND FORECASTING ***

                                          REGRESSION EQUATION
--------------------------------------------------------------------------------------------------------------
 NO. SIGNIFICANT VARIABLES          RESPONSE              S. D.  CORRELATION MATRIX OF REG                      RESSION
--------------------------------------------------------------------------------------- COEFFICIENTS (PERCENTAGE)

                          DEP. VAR. X( 31 )=   2.167

  1  VARIABLE     4          + 10.056 * X(  4 )         1.892    100     0     0     0     0     0
                             (  5.314)

  2  VARIABLE     6          +  9.722 * X(  6 )         1.892      0   100     0     0     0     0
                             (  5.138)

  3  VARIABLE     5          +  9.278 * X(  5 )         1.892      0     0   100     0     0     0
                             (  4.903)

  4  VARIABLE     3          +  9.167 * X(  3 )         1.892      0     0     0   100     0     0
                             (  4.844)

  5  VARIABLE     2          +  8.333 * X(  2 )         1.892      0     0     0     0   100     0
                             (  4.404)

  6  VARIABLE     1          +  5.278 * X(  1 )         1.892      0     0     0     0     0   100
                             (  2.789)
```

Such correlation matrix (in %) is due to orthogonality of the design.

```
--------------------------------------------------------------------------------------------------------------
                    TEST STATISTICS
      CUMULATIVE PROPORTION REDUCED.......   0.963
      MULTIPLE CORRELATION COEFFICIENT....   0.981
      STANDARD ERROR ESTIMATE (SIGMA).....   6.555
      F-VALUE FOR ANALYSIS OF VARIANCE....  21.552
--------------------------------------------------------------------------------------------------------------
```

Main statistics

```
                              *** MODEL ESTIMATION ***
--------------------------------------------------------------------------------------------------------------
 NO. DEPENDENT VARIABLE  RESPONSE         RESIDUALS        STANDARD     RATIO       COMMENTS
         X( 31 )         PREDICTION   ABSOLUTE PERCENTAGE DEVIATION RESID./S.D.
--------------------------------------------------------------------------------------------------------------
  1      -50.1667        -49.6667      -0.5000      1.0    4.6352   -0.1079
  2       29.8333         35.6667      -5.8333     19.6    4.6352   -1.2585
  3       25.8333         23.3333       2.5000      9.7    4.6352    0.5393
  4       20.1667         18.7778       1.3889      6.9    4.6352    0.2996
  5       12.1667          5.6667       6.5000     53.4    4.6352    1.4023
  6        4.1667          6.6667      -2.5000     60.0    4.6352   -0.5393
  7       -7.8333        -10.1111       2.2778     29.1    4.6352    0.4914
  8      -25.1667        -20.5556      -4.6111     18.3    4.6352   -0.9948
  9       -0.8333         -3.0000       2.1667    260.0    4.6352    0.4674
 10       -1.1667         -4.1111       2.9444    252.4    4.6352    0.6352
```

Table of residuals

```
 11      -2.8333        5.4444        -8.2778     292.2    4.6352  -1.7858
 12      21.8333       17.8889         3.9444      18.1    4.6352   0.8510
-----------------------------------------------------------------------------------------------------------------
 * -OUTLIER WITH P=0.05
 ** -OUTLIER WITH P=0.01
-----------------------------------------------------------------------------------------------------------------
 ATTEMPT      1
                    *****  FORECASTING  *****
  X( 1) =    0.                                                 Forecast is made: X1=0, ... , X12=1
  X( 2) =    0.                                                 ===) y= 11.8899
  X( 3) =    0.
  X( 4) =    0.
  X( 5) =    0.
  X( 6) =    1.0000
  X( 7) =    1.0000
  X( 8) =    1.0000
  X( 9) =    1.0000
  X( 10) =   1.0000
  X( 11) =   1.0000
  X( 12) =   1.0000
 FORECASTED VALUE OF DEPENDENT VARIABLE IS     11.8889    WITH  S.D.     6.823
                      *****  END  *****  FORECASTING  *****  END  *****
******** STEPWISE REGRESSION WITH PERMUTATIONS ********        Subroutine STRAN (stepwise regression with permutations)
************************    ************************           is executed. Regression model with 13 variables
0NUMBER OF OBSERVATIONS   12                                   is analyzed (here variables 1 - 12 are independent,
 NUMBER OF VARIABLES      13                                   variable 13 is response).
*************************************
 SCALE FOR A HISTOGRAM:A POINT CORRESPONDS TO 1 VALUE/S/       Scale and number of intervals for a histogram.
 NUMBER OF INTERVALS FOR A HISTOGRAM  5
 MAX.NUMBER OF STEPS  5
 NUMBER OF PERMUTATIONS  30                                    Number of permutations on each step is 30.
************************    ************************
 TOTAL NUMBER OF DELETED VARIABLES-?
  2
*************************************
 THEIR INDEXES-?
  1  2                                                         Variables 1, 2 are deleted from regression.
************************    ************************
************************    ************************
  ENTERED VARIABLES AND THEIR T-STATISTICS,STEP=  1
   11
    3.35
*************************************
 STEP  1
 VARIABLE ENTERED 11                                           Variable 11 is entered on the first step, its T-statistic
*************************************                          is T0= 3.35
 BASIC T-STATISTIC     3.35
 T-MEAN AND ST.DEVIATION    0.5943   2.3092                    Mean and standard deviation of T-statistic after
 MIN. AND MAX.T-STATISTICS AFTER PERMUTATION                   permutation: 0.5943 and 2.3092.
   -2.84   4.40                                                Minimal and maximal T-statistics after permutation.
 HISTOGRAM FOR T-STATISTIC
    -2.8446    -1.3949  ...........*                           Histogram for T-statistic: one point corresponds
    -1.3949     0.0549  *                                      to one value in the interval (according to
     0.0549     1.5046  *                                      assigned scale).
     1.5046     2.9544  ..................*
     2.9544     4.4042  .*
 % OF T,FOR WHICH ABS(T) IS LESS THAN ABS(T0)   96.67
************************    ************************


*************************************
 BASIC F-STATISTIC     11.213
 F-MEAN AND ST.DEVIATION      5.508      3.111
 MIN. AND MAX.F-STATISTICS AFTER PERMUTATION
     2.588    19.397
 HISTOGRAM FOR F-STATISTIC
     2.5884     5.9501  .....................*                 Analogous histograms are for F- and SS-statistics.
     5.9501     9.3117  ........*
     9.3117    12.6733  *
    12.6733    16.0350  *
    16.0350    19.3966  .*
 % OF F,LESS THAN F0   96.67
```

```
************************************
BASIC SS-PROPORTION REDUCED  0.5286
SS-MEAN AND ST.DEVIATION    0.3378   0.0938
MIN. AND MAX.SS-PROPORTIONS AFTER PERMUTATION
 0.2056 0.6598
HISTOGRAM FOR SS-STATISTIC
    0.2056     0.2965  ...........*
    0.2965     0.3873  ............*
    0.3873     0.4781  ......*
    0.4781     0.5690  *
    0.5690     0.6598  .*
% OF SS,LESS THAN SS0   96.67


************************    ************************
************************    ************************
************************    ************************
 ENTERED VARIABLES AND THEIR T-STATISTICS,STEP=  2
  11   6
   4.16   2.54
************************************
STEP  2
VARIABLE ENTERED  6
************************************
BASIC T-STATISTIC     2.54
T-MEAN AND ST.DEVIATION   -0.9889   1.9952
MIN. AND MAX.T-STATISTICS AFTER PERMUTATION
  -3.86   3.32
HISTOGRAM FOR T-STATISTIC
   -3.8553    -2.4197  .......*
   -2.4197    -0.9840  .............*
   -0.9840     0.4516  .*
    0.4516     1.8873  .......*
    1.8873     3.3229  ..*
% OF T,FOR WHICH ABS(T) IS LESS THAN ABS(T0)   76.67
***********************    ************************
```

Variables that are entered into regression (basic model) after 2 steps. Variable 6 is entered into regression on the second step.

Here is the information concerning the statistics on the second step.

```
************************************
BASIC F-STATISTIC     11.871
F-MEAN AND ST.DEVIATION      9.997      4.041
MIN. AND MAX.F-STATISTICS AFTER PERMUTATION
     0.       20.811
HISTOGRAM FOR F-STATISTIC
    0.          4.1622  .*
    4.1622      8.3244  ..........*
    8.3244     12.4867  .............*
   12.4867     16.6489  ...*
   16.6489     20.8111  ...*
% OF F,LESS THAN F0   76.67
***********************    ************************


************************************
BASIC SS-PROPORTION REDUCED  0.1965
SS-MEAN AND ST.DEVIATION    0.1495   0.0647
MIN. AND MAX.SS-PROPORTIONS AFTER PERMUTATION
 0.     0.2936
HISTOGRAM FOR SS-STATISTIC
    0.         0.0587  .*
    0.0587     0.1174  ..........*
    0.1174     0.1762  ...........*
    0.1762     0.2349  .....*
    0.2349     0.2936  ...*
% OF SS,LESS THAN SS0   76.67
```

The following example shows the potentialities of the subroutine FORECAST when transformations and interactions are included into regression equation.

```
************************    ************************

   IDENTIFICATION VECTOR :
  1  1  1  1  1  1  1  2  2  2  2  2  2  2  2  2  2  2  2  2
  2  2  2  2  2  2  2  2  2  2  3


************************************************************

   BLOCK FOR ANALYSIS ?
     CAUTION: TOTAL NUMBER OF VARIABLES IN THE BLOCK
     (INCLUDING TRANSFORMATIONS AND INTERACTIONS)
     MUST BE LESS THAN 60
1
        TABLE OF TRANSFORMATIONS
   1.   X:==X*X             5.   X:==LN(X)
   2.   X:==SQRT(ABS(X))    6.   X:==1/X
   3.   X:==ABS(X)          7.   X:==ARCTG(X)
   4.   X:==EXP(X)

INPUT: VARIABLE NO,  TRANSFORMATION NO.
COMMENT: IF YOU WANT TO STOP INPUT , PRESS    0 0
1  4
0  0

     DEPENDENT VARIABLE  ?
31

   WITH INTERACTIONS  ? ( YES - 1, NO - 0)
1
A NUMBER OF OBSERVATIONS      12

            TABLE OF VARIABLES
        FORMAL VARIABLE   1  REAL VARIABLE   1
        FORMAL VARIABLE   2  REAL VARIABLE   2
        FORMAL VARIABLE   3  REAL VARIABLE   3
        FORMAL VARIABLE   4  REAL VARIABLE   4
        FORMAL VARIABLE   5  REAL VARIABLE   5
        FORMAL VARIABLE   6  REAL VARIABLE   6
        FORMAL VARIABLE   7  REAL VARIABLE   7
        FORMAL VARIABLE   8  REAL VARIABLE  32
        FORMAL VARIABLE   9  INTERACTION OF VARIABLES   1  AND   2
        FORMAL VARIABLE  10  INTERACTION OF VARIABLES   1  AND   3
        FORMAL VARIABLE  11  INTERACTION OF VARIABLES   1  AND   4
        FORMAL VARIABLE  12  INTERACTION OF VARIABLES   1  AND   5
        FORMAL VARIABLE  13  INTERACTION OF VARIABLES   1  AND   6
        FORMAL VARIABLE  14  INTERACTION OF VARIABLES   1  AND   7
        FORMAL VARIABLE  15  INTERACTION OF VARIABLES   2  AND   3
        FORMAL VARIABLE  16  INTERACTION OF VARIABLES   2  AND   4
        FORMAL VARIABLE  17  INTERACTION OF VARIABLES   2  AND   5
        FORMAL VARIABLE  18  INTERACTION OF VARIABLES   2  AND   6
        FORMAL VARIABLE  19  INTERACTION OF VARIABLES   2  AND   7
        FORMAL VARIABLE  20  INTERACTION OF VARIABLES   3  AND   4
        FORMAL VARIABLE  21  INTERACTION OF VARIABLES   3  AND   5
        FORMAL VARIABLE  22  INTERACTION OF VARIABLES   3  AND   6
        FORMAL VARIABLE  23  INTERACTION OF VARIABLES   3  AND   7
        FORMAL VARIABLE  24  INTERACTION OF VARIABLES   4  AND   5
        FORMAL VARIABLE  25  INTERACTION OF VARIABLES   4  AND   6
        FORMAL VARIABLE  26  INTERACTION OF VARIABLES   4  AND   7
        FORMAL VARIABLE  27  INTERACTION OF VARIABLES   5  AND   6
        FORMAL VARIABLE  28  INTERACTION OF VARIABLES   5  AND   7
        FORMAL VARIABLE  29  INTERACTION OF VARIABLES   6  AND   7
```

Formal variable 8 - transformation of the first var.
Formal variables 9 - 29 are interactions of seven variables belonging to the first block which is analyzed.

```
 ********** STEPWISE PROCEDURE **********
VARIABLE     MEAN     STANDARD
  NO.                 DEVIATION
   1         0.         1.04447
   2         0.         1.04447
```

```
   3       0.          1.04447
   4       0.          1.04447
   5       0.          1.04447
   6       0.          1.04447
   7       0.          1.04447
   8       1.54308     1.22746
   9       0.          1.04447
  10       0.          1.04447
  11       0.          1.04447
  12       0.          1.04447
  13       0.          1.04447
  14       0.          1.04447
  15       0.          1.04447
  16       0.          1.04447
  17       0.          1.04447
  18       0.          1.04447
  19       0.          1.04447
  20       0.          1.04447
  21       0.          1.04447
  22       0.          1.04447
  23       0.          1.04447
  24       0.          1.04447
  25       0.          1.04447
  26       0.          1.04447
  27       0.          1.04447
  28       0.          1.04447
  29       0.          1.04447
  30       2.16667    22.90561
NUMBER OF SELECTION    1
CODES
 0  0  0  0  0  0  0  1  1  1                                  Formal variables 8 - 10 are forced into equation.
 0  0  0  0  0  0  0  0  0  0
 0  0  0  0  0  0  0  0  0

 *****************  STEP  7  *****************
VARIABLE ENTERED..... 2
SUM OF SQUARES REDUCED IN THIS STEP....       234.224
PROPORTION REDUCED IN THIS STEP........         0.041
CUMULATIVE SUM OF SQUARES REDUCED......      5662.125
CUMULATIVE PPOPORTION REDUCED..........         0.981  OF      5771.334
   MULTIPLE CORRELATION COEFFICIENT...    0.990
   F-VALUE FOR ANALYSIS OF VARIANCE...   29.627
   STANDARD ERROR OF ESTIMATE.........    5.225
 VARIABLE        REG. COEFF.       ERROR          T-VALUE
     9           -7.61869        1.70167          -4.477              Seven variables are entered into regression.
     8            9.87473        1.64755           5.994
    10           -6.10227        1.73924          -3.509
    20          -17.84344        2.03389          -8.773
    15          -13.34975        1.67873          -7.952
    29           14.48738        2.18110           6.642
     2            5.18056        1.76872           2.929
  INTERCEPT     -13.07085
---------------------------                              --------------------------------------
 ***** END ***** STEPWISE PROCEDURE ***** END *****
```

*** MODEL ANALYSIS AND FORECASTING ***

REGRESSION EQUATION

```
----------------------------------------------------------------------------------------------------------------------------
 NO. SIGNIFICANT VARIABLES            RESPONSE              S. D.  CORRELATION MATRIX OF REGRESSION COEFFICIENTS (PERCENTAGE)
----------------------------------------------------------------------------------------------------------------------------

                                                                 Here is the secondary model:
                               DEP. VAR. X( 31 ):  -13.071
                                                                                                        X31 = -13.071 -
  1  INTER. VAR.  1 AND  2  -  7.619 * X( 1)*X( 2)      1.702     100   -1    -5    23   -12    27    18
                            ( -4.477)                                                                   - 7.619 * X1 * X2 +

  2  TRANSFORM. OF VAR.  1   +  9.875 * EXP(X( 1))       1.648      -1  100   -20   -49    19    42    -8
                            (  5.994)                                                                   + 9.875 * exp( X1 ) -
```

3	INTER. VAR. 1 AND 3	- 6.102 * X(1)*X(3) (-3.509)	1.739	-5	-20	100	26	7	-36	27		- 6.102 * X1 * X3 -
4	INTER. VAR. 3 AND 4	- 17.843 * X(3)*X(4) (-8.773)	2.034	23	-49	26	100	-3	-37	31		- 17.843 * X3 * X4 -
5	INTER. VAR. 2 AND 3	- 13.350 * X(2)*X(3) (-7.952)	1.679	-12	19	7	-3	100	-26	-9		- 13.350 * X2 * X3 +
6	INTER. VAR. 6 AND 7	+ 14.487 * X(6)*X(7) (6.642)	2.181	27	42	-36	-37	-26	100	14		+ 14.487 * X6 * X7 +
7	VARIABLE 2	+ 5.181 * X(2) (2.929)	1.769	18	-8	27	31	-9	14	100		+ 5.181 * X2

(for example, formal variable 9 = X1 * X2,
formal variable 8 = exp (X1) etc.)

TEST STATISTICS
CUMULATIVE PROPORTION REDUCED....... 0.981
MULTIPLE CORRELATION COEFFICIENT.... 0.990
STANDARD ERROR ESTIMATE (SIGMA)..... 5.225
F-VALUE FOR ANALYSIS OF VARIANCE.... 29.627

*** MODEL ESTIMATION ***

NO.	DEPENDENT VARIABLE X(31)	RESPONSE PREDICTION	RESIDUALS ABSOLUTE	PERCENTAGE	STANDARD DEVIATION	RATIO RESID./S.D.	COMMENTS
1	-50.1667	-45.0455	-5.1212	10.2	3.9386	-1.3003	
2	29.8333	34.1414	-4.3081	14.4	3.4933	-1.2332	
3	25.8333	28.4444	-2.6111	10.1	3.9908	-0.6543	
4	20.1667	20.1010	0.0657	0.3	3.3109	0.0198	
5	12.1667	13.9647	-1.7980	14.8	4.8345	-0.3719	
6	4.1667	0.5707	3.5960	86.3	4.2905	0.8381	
7	-7.8333	-9.3586	1.5253	19.5	3.4933	0.4366	
8	-25.1667	-23.3687	-1.7980	7.1	4.8345	-0.3719	
9	-0.8333	-1.5455	0.7121	85.5	3.9386	0.1808	
10	-1.1667	-4.7626	3.5960	308.2	4.2905	0.8381	
11	-2.8333	-7.2424	4.4091	155.6	3.7778	1.1671	
12	21.8333	20.1010	1.7323	7.9	3.3109	0.5232	

* -OUTLIER WITH P=0.05
** -OUTLIER WITH P=0.01

ATTEMPT 1

***** FORECASTING *****

X(1) = 1.0000
X(2) = 1.0000
X(3) = 0.
X(4) = 0.
X(5) = 0.
X(6) = 0.
X(7) = 0.
FORECASTED VALUE OF DEPENDENT VARIABLE IS 11.3333 WITH S.D. 6.127
***** END ***** FORECASTING ***** END *****

Forecast is made: notice that only the values of the basic variables are to be chosen (values of transformations and interactions are calculated by the program).

2 SYSTEM OF ECOLOGICAL FORECASTING
(SEF)

User's Manual

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The authors are very grateful to V. Fedorov and T. Munn for their constructive advice during the preparation of this manual.

1. Introduction

The System of Ecological Forecasting (SEF), created in the All-Union Research Institute for Systems Studies (USSR) is a set of programs in Fortran 77. It provides an opportunity to analyze and forecast (up to 200 years) the state of the environment on a regional scale.

A region is defined as a landscape with linear extension >= 50 km, situated in one of the geographical belts which has more or less homogeneous ecological characteristics, including types of soil, lithology, relief and vegetation. A region contains three subregions which are described separately:

1. non-cultivated lands;
2. arable lands;
3. flood-lands.

The environment is described by an index of soil fertility, plant biomass, surface and ground runoffs, pollutant levels for different ecosystem components, etc. (For a list of parameters see Appendix D.) SEF can be used to analyze climatic trends and anthropogenic impacts on nature, such as pollution, fertilization, lumbering, etc., which may occur in different development scenarios. (See the list of admissible scenarios in Chapter 2.2.4.)

SEF is based on a set of dynamics models of natural components described in [1]. The essential features of SEF are rather simple system adjustments for any given region (adjustment time 1-5 min) and integrity in region representation. SEF can be easily used both by managers and experts; also, it can be used in learning and business games.

2. How SEF is Used

2.1. General Notes

SEF does not demand any special background in programming. User-system dialogue is realized in the form of answers to the system's requests (e.g., see Appendix F), which are of two types:

1. menu, i.e., list of options; user is supposed to point out any available option number;
2. variable value request consisting of variable verbal description and current value in brackets; the user should input new value or press <RETURN> if he doesn't want to change anything.

In case of an inconsistent input, the system ignores it, displaying an error message and repeating the request. If an input value is beyond the variable's prescribed boundaries, the system enters this value but displays a warning message.

The system has so-called "shadow" dialogue commands. This enables the user to manipulate the system and receive necessary information. A description of these commands follows (see also Appendix B):

<?> - "help": this command provides the user with brief additional information about the variable under consideration;

<!> - "show system state": the response is a table with current values of the major system variables. The variables' units are indicated in brackets. If the "protocol" file (see below) is opened at this moment, the system state is saved by entering it into this file.

SYSTEM STATE			
land type	natur	agricul	hydromph.
proportion (%)	70.0452	20.0000	9.9548
humidity	115.56	115.06	118.59
climate index	2.542	0.	2.759
pollution index	1.00000	1.00000	1.00000
surf. erosn.(mm)	0.0241	0.2075	3.897
wind erosn.(mm)	0.0229	0.1523	0.0174
incr.soil.q.indx	0.	0.	0.
vegetation type	3	2	3
biomass (t/ha)	415.34	0.	336.67
soil prod.(t/ha)	0.	0.	0.
mort biom.(t/ha)	0.646	0.	0.689
soil salinity(%)	0.0439	0.0360	0.1240
soil index	4.080	4.000	3.046

climate: temper. = 22.500/o/
precipit. = 1705.04/mm/
lakes (%) = 0
tot.dissect.(km/km2) = 5.0273; dissect.by rivers(km/km2) = 3.0164;
riv.wat.sal.(g/l) = 0.047; wat.sal.1gr(g/l) = 0.337; wat.sal.2gr(g/l) = 0.153

For more information on variables, see Appendix C.

The work continues by answering the question, "Do you want to keep the System State (y/n)?" If you answered "y", SEF asks one more question: "What is the name of this System State?" The system saves this "System State" in the file "sys.st" under the name given in your answer. This file contains all

System States which you wanted to save during the course of a session. It is necessary to remember that at the beginning of the next session the previous file "sys.st" is removed.

<^D> - "reverse" (Control D): this command returns you to the previous request.

<#file> - "open protocol": after this command the system-user dialogue will be saved in a user-specified file. If the filename is omitted, the system asks for it.

<#!> - "show protocol": enables the user to look through the protocol.

<##> - "close protocol": dialogue recording ceases and the file of protocol is closed.

<@file> - "external input": with this command, the specified file becomes the system's input. At this moment the interactive regime is canceled until the end of the file or until an error condition occurs. In the latter case the error message is displayed and the appropriate request is repeated. In both cases the input is switched back to the terminal being operated by the user. Such a command can also be the last command in the file itself. In this case the input will be switched from this file to another one. If the file "ans.inp" exists, the system reads the required information from this file immediately after initiation. If the user is aware of the sequence of the system questions, it is possible on one line to obtain a reply to a number of questions, succesive answers being separated by a semicolon (;). In this case the system is silent until the end of the input line or until an error occurs.

< $ TABLE -(year 1,value 1, ... ,year i,value i,...)>: this command enables the variable to be specified as a piecewise linear interpolation. This command is available only during the scenario specification stage. If a current year of simulation is beyond the indicated years, the command will not affect the appropriate variable.

2.2. Session Stages

Every scenario involves seven steps as follows:

1. system start
2. specify region
3. adjustment of the model to regional data
4. specify scenario
5. set time interval and simulation run
6. observe and output results
7. choose next stage.

The session always starts with stage 1, although the sequence of other stages can be chosen in any convenient order. A few technical remarks should be mentioned:

- When you specify the value of a certain variable, make certain that it is measured in the units indicated in the [prompt];
- When a list of options is displayed, the user is expected to input a number;
- In the case of an erroneous input, the system will repeat its question. An example of an interactive session is presented in Appendix F.

2.2.1. How to Start the Session

In running the model type "sef.e" on your terminal, if you want to use input from some file instead of input from the terminal (@file option), you must "tell" the system the identifiers of your terminal using the command "tty > wfil" (for UNIX operating system) before you begin the run..

The session opens with the following message:

```
|
| Y O U   A R E   W E L C O M E   T O   T H E   S Y S T E M   F O R
|
|         E C O L O G I C A L   F O R E C A S T I N G
|
|
| ******************************************************
|
|      IN THE COURSE OF INTERACTION WITH SEF
|
| 1. Use '?' if you need additional information.
| 2. Use '!' if you need to see the 'SYSTEM STATE'.
| 3. Use 'control-D' if you need to return to the previous
|     point of interaction.
| 4. If the SEF question has a current value of
|     "variable" in the brackets {...} you may use
|     'RETURN' if you do not need to change a value.
| 5. See details in SEF User's Manual and SEF Model
|     Description.
| ******************************************************
|
|    System loading - PLEASE WAIT - System loading
|
```

All program messages apearing in this manual which are shown on the display screen are marked with a | sign in the first column (except Appendix F).

2.2.2. Specify Region

The stage opens with a heading

```
|
|              S P E C I F Y   R E G I O N
|
```

The user will be requested to specify some characteristics of the region that he has chosen. The input values should be long-term averages rather than current values. If the user is interested in the behavior of the system under unusual circumstances, he should specify all the external disturbances at the stage of scenario specification.

There are several ways in which the user may specify the region. These are listed in the first display of this stage:

```
|
|    MODES OF REGION SPECIFICATION
|
| 1 - Detailed
| 2 - Brief
| 3 - Geographical
| 4 - Direct
| 5 - Previous region
| 6 - Adjusted previous region
| 7 - CONTINUE
|
```

Options 1-5 are closed in the sense that after the user has reached the end of any path, the system returns to the initial display so that if any alterations are necessary the user may go through the procedure again. Options 6,7 lead to the next stage of the session, named "Scenario specification."

2.2.2.1. Option 1: Detailed Specification

The user is requested to specify detailed regional characteristics by answering the system's prompts.

The procedure is divided into several substages, ending with a question:

```
|
| any alterations ? (y/n) -
|
```

If the answer is "y", the user is offered a chance to input corrections within the current portion of the list, or he can return to the previous request using < ^D >.

For a better understanding of some characteristics, see Figures 4 and 5.

The full list of specifications is as follows. The number in brackets is the current value of the specified parameter. If the user does not want to change it, he can go to the next question by pressing <RETURN>:

```
|
| depth of 1-st water table (m) {0.150e+02} -
|
| depth of 2-nd water table (m) {0.410e+02} -
|
| depth of 1-st aquifer (m) {0.200e+02} -
|
| depth of 2-nd aquifer (m) {0.510e+02} -
|
| depth of 2-nd water-bearing horizon roof (m) {0.410e+02} -
|
| filtration from transit rivers (mm) {0.e+00} -
|
| total dissection (km/km2) {0.290e+01} -
|
| dissection by transit rivers (km/km2) {0.290e+00} -
|
| maximum depth of local valleys (m) {0.500e+02} -
|
| average depth of local valleys (m) {0.800e+01} -
|
| share of total area (%), covered with lakes {0.250e+01} -
|
| average surface slope (tangent) {0.300e-03} -
|
| average width of valleys (m) {0.160e+02} -
|
| downward infiltration of ground-water (%) {0.750e+01} -
|
| infiltration of ground-water, 2-nd layer, into rivers (%) {0.469e+01} -
|
| ground-water salinity (gr/l) {0.270e+00} -
|
| deep ground-water salinity (gr/l) {0.270e+00} -
|
| maximum of monthly surface flow (share of total flow) {0.550e+00} -
|
| any alterations ? (y/n) - n
|
```

Second substage. The user is expected to specify the biotic parameters by three types of lands:

```
|
| biomass, average (t/ha-yr)
|
|
| 1 - non-cultivated lands {0.400e+03} -
|
| 2 - arable lands  {0.e+00} -
|
| 3 - flood-lands {0.300e+03} -
|
| mortmass, average (t/ha-yr)
|
|
| 1 - non-cultivated lands {0.220e+02} -
|
| 2 - arable lands  {0.300e+01} -
|
| 3 - flood-lands {0.220e+02} -
|
| index of soil
|
|
| 1 - non-cultivated lands {0.850e+01} -
|
| 2 - arable lands  {0.600e+01} -
|
| 3 - flood-lands {0.500e+01} -
|
```

The soil index is a measure of soil fertility. The lowest value of the index is 0, the highest is 20. The following approximate estimates may prove helpful: podzols - 4; grey forest soil - 9; siliceous soils - 9; brown, savanna soil - 12/15; black soil - 18/19.

```
|
| soil salinity (%)
|
|
| 1 - non-cultivated lands {0.700e-01} -
|
| 2 - arable lands  {0.700e-01} -
|
```

Third substage. It should be noted here that the values of the requested parameters should be consistent with the altitude of the area in question. The user has to input average annual values accounting for the climatic differences in mountain areas and plains.

```
|
| Precipitation (mm) {0.510e+03} -
|
|  do you want to randomize precipitation ? (y/n) - y
|
```

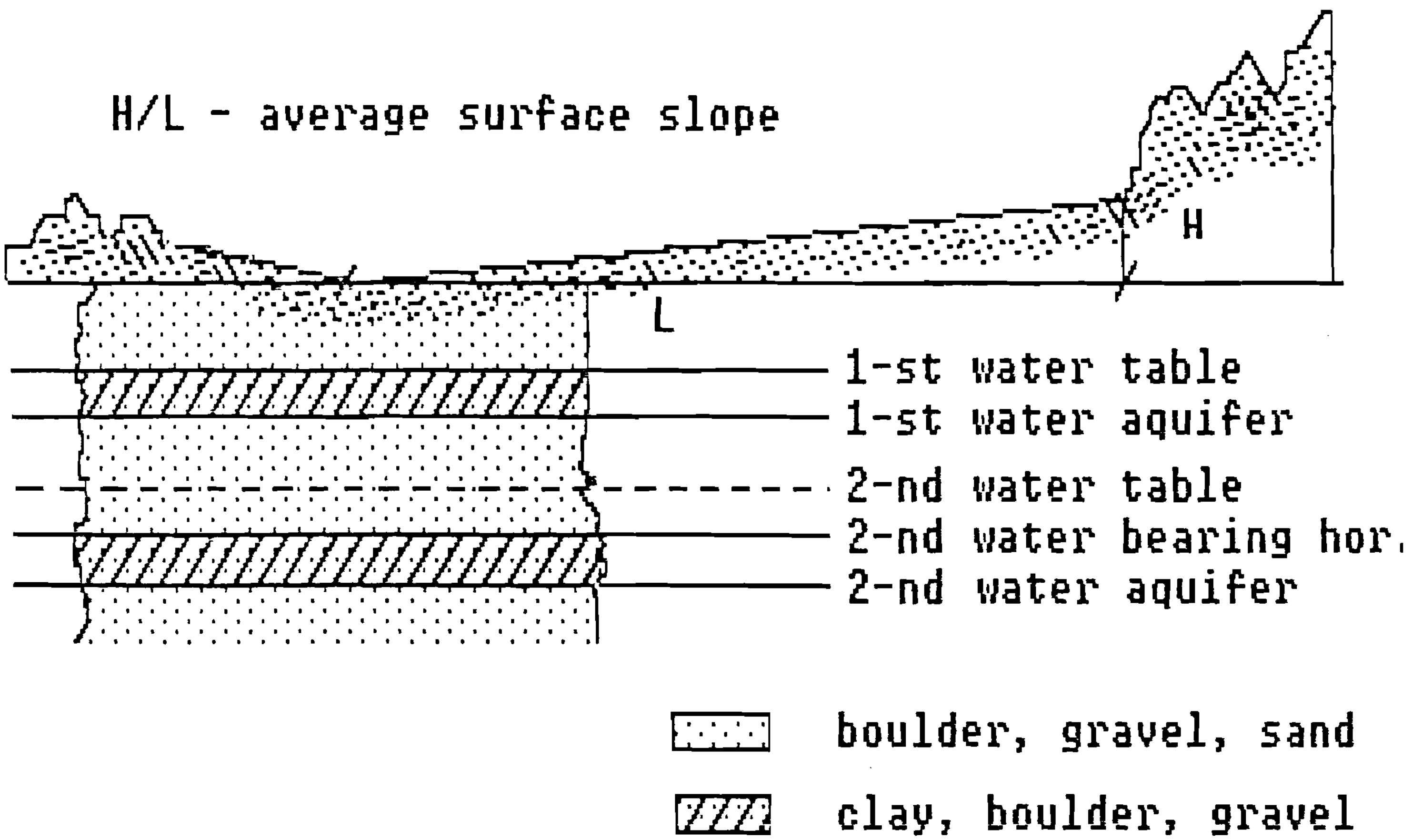

Figure 4 Water tables.

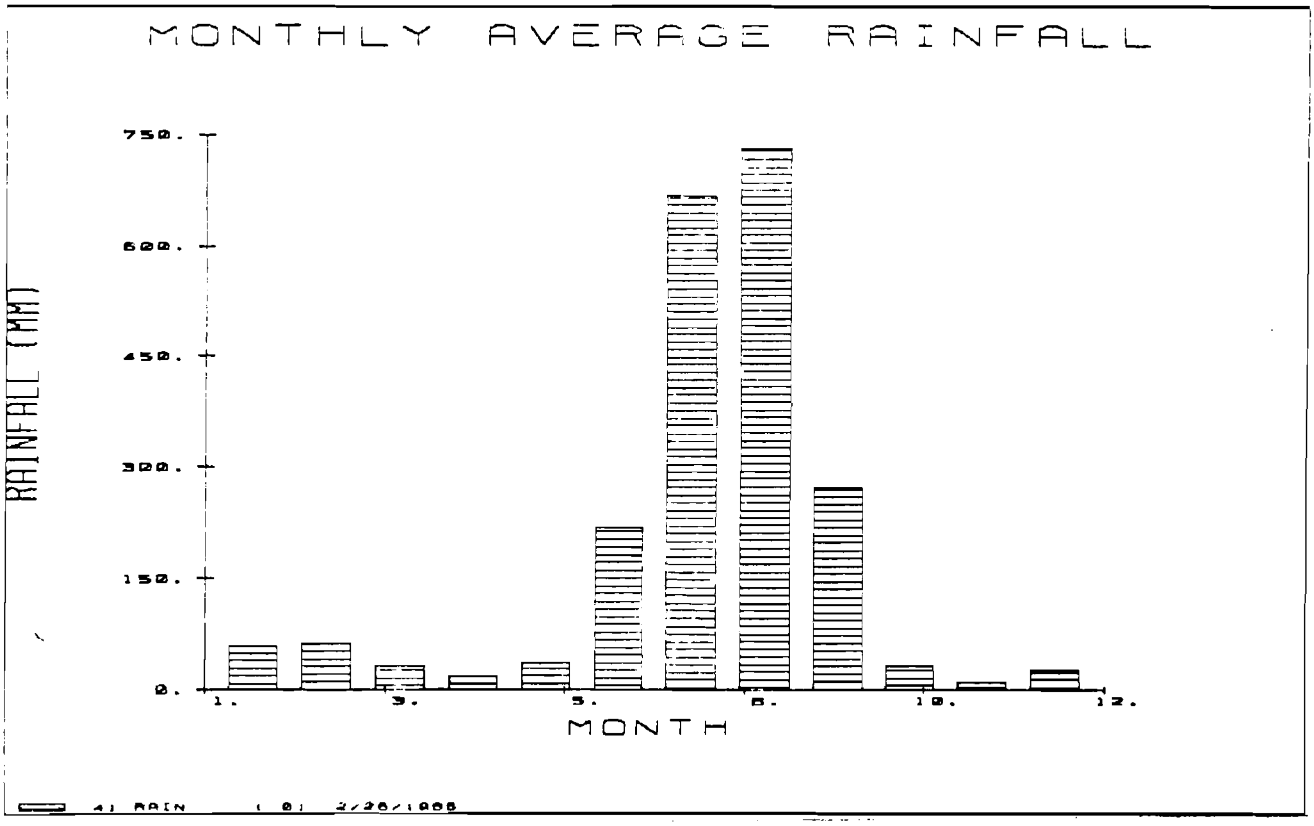

Figure 5 Maximum of monthly surface flow (share of total flow) for Dehra Dun is rainfall in August (max. rainfall) divided by rainfall for the whole year.

If the answer is "y", the user has to answer the following questions (to set the percentage for randomizing the precipitation). The predefined values for this and the next temperature randomizations can be set in the file "wthr.dat".

```
|
|  standard deviation (%) {0.e+00} - 0.5
|
| Temperature (grad) {0.630e+01} -
|
| do you want to randomize temperature? (y/n) - y
|
|  standard deviation (%) {0.e+00} - 0.2
|
| Wind velocity (m/s) {0.400e+01} -
|
| Difference of temperatures for valleys and uplands {-0.400e+00} -
|
```

Fourth substage. The user has to specify the prevailing type of lithology.

```
|
|     TYPE OF LITHOLOGY
|
| 1 - Sand
| 2 - Loamy sand
| 3 - Loam
| 4 - Clay
| 5 - Marl
| 6 - Compact sedimentary rocks
| 7 - Intrusive and metamorphic rocks
| 8 - Shingle beds
| 9 - Karsted rocks
|
| input option number -
|
```

This terminates the detailed input procedure and the system returns to the initial list. The user may either pass on to the next stage or change the specifications.

2.2.2.2. Option 2: Brief Specification

This mode does not require so much input information as the previous one. The user should answer only 6 questions (in contrast to 38 in the detailed mode). All necessary data will be automatically reconstructed by the system on the basis of the verbal description. The first list deals with the type of geographical belt.

```
|
|    TYPE OF GEOGRAPHICAL BELT
|
| 1 - Arctic
| 2 - Temperate
| 3 - Temperate belt of central sector
| 4 - Subtropical
| 5 - Tropical
| 6 - Equatorial
|
| input option number -
|
```

In India, only options 4 and 5 will apply. The second list deals with the type of vegetation. The content of it depends on the response of the user to the previous one. If the answer was "4" you can choose one of the following types of vegetation:

```
|
|    TYPE OF VEGETATION
|
|
| 19 - Subtropical desert
| 20 - Subtropical steppe
| 21 - Subtropical prairie
| 22 - Subtropical sclerophillous forest
| 23 - Sclerophillous forest, sparse growth of trees
| 24 - Subtropical monsoon forest
|
| input option number -
|
```

The next list is the "type of relief".

```
|
|    TYPE OF RELIEF
|
| 1 - Low land
| 2 - Plainland
| 3 - Upland
| 4 - Low mountains
| 5 - Plateau
| 6 - Mountains, of medium altitude
| 7 - Table-land
|
| input option number -
|
```

The next list contains different types of lithology and is equivalent to the relevant list of the detailed mode:

```
|
|    TYPE OF LITHOLOGY
|
| 1 - Sand
| 2 - Loamy sand
| 3 - Loam
| 4 - Clay
| 5 - Marl
| 6 - Compact sedimentary rocks
| 7 - Intrusive and metamorphic rocks
| 8 - Shingle beds
| 9 - Karsted rocks
|
| input option number -
|
```

The following list contains various intensities of waterlogging for different types of hydrological land structures. A high level of waterlogging is typical for aquifer 0.5 - 2 meters deep; medium for 2.5 - 3.5 meters deep; low for 3.5 - 5 meters deep. The display is:

```
|
|    WATERLOGGING DUE TO HIGH AQUIFER
|
| 1 - Absent
| 2 - Intensive
| 3 - Moderate
| 4 - Low
|
| input option number -
|
```

The last request is:

```
|
| filtration from transit rivers (mm) {0.e+00} -
|
```

This terminates the brief specification mode.

2.2.2.3. Option 3: Geographical Specification

This mode is the simplest way to specify a region. The user is requested to answer only two questions:

```
|
| Input region number (from 1 to 163) -
|
| filtration from transit rivers (mm) {0.e+00} -
|
```

To answer the first question, the user should consult the geographic map and the list of regions (see Appendix A). Having entered this information the system takes detailed regional data from the data bank. We were not in a position to determine all parameters, which characterise the region, precisely because of the lack of information. So the user is supposed to check regional data and correct them if necessary. This can be done in two ways. The first is the "Detailed mode".

In this case one must look through the list of input variables, checking the values in brackets and correcting them if necessary. This method is very suitable but takes a long time. A shorter method is the "Direct mode".

2.2.2.4. Option 4: Direct Specification

This mode has been developed for users who are well aware of the system itself and the meaning of its main variables. Such a user can set the required variable value directly if he knows its name:

```
|
| Name of variable - b(1)
|
```

Having entered the name, the system checks it and in the case of correct input name, displays a second prompt:

```
|
| Value of variable {0.800e+00} - 0.9
|
```

The number in the brackets is the current value of the variable. One should print a new value or press <RETURN>. Then the first prompt is displayed again:

```
|
| Name of variable -
|
```

The user may either input the new name or press <RETURN> to interrupt the mode.

The description of system variables is given in Appendix C.

2.2.2.5. Option 5: Previous Region

In case the user has chosen to work with the previous region, the system restores the specification of the region as it was immediately after the last region specification procedure. This mode of specification, however, may only be chosen when the previous region has been specified by the user. It can be used if the user wants to specify a new scenario and begin the simulation from zero time point.

2.2.2.6. Option 6: Adjusted Region

In response to option 6 the system takes the information for the previously adjusted region and proceeds to the "Specify scenario" stage.

2.2.2.7. Option 7: Continue

In this case the system displays:

```
|
| Input share of arable lands (%) -
|
```

The next message to appear on the screen is:

```
|
|     INPUT COMPLETED, MODEL IS ADJUSTING TO THE REGIONAL DATA
|
```

This indicates that the specification of the region is complete. System control is then transmitted to the next stage - model adjustment to regional data, which is performed automatically.

2.2.3. Model Adjustment

Model adjustment does not require participation of the user. Once the procedure is over, the screen displays the following message:

```
|
|              MODEL ADJUSTMENT COMPLETED
|
```

After that, the system passes the control to the next (fourth) stage.

2.2.4. Specify Scenario

This stage starts with a prompt:

```
|
|
|          S P E C I F Y   S C E N A R I O
|
|
|   HUMAN FACTORS
|
| 0 - CONTINUE
| 1 - RETURN to previous scenario
| 2 - Sensitivity investigation
| 3 - Temperature trend
| 4 - Precipitation trend
| 5 - Pollution and fertilization rates
| 6 - Irrigation regime
| 7 - Drainage intensity
| 8 - Specific features of agriculture
| 9 - Fires in non-cultivated lands
|10 - Artificial destruction of biomass
|11 - Changes in the area of arable lands
|12 - New plantation in non-cultivated lands
|13 - New shelter belts in arable lands
|14 - Changes in the stock of wood due to lumbering
|
```

It is assumed that the policy/scenario options will remain unchanged over the next simulation period. It should be mentioned, that the user is able to define any of the specified scenario variables as a function of time, using command $ TABLE. Any policy change may be introduced only after this period is over. A user may define as many succesive policies of regional development as he wishes, provided that he does not exceed the upper limit of total simulation time, which is 199 years.

It should be noted that the model does not compute the effects of previous policy decisions on successive periods; if the user wishes to trace them, he should formulate his policy options respectively.

The interactive procedure at the stage of scenario specification is very similar to that of region specification. The system prompts the user with a list of 15 options, of which all but zero option are closed.

It should be noted that option 14 refers only to forest areas.

2.2.4.1. Option 0: Continue Modelling

If the user has specified option 0, the system responds with:

```
|
| Input modelling time (max 199 years) -
|
```

which indicates that the control passes to the next (fifth) stage. The scenario, which was selected at stage 4 is stored in a file for possible future uses.

2.2.4.2. Option 1: Return to Previous Scenario

This option restores the previous scenario and enables the user to formulate new scenarios by altering previous ones.

2.2.4.3. Option 2: Sensitivity Investigation

The sensitivity of model outputs to variations of some exogeneous variables can be studied under this option. The current version of the system provides an opportunity to investigate the influence of the following system variables:

fl - total drainage rate (mm/year)
dn - total dissection (km/km2)
hgw - depth of first ground water table (m)
rws - surface flow (mm)
rwg - ground water flow (mm)
rwdg - deep ground water flow (mm)

while disturbing one of the lithology coefficients:

clg(i), clw(i), clr(i), where i=1,...,9

depending on lithology type. Predesignated values of these coefficients are stored in the table below:

Type of lithology	clg	clw	clr
1 - Sand	69.0	0.10	1.60
2 - Loamy sand	39.0	0.80	0.64
3 - Loam	26.0	0.85	0.80
4 - Clay	12.7	0.92	0.53
5 - Marl	9.0	0.92	0.17
6 - Compact sedimentary rocks	6.7	0.93	0.11
7 - Intrusive and metamorp rocks	6.7	0.93	0.08
8 - Shingle beds	97.5	0.40	0.80
9 - Karsted rocks	162.5	0.30	0.32

The sensitivity investigation proceeds as follows. First, the user must choose a disturbed coefficient (if he has forgotten their names he may use "?" command as a "help"):

```
|
| input name of coefficient - ?
|
| ---> input legal name of lithological coefficient:
|     clg(1-9); clw(1-9); clr(1-9)
|
| input name of coefficient - clg(9)
|
```

The number in brackets must correspond to the lithology type of region in question. Then he enumerates the variables which he is interested in (fl, dn and so on) using <RETURN> for input interruption. The last request is:

```
|
| input number of random value -
|
```

The answer is an arbitrary integer number which defines the initial point in pseudo random values row. The system uses these random values to disturb the specified coefficient. Then the system returns to the main scenario menu and the user should input 0 (to continue) and modelling time (for example 100 years):

```
|
|     HUMAN FACTORS
|
|  0 - CONTINUE
|  1 - RETURN to previous scenario
|  2 - Sensitivity investigation
|  3 - Temperature trend
|  4 - Precipitation trend
|  5 - Pollution and fertilization rates
|  6 - Irrigation regime
|  7 - Drainage intensity
|  8 - Specific features of agriculture
|  9 - Fires in non-cultivated lands
| 10 - Artificial destruction of biomass
| 11 - Changes in the area of arable lands
| 12 - New plantation in non-cultivated lands
| 13 - New shelter belts in arable lands
| 14 - Changes in the stock of wood due to lumbering
|
| input option number - 0
|
| Input modelling time (max 199 years) - 100
|
|              S I M U L A T I O N    R U N
|
```

Having completed the calculations, the system displays values of coefficients (original and disturbed):

```
|
|    coeff: old = ... , new - ... , rel err = ... (%)
|
```

and relative deviations of variables averaged by decades. The next question is

```
|
| print the result? (y/n) -
|
```

After receiving a replay, the system returns to the main menu of scenario specification stage.

2.2.4.4. Option 3: Temperature Trend

The system displays the following prompt:

```
|
| Temperature trend (grad per year) -
|
```

The user is expected to input average yearly rate of temperature change within a region. The temperature trends specified by the user are continued over the specified period.

2.2.4.5. Option 4: Precipitation Trend

The system displays the following phrase:

```
|
| Precipitation trend (mm per year) -
|
```

The user should input average yearly rate of precipitation change that will continue over the specified time period.

2.2.4.6. Option 5: Pollution and Fertilization Rates

The system displays the following list:

```
|
|    POLLUTION DEPOSITION AND FERTILIZATION RATES
|
| pollutants (t/ha-year)
|
| 1  - SOx
| 2  - NOx
| 3  - CxHy
| 4  - Pb
| 5  - Hg
| 6  - Cd
| 7  - Nitrogen fertilizes
| 8  - Phosphorus fertilizers
| 9  - Potassic fertilizers
| 10 - Organic fertilizers
| 11 - Continue
|
| input option number -
|
```

Options 1 - 10 will return the system to the same list. To return to the list of scenario options indicate option 11. If any number from the range 1 - 6 was chosen, the user will have to specify the distribution of the relevant pollutant between different types of environment by answering to prompts:

| into the soil of non-cultivated lands -
| into the soil of arable lands -
| air pollution -
| water pollution -

All fertilizers are applied:

| into the soil of non-cultivated lands -

and

| into the soil of arable lands -

while organic fertilizers caused

| water pollution -

as well.

Having specified the distribution of pollutants and fertilizers, the user should indicate option 11. The system displays:

| thermal pollution (grad) -

Thermal pollution, as it is assumed here, is the yearly averaged increment of the yearly averaged temperature due to thermal wastes.

2.2.4.7. Option 6: Irrigation Regime

The user is requested to specify the sources and the intensity of watering in the region:

| AGRICULTURAL WATERING
|
| with ground water (mm) -
|
| with deep ground water (mm) -
|
| with artesian water (mm) -
|
| from rivers and lakes (mm) -
|
| from transit rivers and canals (mm) -
|
| the reduction in surface flow due to water retention -

As for the last question, it should be noted that the user is supposed to input a number from 1 to 10 to indicate the degree of surface flow decrease as a result of water retention. (1-no decrease, 2 - moderate water retention,..., 10 - significant water retention.) We want to stress that 1 (not 0) means no water retention in the region.

2.2.4.8. Option 7: Drainage Intensity

The following inquires are displayed:

| HYDRAULIC AND DRAINAGE RECLAMATION
|
| DRAINAGE
|
| 0 - Absent
| 1 - Intensive
| 2 - Moderate
| 3 - Low
| input option number -
|
| Change in the surface of lakes due to engineering reclamation (%) -

2.2.4.9. Option 8: Specific Features of Agriculture

The equations describing the crop production block of the model were originally identified for wheat. So the biomass of arable lands is supposed to be the wheat biomass. If the user wants to investigate another crop, he has to specify values of the appropriate coefficients. To do this, he should answer the following requests:

```
|
| SPECIFIC FEATURES OF AGRICULTURE
|
| The part of biomass removed from the fields (% of total) {0.750e+02} -
|
| The grain/straw ratio in the removed biomass (%) {0.330e+02} -
|
```

Having received this information, the system determines a new value for the harvest and asks the user about the actual harvest in the area in question in order to correct the coefficients:

```
|
| The predicted harvest is (0.100e+01t/ha); input the actual harvest -
|
```

Then the system adjusts the values of the new coefficients and returns to the main menu of the stage.

2.2.4.10. Option 9: Fires on Lands Not Used for Agricultural Purposes

The system will request the user to specify the damage done by fires by displaying the following prompt:

```
|
|    THE INTENSITY OF FIRES IN NON-CULTIVATED LANDS
|
| 0 - Absent
| 1 - Low (ground fire)
| 2 - Medium
| 3 - Significant (crown fire)
|
| input option number -
|
```

It should be kept in mind that forest fires usually occur, for instance, during every twentieth or tenth year in the period of simulation. So the time interval under consideration has to be divided appropriatly.

2.2.4.11. Option 10: Artificial Destruction of Biomass

The requests are:

```
|
| Destruction of biomass by vehicles (%) -
|
```

2.2.4.12. Option 11: Changes in the Area of Arable Lands

The user should specify the annual average increase (or decrease) in the area of arable lands in percentage of total arable lands area in the previous year:

| CHANGE IN THE AREA OF ARABLE LANDS (% of total area per year)
|
| increase -
|
| decrease -

2.2.4.13. Option 12: New Plantations in Non-Cultivated Lands

The questions are:

| New plantations in non-cultivated lands (% of total area) -
|
| The age of the trees (years) -

2.2.4.14. Option 13: New Shelter Belts in Arable Lands

The questions are similar to the previous option:

| New shelter belts in arable lands (% of total area) -
|
| The age of the trees (years) -

2.2.4.15. Option 14: Changes in the Stock of Wood Due to Lumbering

It might be pointed out that this option is valid only in the forest areas. The user is to specify the reduction in the amount of wood due to lumbering in percentage of total biomass:

| Changes in the stock of wood due to lumbering (%) -
|
| Is it selective cutting of young trees? (y/n) -

2.2.5. Set Time Interval, Run the Model

This stage opens with the following request:

| Input modelling time (max *** years) -

where *** means the number of years left before the simulation time expires. The total length of simulation period should not exceed 199 years.

After the system has received an answer, it replays the following message:

|
| SIMULATION RUN
|

When the run is over, the system passes on to the next stage.

2.2.6. Output Modes

The following menu is offered here:

```
|
|    OUTPUT MODES
|
| 1 - Standard output
| 2 - Direct output
| 3 - Continue modelling
|
| input option number -
|
```

2.2.6.1. Option 1: Standard Output

Option 1 is followed by displaying the sets of the major variables, grouped in some reasonable way. The first list is as follows:

```
|
|    STANDARD OUTPUT
|
|    Biocenoses dynamics
|
| 1  - soil - vegetation
| 2  - soil productivity - soil index - humidity
| 3  - soil - fertilizers
|
|      Water parameters
|
| 4  - total flow
| 5  - surface dissection
| 6  - ground-water flow
| 7  - deep ground-water flow
|
|    Salinity parameters
|
| 8  - soil - ground-water
| 9  - ground-water - river water
| 10 - pollution parameters
|
| input option number - 10
|
```

If option 10 was chosen, then the second list would be displayed:

```
|
|   TYPE OF ENVIRONMENTAL COMPONENT & POLLUTANT
|
|      Pollution of :
| 1 - plants with toxic metals
| 2 - soil   with toxic metals
| 3 - air
| 4 - surface waters with metals
| 5 - surface waters with hydrocarbons, nitrogen, phosphorus & potassium
| 6 - ground-waters  with metals
| 7 - ground-waters  with hydrocarbons, nitrogen, phosphorus & potassium
| 8 - deep ground-waters with metals
| 9 - deep ground-waters with hydrocarbons, nitrogen, phosphorus & potassium
|
| input option number - 1
|
```

Options 1, 3 of the first list and 1, 2 of the second one require additional information concerning type of land:

```
|
|   TYPE OF LAND
|
| 1 - non_cultivated
| 2 - arable
| 3 - wetlands
|
| input option number -
|
```

Having received the required information, the system passes to the next stage and displays the list of output forms.

2.2.6.2. Option 2: Direct Output

Option 2 implies that the user should specify the names of the output variables. The prompt is:

```
|
| input name of * variable -
|
```

The asterisk is substituted by the numbers 1 to 4 because the number of output variables cannot exceed 4. To interrupt input, the <RETURN> should be pressed. The list of accessible output variables is in Appendix C.

2.2.6.3. Option 3: Continue Modelling

This option transfers control to the stage of "session continuation options" (2.2.8).

2.2.7. Output Forms

The user has to choose the type of representation for the output information:

```
|
|    OUTPUT FORMS
|
| 1 - Table on display
| 2 - Plot  on display
| 3 - Plot  on graphics device
|
| input option number -
|
```

Option 1 is followed by a table of output variables. The other two options require additional information.

2.2.8. Scaling Modes

The user must choose from:

```
|    SCALING MODES
|
| 1 - automatic, single   scale for all   variables
| 2 - automatic, separate scale for every variable
| 3 - manual,    single   scale for all   variables
| 4 - manual,    separate scale for every variable
|
| input option number -
|
```

Option 1: The system initiates a procedure for defining the minimum (Y min) and the maximum (Y max) values among all the values of the output variables. (This may be done only if the output variables are measured in the same units.) These values then serve as the upper and lower boundaries of the plotted output along the Y axis.

Option 2: The system automatically defines the minimum ($Y_i$min) and the maximum ($Y_i$max) values for each of the output variables (where i is the index of the output variable). The output curves are then scaled separately to fit into the same box.

Option 3: The minimum (Y min) and the maximum (Y max) among all values of the output variables are specified by the user in response to the prompts:

```
|
| PARAMETERS FOR MANUAL SCALING
|
| y min -
|
| y max -
|
```

In case some values of an output variable exceed (or are less than) the upper (or lower) limit defined by the user, the system cuts off some parts of the curve.

Option 4: The user is requested to specify the $Y_i$min and $Y_i$max values for each of the output variables separately (i is index of the output variable) by answering to a sequence of prompts:

|
| min of variable number [i] -
|
| max of variable number [i] -

Having finished the scaling procedure and receiving a response on request:

|
| title for plot -
|

the system displays a graphic of the specified parameter. In case of option 2 (see 2.2.7 - Output forms menu), it would be a user's terminal. When the whole graph is displayed on the terminal, the program waits for <RETURN>. Only after doing this does the following message occur:

|
| print the graph y/n ?
|

The user can print this graph on the printer choosing "y".

2.2.8.1. The Usage of Graphics Devices

The user can display graphs on the graphics devices by choosing option 3 for the "OUTPUT FORMS" menu.

In order to create smooth graphics, the system uses the "Newplot" utility which is available on the IIASA VAX 11/780 computer. The system prepares all necessary information, puts it into the files "plot.dat" and "plot.cmd" and transfers the control to the Newplot program. It should be noted that the graphics device is specified in the file "plot.dev" on the first line. It can be a graphical terminal, "bbc-plotter", or any dot matrix printer. Here is an example of a "plot.dev" file:

```
mann

c ---- COMMENTS -----
First string of this file contains the name of the graphic device, i.e.,

        a) '/dev/tty..'  - for particular graphical display
        b) 'screen'      - for graphical display
        c) 'bbc'         - for bbc plotter
        c) 'varian'      - for varian printer
        e) 'tektronix'   - for tektronix terminal
        f) other filename - output will go to the file in the current directory
                    and later can be redirected to any other previous
                    devices or matrix printer
```

In order to change the first string of this file one can change the output device for the Newplot. We used the f) option in this file, e.g., the output goes to the file with the name "mann"; after that, it is automatically printed on the central Mannesmann Tally dot matrix printer.

If the user is working from the graphical display, he has to choose option b) to obtain the graph on his display. Of course he can redirect this output to another hardcopy device using the "devi" command. This is possible because when the Newplot finished its last command from the file "plot.cmd", it switched the input from the terminal. The user has to issue some of Newplot command to continue or to stop the Newplot program. For a description of Newplot, see [2]. For our purposes, three commands are enough:

stop - to terminate Newplot
devi - to override the device
plot - to produce a graph.

After each command the Newplot prompts with ">" and after the last command, the user can return to the system by typing:

> stop

or if he wants to plot a graph on "bbc-plotter", he should type the following sequence of commands:

> devi bbc
> plot
> stop

Newplot creates graphics on the bbc-plotter and returns the control to the sixth stage of the system.

2.2.9. Choose the Next Stage

When the user has reached this stage, he is offered the following list of options:

```
SESSION CONTINUATION OPTIONS

0 - Terminate session
1 - Define region
2 - Define scenario
3 - Continue modelling
4 - Output results

input option number -
```

Option 0 terminates the session; options 1 - 4 transfer control to the corresponding stages of the system.

3. How to Generate the System

A list of necessary files is in Appendix E.

3.1. System Executable Module Generation

The following files should be compiled and linked together to create the executable file "sef.e" using the following UNIX command:

```
xf77 sef.f syssef.f ecmod.f regn.f scen.f outp.f dial.f
str.f ran.f sensef.f grafn.f -o sef.e
```

It must be mentioned that files "sef.cmn" and "grsys.cmn" are indispensable during compilation. It is also necessary to compile some auxiliary programs "trans.f" "cre.f" and "vndt.f " for direct access files formation. The program "trans.f" translates the dialogue files. Program "cre.f" is used for creation of a hash table of system variables which is necessary for direct input-output modes. Program "vndt.f" alternates the data file "vn.dat".

3.2. The Content of Files

"sef.cmn" - common block, includes all the system variables
"grsys.cmn" - common block, includes variables for output programs ("outp.f" and "grafn.f")
"namtbl.sef" - direct access file having address table for SEF common variables
"vnun.dat" - direct access file, having model parameters data
"grspe.dat" - standard output control file
"save.sef" - output variables list file
"regn.eng" , "scen.eng" , "outp.eng" - direct access files, having dialogue texts
"regn.f" - region specification program
"scen.f" - scenario specification program
"outp.f" - output result program
"sef.f" - main supervisor program
"syssef.f" - service programs
"ecmod.f" - ecology dynamic model
"dial.f" - dialog realisation program
"str.f" - string information processing
"ran.f" - random generator
"sensef.f" - sensitivity investigation program.
"wthr.dat" - file for random generator control
"plot.dev" - file for choosing the output device for print figures.

3.3. Direct Access Files Creation

For successful system execution, it is necessary to alternate a number of successive access files into direct access files:

initial files:	program:	direct access files:
vn.dat	vndt.e	vnun.dat
sef.cmn	cre.e	namtbl.sef
regn.dil	trans.e	regn.eng
scen.dil	trans.e	scen.eng
outp.dil	trans.e	outp.eng

To realize the above tasks, one should successively execute appropriate programs "vndt.e", "cre.e" and "trans.e" answering the required questions from the programs. It should be mentioned that all "*.eng" files can be created within one run of the program "trans.e".

To get executable programs "vndt.e" "cre.e" and "trans.e", the user must use the following UNIX commands

```
xf77 vndt.f -o vndt.e
xf77 cre.f -o cre.e
xf77 trans.f -o trans.e
```

REFERENCES

Pegov, S., P. Komyakov, V. Kroutko: Modelling system of region environment state dynamics

Schweeger, B.: Newplot version 1.2 Reference manual, IIASA, 1982 LS-8

Appendix A List of regions for geographical input mode

Region number	Type of vegetation (NZ)	Type of relief (NR)	Type of lithology (NL)	Type of waterlogging (NH)
1	1	3	6	1
2	3	1	6	1
3	2	3	6	1
4	4	3	6	1
5	5	3	6	1
6	6	3	3	1
7	6	1	3	1
8	7	3	3	1
9	8	3	3	1
10	9	4	3	1
11	10	5	6	1
12	24	1	2	1
13	22	6	6	1
14	21	1	2	1
15	21	6	6	1
16	20	6	6	1
17	20	1	3	1
18	27	1	3	1
19	28	1	3	4
20	30	1	3	1
21	31	1	3	4
22	32	1	3	1
23	31	3	3	1
24	30	4	6	1
25	27	2	3	1
26	27	3	6	1
27	29	3	6	1
28	28	1	3	1
29	25	3	2	1
30	20	3	2	1
31	21	2	2	1
32	24	3	3	1
33	22	2	8	1
34	24	2	3	1
35	9	4	6	1
36	9	2	3	1
37	6	2	6	1
38	26	4	6	1
39	1	1	2	1
40	1	4	6	1
41	2	1	2	1
42	2	4	6	1
43	3	4	6	1
44	3	1	1	1
45	3	7	7	1
46	3	6	7	1
47	4	1	3	1
48	4	7	7	1
49	4	6	7	1
50	5	5	7	1

51	5	2	7	1
52	5	2	3	1
53	13	1	3	4
54	13	7	7	1
55	5	3	7	1
56	6	2	3	1
57	6	3	3	1
58	14	1	2	1
59	14	6	7	1
60	6	6	7	1
61	15	2	3	1
62	7	2	3	1
63	7	4	6	1
64	7	2	3	1
65	7	4	7	1
66	7	3	3	1
67	8	2	3	1
68	8	3	6	1
69	16	2	3	1
70	8	3	3	1
71	9	2	3	1
72	16	2	3	1
73	16	1	3	1
74	16	4	6	1
75	10	1	4	1
76	17	2	3	1
77	17	5	5	1
78	17	4	6	1
79	11	3	4	1
80	18	2	3	1
81	18	4	6	1
82	12	2	2	1
83	19	3	3	1
84	23	2	3	1
85	23	4	5	1
86	19	2	2	1
87	19	2	3	1
88	19	4	6	1
89	19	6	6	1
90	20	6	6	1
91	24	2	2	1
92	24	4	6	1
93	25	3	2	1
94	26	4	6	1
95	26	3	1	1
96	26	5	1	1
97	26	6	6	1
98	26	1	2	1
99	26	4	5	1
100	28	1	3	4
101	30	2	3	1
102	30	5	3	1
103	30	6	3	1
104	30	7	7	1

105	30	6	7	1
106	30	1	3	4
107	31	6	3	1
108	31	4	7	1
109	31	1	3	4
110	31	4	5	1
111	31	1	3	1
112	32	3	3	1
113	32	1	3	1
114	32	4	7	1
115	31	5	6	1
116	31	1	3	1
117	30	5	6	1
118	30	1	3	1
119	27	5	6	1
120	27	3	3	1
121	26	5	6	1
122	20	5	3	1
123	23	4	6	1
124	24	6	6	1
125	31	2	3	1
126	31	6	6	1
127	26	2	2	1
128	27	4	6	1
129	26	3	2	1
130	19	2	3	1
131	20	4	6	1
132	20	2	3	1
133	24	4	6	1
134	21	4	6	1
135	23	4	6	1
136	24	6	6	1
137	24	4	6	1
138	6	4	6	1
139	8	2	3	1
140	20	2	3	1
141	22	2	3	1
142	30	2	3	1
143	12	2	2	1
144	12	5	2	1
145	30	4	7	1
146	27	2	3	1
147	25	2	3	1
148	25	4	3	1
149	27	1	3	1
150	30	2	7	1
151	8	1	3	1
152	24	6	3	1
153	19	5	6	1
154	32	1	3	1
155	30	5	6	1
156	30	2	3	1
157	30	5	6	1
158	27	5	6	1

159	30	1	2	1
160	19	2	2	1
161	21	3	3	1
162	27	2	2	1
163	25	2	3	1

Appendix B Synopsis of the shadow dialogue commands

? -	help
! -	show system state
^D -	reverse
# file -	open protocol (protocol writes into the specified file)
#! -	show protocol
## -	close protocol
@ file -	external input (input stream from the specified file)

Appendix C Description of system variables

The following notation is used:

1. The units of measurement are indicated in brackets after the full name of the variable.
2. Index 'i' appearing in the name of certain variables should be interpreted as follows:

   i=1 - lands not used for agricultural purposes;

   i=2 - lands used for agricultural purposes;

   i=3 - wetlands.
3. Index 'j' indicates different kinds of pollutants and fertilisers:

   j=1 - sulfur concentrations;

   j=2 - nitrogen concentrations;

   j=3 - hydrocarbons;

   j=4 - concentrations of Pb;

   j=5 - concentrations of Hg;

   j=6 - concentrations of Cd;

   j=7 - nitrogen fertilizers;

   j=8 - phosphorus fertilizers;

   j=9 - potassic fertilizers;

   j=10 - organic fertilizers;

   j=11:15 - reserved indexes.

Biotic parameters

B(i) - biomass (tonnes per hectare)
BM(i) - dead biomass (tonnes per hectare)
CLV(i) - climate index
CPOL(i) - pollution index
D(i) - proportion of the i-th type of land in the total area (lakes not included) (%)
DV(i) - proportion of the i-th type of land in the total area (lakes included) (%)
DWNV(i) - wind erosion rate (mm/year)
FIS(i) - increment of soil quality index due to fertilisation
GH(i) - soil productivity (tonnes per hectare)
HFF(i) - humidity
HFV(i) - humidity for i-th type of land
KV - vegetation type:
KV=1 - grass;
KV=2 - forest-steppe;
KV=3 - forest;
KV=4 - moss-lichen;
SLTV(i) - soil salinity (%)
SPWV(i) - rate of surface errosion by type of land (mm/year)
SV(i) - soil index

Drainage parameters

CFWV(1) - proportion of surface drainage in total drainage (%)
CFWV(2) - proportion of drainage from upper ground layer in total drainage (%)
CFWV(3) - proportion of drainage from lower ground layer in total drainage (%)
DN - total dissection (km/km2)
DNR - dissection by rivers (km/km2)
FL - total drainage rate (mm/year)
FL1 - surface drainage rate (mm/year)
FL2 - rate of drainage from upper ground layer (mm/year)
FL3 - rate of drainage from lower ground layer (mm/year)
FL1+FL2 - sum of FL1 and FL2 (mm/year)
FL12+FL3 -sum of FL1, FL2 and FL3 (mm/year)
HEX - maximum cut (m)
HGW - depth of first ground water table (m)
HGWD - depth of second ground water table (m)
HP1 - depth of first aquifer
HPW - depth of first aquifer (m)
HWPD - depth of second aquifer (m)
RMDV - effective surface drainage (%)

SW1V - water salinity, first ground water table (g/l)

SW2V - water salinity, second ground water table (g/l)

RCSV - river water salinity (g/l)

Parameters of pollutants and fertilizers (tonnes per hectare)

PLA(j) - atmospheric pollution

PLDW(j) - water pollution, second ground water table

PLGM(j) - ground pollution, between first and second water tables

PLGW(j) - water pollution, first ground water table

PLP(j,i) - vegetation pollution

PLS(j,i) - soil pollution (mobile compositions)

PLSG(j,i) - soil pollution (connected compositions)

PLWT(j) - surface water pollution

Variables defined during region specification stage

HGW - depth of first water table (m)

HGWD - depth of second water table (m)

HWP - depth of first aquifer (m)

HWPD - depth of second aquifer (m)

H7 - depth of second water bearing-horizon roof (m)

HPF - depth of permaffrost (m)

AWF - filtration from transit rivers (mm)

DN - total dissection (km/km2)

DNT - dissection by transit rivers (km/km2)

HEX - maximum depth of valleys (m)

HEM - average depth of valleys (m)

CLAK - share of total area covered with lakes (%)

DEC - average surface slope (tangen)

CEH - average width of valleys (m)

CPDG - downward infiltration of ground-water (%)

CLDG - infiltration of ground-water, second layer, into rivers (%)

SW1 - ground-water salinity (gr/l)

SW2 - deep ground-water salinity (gr/l)

RMDO - maximum of monthly surface flow as percent of total flow (%)

biomass, average (t/ha-yr)

B(1) - non-cultivated lands

B(2) - arable lands

B(3) - flood-lands

mortmass, average (t/ha-yr)

BM(1) - non-cultivated lands

BM(2) - arable lands

BM(3) - flood-lands

index of soil

S(1) - non-cultivated lands

S(2) - arable lands

S(3) - flood-lands

soil salinity (%)

SLS - non-cultivated lands

SLSA - arable lands

RI - precipitation (mm)

TI - temperature (grad)

V1 - wind velocity (m/s)

DTB - difference of temperatures between valleys and uplands

Appendix D List of variables accessible in direct output mode

dn	dnr	fl
fl3	fl32	fl123
fl12	hgw	hgwneg
hgwd	hwp	hwpd
sw1v	sw2v	rcsv
rws	rwg	rwdg
ti	ri	tpl
tt	tr	caf(1)
pstr	ddna	clak
pg	pgt	caw
frs	paq	daq
u(1)	u(2)	u(3)
b(1)	b(2)	b(3)
cfwv(1)	cfwv(2)	cfwv(3)
cpol(1)	cpol(2)	cpol(3)
gh(1)	gh(2)	gh(3)
hff(1)	hff(2)	hff(3)
sv(1)	sv(2)	sv(3)
sltv(1)	sltv(2)	sltv(3)
pla(1)	pla(2)	pla(3)
pls(7,1)	pls(8,1)	pls(9,1)
pls(7,2)	pls(8,2)	pls(9,2)
pls(7,3)	pls(8,3)	pls(9,3)
plp(4,1)	plp(5,1)	plp(6,1)
plp(4,2)	plp(5,2)	plp(6,2)
plp(4,3)	plp(5,3)	plp(6,3)
pls(4,1)	pls(5,1)	pls(6,1)
pls(4,2)	pls(5,2)	pls(6,2)
pls(4,3)	pls(5,3)	pls(6,3)
plwt(3)	plwt(4)	plwt(5)
plwt(6)	plwt(7)	plwt(8)
plwt(9)		
plgw(3)	plgw(4)	plgw(5)
plgw(6)	plgw(7)	plgw(8)
plgw(9)		
pldw(3)	pldw(4)	pldw(5)
pldw(6)	pldw(7)	pldw(8)
pldw(9)		
dpls(1,1)	dpls(2,1)	dpls(3,1)
dpls(4,1)	dpls(5,1)	dpls(6,1)
dpls(7,1)	dpls(8,1)	dpls(9,1)
dpls(10,1)		
dpls(1,2)	dpls(2,2)	dpls(3,2)
dpls(4,2)	dpls(5,2)	dpls(6,2)
dpls(7,2)	dpls(8,2)	dpls(9,2)
dpls(10,2)		
dpla(1)	dpla(2)	dpla(3)
dpla(4)	dpla(5)	dpla(6)
dpla(7)	dpla(8)	dpla(9)
dpla(10)		
dplw(1)	dplw(2)	dplw(3)
dplw(4)	dplw(5)	dplw(6)
dplw(7)	dplw(8)	dplw(9)
dplw(10)		

Appendix E List of system files

1. Necessary for normal system operation:

sef.e

sef.cmn	grsys.cmn	namtbl.sef
vnun.dat	grspe.dat	save.sef
regn.eng	scen.eng	outp.eng
wthr.dat	plot.dev	

2. Created by the system during a session:

inireg.ssf	iniscn.ssf	wfil
plot.dat	plot.cmd	pltt
newplot.dat	newplot.graf	newplot.prot
adj.	buff0	

3. Necessary for system generation:

sef.cmn	grsys.cmn	
sef.f	syssef.f	ecmod.f
regn.f	scen.f	outp.f
dial.f	str.f	ran.f
sensef.f	grafn.f	

trans.f	regn.dil	scen.dil	outp.dil

cre.f

vndt.f	vn.dat

Appendix F: Example of one session

Y O U   A R E   W E L C O M E   T O   T H E   S Y S T E M   F O R

E C O L O G I C A L   F O R E C A S T I N G

****

IN THE COURSE OF INTERACTION WITH SEF

1. Use '?' if you need additional information.
2. Use '!' if you need to see the 'SYSTEM STATE'.
3. Use 'control-D' if you need to return to the previous point of interaction.
4. If the SEF question has a current value of the variable in brackets {...} you may use 'RETURN' if you do not need to change a value.
5. See details in SEF User's Manual and SEF Model Description.

****

System loading - PLEASE WAIT - System loading

S P E C I F Y   R E G I O N

MODES OF REGION SPECIFICATION

1 - Detailed
2 - Brief
3 - Geographical
4 - Direct
5 - Previous region
6 - Adjusted previous region
7 - CONTINUE

input option number - ?

---> 1. Detailed description of the area has to be given by the user for precise adjustment.
2. Eco-physical characteristics are been taken from the data bank for approximate adjustment of the area.
3. The same as before, but the user has to point out only the number of the region in accordance with Appendix A from the SEF user's manual.
4. In addition to 1, some internal parameters can be redefined.
5. The region characteristics will be the same as before the model adjustment from the previous run.
6. The same as 5. but after adjustment.

7. Adjustment of region to chosen parameters.

input option number - 2

TYPE OF GEOGRAPHICAL BELT

1 - Arctic
2 - Temperate
3 - Temperate belt of central sector
4 - Subtropical
5 - Tropical
6 - Equatorial

input option number - 5

TYPE OF VEGETATION

25 - Tropical subdesert
26 - Tropical desert
27 - Tropical savanna
28 - Tropical monsoon forest
29 - Tropical forest

input option number - 28

TYPE OF RELIEF

1 - Low land
2 - Plainland
3 - Upland
4 - Low mountains
5 - Plateau
6 - Mountains, of medium altitude
7 - Table-land

input option number - 4

TYPE OF LITHOLOGY

1 - Sand
2 - Loamy sand
3 - Loam
4 - Clay
5 - Marl
6 - Compact sedimentary rocks
7 - Intrusive and metamorphic rocks
8 - Shingle beds
9 - Karsted rocks

input option number - 9

WATERLOGGING DUE TO HIGH AQUIFER

1 - Absent

2 - Intensive
3 - Moderate
4 - Low

input option number - 3

filtration from transit rivers (mm) {0.e+00} - 0.

MODES OF REGION SPECIFICATION

1 - Detailed
2 - Brief
3 - Geographical
4 - Direct
5 - Previous region
6 - Adjusted previous region
7 - CONTINUE

input option number - 1

depth of 1-st water table (m) {0.857e+01} -

depth of 2-nd water table (m) {0.950e+02} -

depth of 1-st aquifer (m) {0.100e+02} -

depth of 2-nd aquifer (m) {0.100e+03} -

depth of 2-nd water-bearing horizon roof (m) {0.900e+02} -

filtration from transit rivers (mm) {0.e+00} -

total dissection (km/km2) {0.550e+01} -

dissection by transit rivers (km/km2) {0.e+00} -

maximum depth of local valleys (m) {0.350e+03} -

average depth of local valleys (m) {0.200e+02} -

share of total area (%), covered with lakes {0.e+00} -

average surface slope (tangens) {0.140e-02} -

average width of valleys (m) {0.300e+02} -

downward infiltration of ground-water (%) {0.e+00} -

infiltration of ground-water, 2-nd layer, into rivers (%) {0.e+00} -

ground-water salinity (gr/l) {0.153e+00} -

deep ground-water salinity (gr/l) {0.153e+00} -

maximum of monthly surface flow (share of total flow) {0.190e+00} -

any alterations ? (y/n) - n

biomass, average (t/ha-yr)

1 - non-cultivated lands {0.469e+03} -

2 - arable lands {0.e+00} -

3 - flood-lands {0.363e+03} -

mortmass, average (t/ha-yr)

1 - non-cultivated lands {0.400e+00} -

2 - arable lands {0.e+00} -

3 - flood-lands {0.500e+00} -

index of soil

1 - non-cultivated lands {0.500e+01} -

2 - arable lands {0.400e+01} -

3 - flood-lands {0.400e+01} -

soil salinity (%)

1 - non-cultivated lands {0.516e-01} -

2 - arable lands {0.516e-01} -

Precipitations (mm) {0.168e+04} -

do you want to randomize precipitation ? (y/n) - n

Temperature (grad) {0.225e+02} -

do you want to randomize temperature? (y/n) - n

Wind velocity (m/s) {0.350e+01} -

Difference of temperature between valleys and uplands {0.100e+00} -

TYPE OF LITHOLOGY

1 - Sand
2 - Loamy sand

3 - Loam
4 - Clay
5 - Marl
6 - Compact sedimentary rocks
7 - Intrusive and metamorphic rocks
8 - Shingle beds
9 - Karsted rocks

input option number - 9

MODES OF REGION SPECIFICATION

1 - Detailed
2 - Brief
3 - Geographical
4 - Direct
5 - Previous region
6 - Adjusted previous region
7 - CONTINUE

input option number - 7

Input share of arable lands (%) - 20

INPUT COMPLETED, MODEL IS ADJUSTING TO THE REGIONAL DATA

MODEL ADJUSTMENT COMPLETED

S P E C I F Y   S C E N A R I O

HUMAN FACTORS

0 - CONTINUE
1 - RETURN to previous scenario
2 - Sensitivity investigation
3 - Temperature trend
4 - Precipitation trend
5 - Pollution and fertilization rates
6 - Irrigation regime
7 - Drainage intensity
8 - Specific features of agriculture
9 - Fires in non-cultivated lands
10 - Artificial destruction of biomass
11 - Changes in the area of arable lands
12 - New plantation in non-cultivated lands
13 - New shelter belts in arable lands
14 - Changes in the stock of wood due to lumbering

input option number - 14

Changes in the stock of wood due to lumbering (%) - 5

Is it selective cutting of young trees? (y/n) - n

HUMAN FACTORS

0 - CONTINUE
1 - RETURN to previous scenario
2 - Sensitivity investigation
3 - Temperature trend
4 - Precipitation trend
5 - Pollution and fertilization rates
6 - Irrigation regime
7 - Drainage intensity
8 - Specific features of agriculture
9 - Fires in non-cultivated lands
10 - Artificial destruction of biomass
11 - Changes in the area of arable lands
12 - New plantation in non-cultivated lands
13 - New shelter belts in arable lands
14 - Changes in the stock of wood due to lumbering

input option number - 0

Input modelling time (max 199 years) - 50

S I M U L A T I O N   R U N

OUTPUT MODES

1 - Standart output
2 - Direct output
3 - Continue modelling

input option number - 1

STANDARD OUTPUT

Biocenoses dynamics

1 - soil - vegetation
2 - soil productivity - soil index - humidity
3 - soil - fertilizers

Water parameters

4 - total flow
5 - surface dissection
6 - ground-water flow
7 - deep ground-water flow

Salinity parameters

8 - soil - ground-waters
9 - ground-waters - river waters

10 - pollution parametres

input option number - 1

TYPE OF LAND

1 - non_cultivated
2 - arable
3 - wetlands

input option number - 1

OUTPUT FORMS

1 - Table on display
2 - Plot on display
3 - Plot on graphics device

input option number - 2

SCALING MODES

1 - automatic, single scale for all variables
2 - automatic, separate scale for every variable
3 - manual, single scale for all variables
4 - manual, separate scale for every variable

input option number - 2

Title for plot - firsttable
print the result? (y/n) - y

OUTPUT MODES

1 - Standart output
2 - Direct output
3 - Continue modelling

input option number - 1

STANDARD OUTPUT

Biocenoses dynamics

1 - soil - vegetation
2 - soil productivity - soil index - humidity
3 - soil - fertilizers

Water parameters

4 - total flow
5 - surface dissection
6 - ground-water flow
7 - deep ground-water flow

Salinity parameters

8 - soil - ground-water
9 - ground-water - river water
10 - pollution parameters

input option number - 5

OUTPUT FORMS

1 - Table on display
2 - Plot on display
3 - Plot on graphics device

input option number - 3

SCALING MODES

1 - automatic, single scale for all variables
2 - automatic, separate scale for every variable
3 - manual, single scale for all variables
4 - manual, separate scale for every variable

input option number - 2

Title for plot - fifthtable

OUTPUT MODES

1 - Standart output
2 - Direct output
3 - Continue modelling

input option number - 3

SESSION CONTINUATION OPTIONS

0 - Terminate session
1 - Define region
2 - Define scenario
3 - Continue modelling
4 - Output results

input option number - 0

3 EXAMPLES

V. Fedorov, M. Lenko

Example 1. Scenario: Soil Quality

Traditional Development of the Agricultural Sector

To illuminate the possibilities of SEF, several scenarios were tested and one of them is described briefly in this section. This scenario deals with the area between the Lesser Himalayas and Siwalik. The geophysical characteristics available in the Project's Data Bank (see Chapter II) were used to respond to the requests of the SEF section "detailed region specification".

For the first 50 years of the run, it was assumed also that 3% of the forest cover of the valley was removed annually. The volume of fertilizers was taken at a level three times less than the currently reported one. This 50-year run was done to imitate the previous development. From Figure 6 it is clear that after 40 years, the soil quality significantly deteriorated and approached some low bound without noticable changes during the next 10 years.

Developments for the next 50 years were imitated under the assumption that 0.016 t/ha of nitrogen, 0.005 t/ha of phosphate, 0.0015 t/ha of potash, and 0.1 t/ha of organic fertilizers were used annually (reported in the Yearbook 1984, Dehra Dun). One can observe that even at the same rate of deforestation, the fertilization of agricultural land leads to a significant improvement during the next 50 years. But it also can be observed (see Figure 7) that the dissection of land continuously increased during the considered interval, presumably because of a rather high level of deforestation which can be the result not only of timbering, but also of industrial activities (road construction, limestone quarrying).

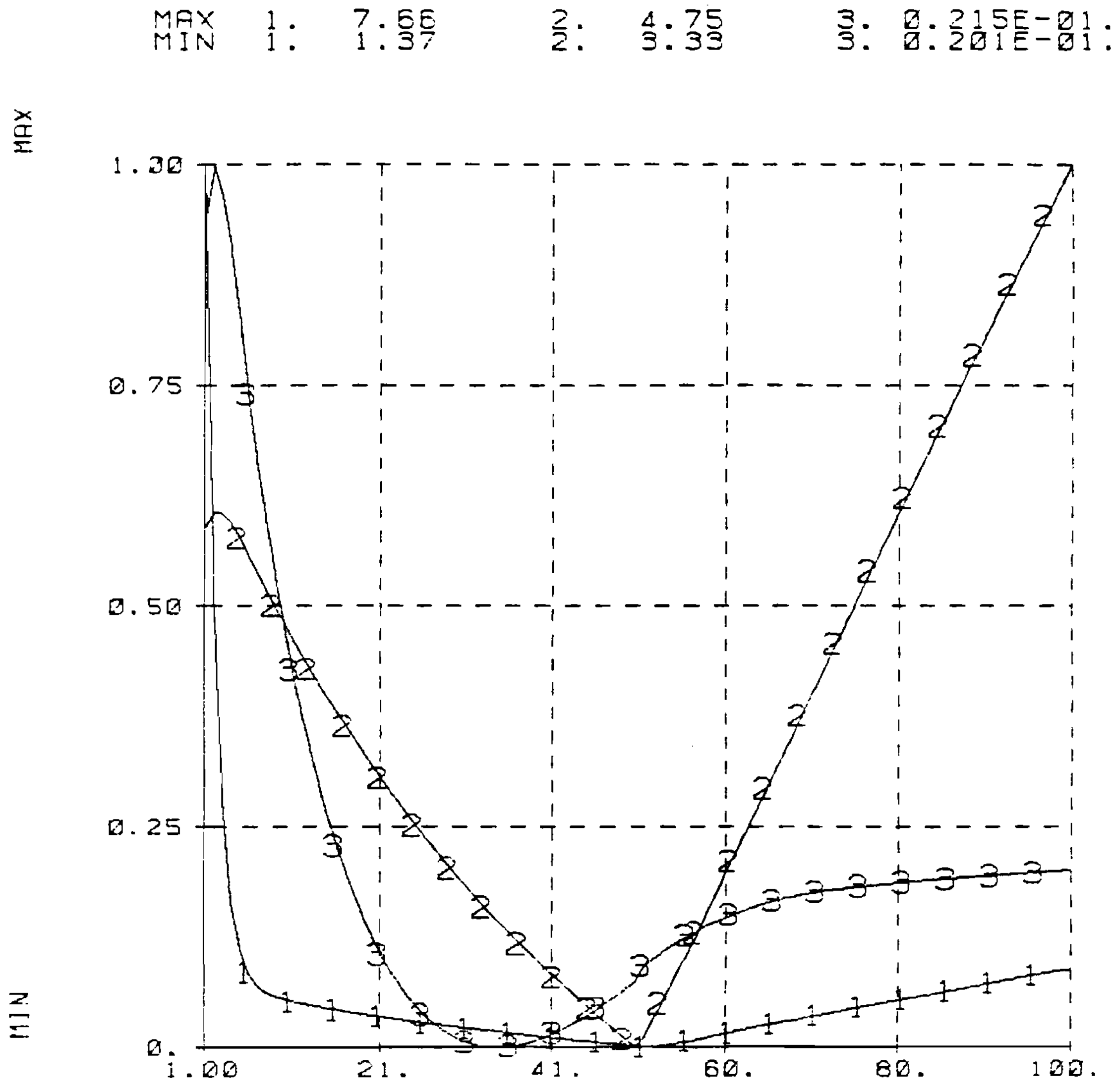

Figure 6 Soil productivity (1), soil index (2) and soil salinity (3) for arable land

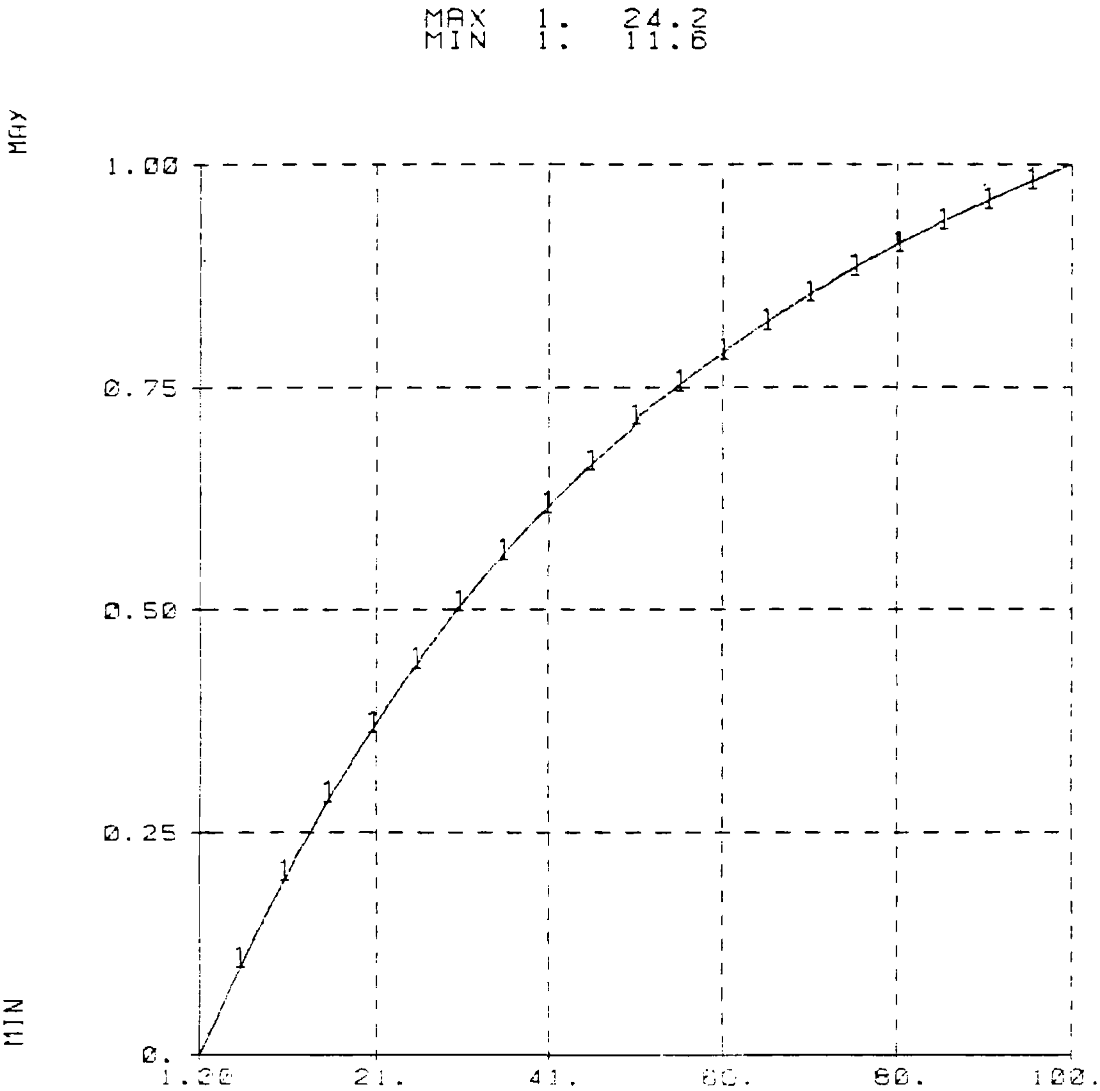

Figure 7 Total dissection (in km / km^2)

Example 2. Design and Analysis of Simulation Experiments

To clarify the facilities of the software on design and analysis of simulation experiments and to assess the sensitivity of SEF to the variation of different input parameters, the simulation experiment was carried out with SEF adjusted to the Doon Valley conditions. It is worthwhile to emphasize "adjusted" to some region because the final results strongly depend upon the regional characteristics.

For the sake of simplicity, only 31 parameters were chosen for the exercise. With the help of the module "PLAN" (see Chapter I), the two-level othogonal plan was constructed (it contains 32 "observations"; of course, this plan can be found in some catalogues but we want to demonstrate the work of the software). The levels of variations for all 31 parameters are in Table 1. Most of them can be changed under "Detailed" description of the region. Others can be fixed in the "Scenario" regime. As a response "soil productivity" was chosen.

When all 32 observations were executed, the module "SYS" (see Chapter I) was used to get the set of the most significant parameters. This included only five out of the 31; see Figure 8. The simplest secondary model

$$y_i = \vartheta_0 + \sum_{\alpha=1}^{m} \vartheta_\alpha x_\alpha + \varepsilon_i$$

where x_α are input parameters, and ε_i are deviations from the primary model, was chosen. The normalized sum of square residuals

$$v_N^2 = (n - N)^{-1} \sum_{i=1}^{32} (y_i - \hat{y}_i^m)^2$$

where $N = m + 1$, $\hat{y}^m = \hat{\vartheta}_0^m + \sum_{\alpha=1}^{m} \hat{\vartheta}_\alpha^m x_\alpha$, $\hat{\vartheta}^m$ are the stepwise least square estimates, $m = 1,\ldots,31$, was used as a measure of the accuracy of a secondary model.

From Figure 8 it is easy to see that 5 primary chosen parameters explain ~90% of the total fluctuation of SEF prognoses for "soil productivity." The set of significant parameters depends upon the chosen response. For example, for "total dissection" it was average surface slope, precipitation, biomass and the rate of forest cutting.

Table 1

		-	0	+	
1	1st water table (+ 1st aquifer)	13.	15.	18.	*m*
2	2nd water table (+ 2nd aquifer)	33.	41.	49.	*m*
3	filtration from transit rivers	0.	25.	50.	*mm*
4	total dissection	2.	3.	5.	km / km^2
5	dissection by transit rivers	0.1	0.3	0.5	km / km^2
6	max. depth of local valleys	25.	50.	75.	*m*
7	average depth of local valleys	5.	8.	20.	*m*
8	area covered by lakes in %	1.5	2.5	3.5	%
9	average surface slope	0.001	0.05	0.1	*tangent*
10	average width of valleys	8.	16.	24.	*m*
11	downward filtration	4.	8.	12.	%
12	filt. of gr.water into rivers	2.5	5.	7.5	%
13	max. monthly surface flow	0.2	0.4	0.6	*share −tot.flow*
14	biomass non-cultivated	200.	300.	400.	*t / ha / y*
15	biomass arable	0.	1.	2.	*t / ha / y*
16	biomass floodlands	100.	200.	300.	*t / ha / y*
17	mortmass non-cultivated	10.	20.	30.	*t / ha / y*
18	mortmass arable	1.	2.	3.	*t / ha / y*
19	mortmass flood-lands	10.	20.	30.	*t / ha / y*
20	index of soil non-cultivated	4.	8.	12.	
21	index of soil arable	4.	6.	8.	
22	index of soil flood-lands	3.	5.	7.	
23	precipitation	1000.	1500.	2000.	*mm*
24	temperature	15.	20.	25.	°*C*
25	wind velocity	2.	3.	4.	*m / s*
26	temp diff.-valleys/highlands	-0.2	-o.4	-o.6	°*C*
27	input share of arable land	10.	30.	50.	%
28	fertilizer N	0.012	0.015	0.018	*kg / ha*
29	fertilizer Ph	0.0036	0.0045	0.0054	*kg / ha*
30	fertilizer K	0.0012	0.0015	0.0018	*kg / ha*
31	forest cut	1.	3.	5.	%

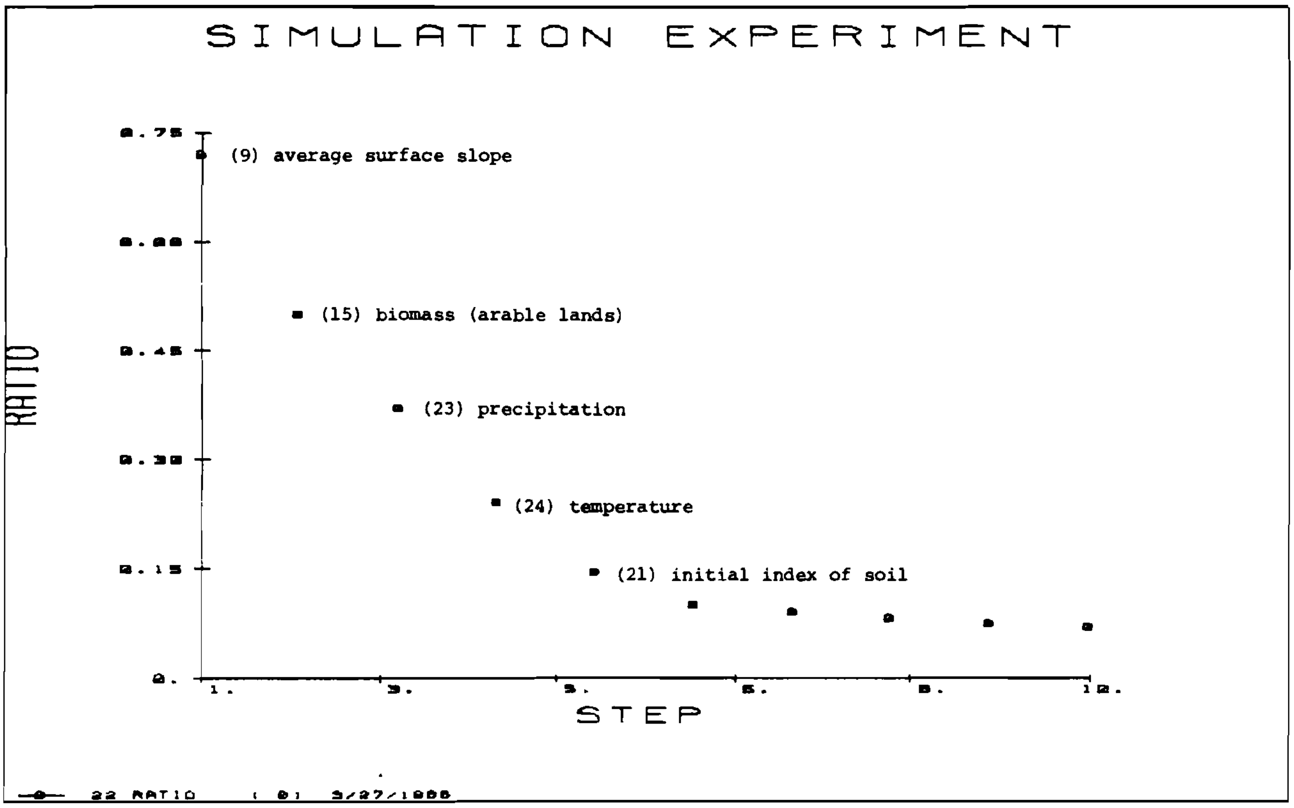

Figure 8 Simulation experiment - soil productivity (ratio v_n^2 / v_0^2)

II DATA BANK

1 TABLES

General data about Doon Valley

Sources are: Gazetteer about Dehra Dun and other short articles

	Dehra Dun town regulated area	Dehra Dun Tehsil 1961	1971	Dehra Dun District 1961	1971	1981
Total area:	750 km2	2003.	2363.	2455.	3088.	3088.
nonarable land	0.1 %	2. %				
forest land	44.6 %			70 %		73 %
cultivable land	55.3 %			18 %		18 %
land under habituse	5.8 %					
popultion total	249879	362300	498200	429014	577306	761668
rural population	184614	167700	232500	231179	305529	389527
density total	334 per km2	211	211	175	187	246
density rural	247 per km2					
livestock	185617					359085
livst.density	248 per km2					116

General data from Yearbook 1984:

Item	unit	Year	Value
Area	sq km	1981	3088
Population			
male	1000	1981	420.465
female	1000	1981	341.203
total	1000	1981	761.668
rural	1000	1981	389.527
urban	1000	1981	372.141
Percent of working class		1981	32.56
Cultivated area	1000 ha	1982-83	57.340
More than oncw cultiv. area	1000 ha	1982-83	30.594
Net irrigated area	1000 ha	1982-83	23.542
Production of food grains	metric tonns	1981-82	82343
Irrigation			
length of cannals	km	1983-84	336
State Tubewells	no	1983-84	35
Total number of cattle	no.	1982	359085
Percentage of cultivated land		1981-82	17.69
		1982-83	17.91
Percenatge of land cultivatet more than once		1981-82	50.96
		1982-83	53.35
Percentage of the irrigated land in total cultivated area		1981-82	39.74
		1982-83	41.05
Fertilizer used per hectare	kg	1981-82	23.31
	kg	1982-83	20.96
Food production per capita	100 kg	1981-82	1.08
	100 kg	1982-83	1.006

Per capita production in the District
(prevailing rates)
(Rupees)

1970-71	253
1975-76	506
1976-77	606
1978-79	531
1980-81	840
1981-82	791

Times of sunrise (SR) and sunset (SS) on IST
(Indian Standard Time) at Doon Valley (30.4 N, 78 E)

Date	SR	SS
Mar. 21	06 21	18 30
June 21	05 16	19 23
Sep. 21	06 06	18 16
Dec. 21	07 11	17 21

Data about Dehra Dun from Gazetter 1979:

Area (1981) 3088 sq km
Area for land utilisation 2627.3 sq km

Total population (1971)	577306	(females 251198)
Rural population	305529	(136840)
Urban population	271777	(114358)

Dehra Dun tahsil	2363.4 sq km	498178	(fem. 219303)
Chakrata tahsil	263.9 sq km	79128	(31875)

Rainfall: 87 % in June-September
Frequency of rainfall between 1901-1950:

Range in mm	no of years
1301-1500	2
1501-1700	2
1701-1900	6
1901-2100	11
2101-2300	9
2301-2500	6
2501-2700	2
2701-2900	4
2901-3100	6
3101-3300	1
3301-3500	1

average 79 rainy days (with rainfall > 2.5mm)
heaviest rainfall in 24 hours Rajpur 25. Aug 1954 = 440.4 mm
Temperature:
highest month May 36.2 oC
lowest month Jan 6.1 oC
highest max Dehra Dun 43.9 oC on Jun 4, 1902
min -1.1 Feb 1, 1905
Relative humidity more than 70 %
Winds:
postmonsoon and winter mornings N, NE
in afternoons SW, NW throughout the year

Forest Areas: (in hectars)

Year	forest depart.	private	total
1966-67	150517	16500	167017
1967-68	152786	16500	169286
1968-69	153058	16500	169558
1969-70	153320	16500	169895
1970-71	150803	16575	167378

area under forest (1961)	171021 ha	(1971) 167378
uncultivated land	23652	
area under current fallows	3430	
cultivated area	56748	

total area affected by soil erosion 35266 ha in the plains
14625 ha in hilly tracts (1970)

cultivated area:

1901	38999 ha	e.g. 12 % to total area
1921	40141	10
1941	41947	11
1961	56748	20
1967	55557	21
1971	55647	

culturable area (areas under groves, forests, pastures, grazing land, fallows)

1906	224961 ha
1921	291666
1941	268329
1961	190698
1967	190636
1971	194224

unculturable area (water, buildings, roads and railways, habitation sites)

1901	42569 ha
1921	44199
1941	96062
1961	23652
1967	16737
1971	15854

C L I M A T O L O G I C A L   T A B L E

station: Dehra Dun City

Month	pressure mb	Air temperature dry bulb oC	wet bulb oC	mean daily max oC	mean daily min oC	high mont oC	lowe mont oC	extremes high oC	date year	lowe oC	date year
jan I	958.7	8.9	7.1	19.1	6.1	23.1	2.7	26.1	16	-1.1	11
jan II	937.2	15.6	11.4						1946		1944
feb I	936.6	11.5	8.9	21.4	8.2	26.0	3.9	29.4	28	-1.1	1
feb II	935.0	18.8	12.7						1956		1905
mar I	934.9	16.9	12.3	26.4	12.4	31.4	7.4	37.2	28	2.2	6
mar II	932.9	23.7	14.9						1892		1945
apr I	932.5	23.2	15.6	32.1	17.0	37.0	12.0	40.6	27	7.8	4
apr II	929.8	29.8	16.9						1892		1944
may I	928.7	27.8	18.9	36.2	21.5	40.2	16.7	42.8	28	12.8	6
may II	925.7	33.9	19.9						1944		1947
jun I	925.4	28.5	22.4	35.5	23.6	40.1	19.1	43.9	4	13.9	10
jun II	922.1	33.2	22.8						1902		1906
jul I	925.2	26.0	24.1	30.4	23.1	34.7	20.7	40.6	1	18.3	28
jul II	922.5	28.3	25.0						1931		1902
aug I	926.8	25.4	23.8	29.5	22.7	32.4	20.8	37.2	5	19.4	27
aug II	924.2	27.1	24.6						1949		1932
sep I	930.4	24.6	22.1	29.6	21.3	32.1	17.8	34.4	30	14.4	30
sep II	927.8	27.1	23.4						1938		1940
oct I	955.7	20.4	16.7	28.2	16.1	30.9	11.8	36.1	2	9.4	31
oct II	933.4	25.1	19.9						1901		1938
nov I	938.1	14.2	11.3	24.7	10.5	27.5	7.1	30.1	1	2.8	30
nov II	936.2	19.8	15.4						1952		1938
dec I	959.1	9.9	7.9	20.9	7.0	24.3	5.7	27.2	30	0.0	31
dec II	937.3	16.3	12.6						1960		1934
annual	932.7	19.8	15.9	27.8	15.8	40.9	2.1	43.9		-1.1	
mean	930.3	24.9	18.3								
nro	30	30	30	30	30	30	30	80		80	
years	24	24	24								

Month	humidity rel humid %	vapour press mb	cloud amount all clouds oktas of sky	low clouds	rainfall monthly total mm	nro rainy days	total in wettest month with year mm	total in driest month with year mm	heaviest fall in 24 hours mm	date and year	mean wind speed km/h
jan I	78	8.7	3.1	1.5	62.2	4.1	229.9	0.0	79.5	5	2.6
jan II	59	10.2	3.5	2.0			1911			1945	
feb I	71	9.4	2.8	1.1	59.4	3.6	107.0	0.0	106.2	5	3.1
feb II	47	9.7	3.2	1.4			1937			1949	
mar I	58	10.8	3.0	1.0	39.7	3.4	196.6	0.0	81.5	7	3.6
mar II	38	10.4	3.1	1.5			1926			1926	
apr I	43	11.9	1.9	0.7	17.4	1.7	97.8	0.0	39.1	16	4.2
apr II	25	9.7	2.8	1.2			1909			1898	
may I	41	15.2	1.8	0.7	41.7	3.2	193.0	0.0	79.3	28	4.1
may II	26	12.7	2.5	1.3			1933			1940	
jun I	58	21.4	3.2	1.8	185.9	8.3	554.0	21.1	188.0	28	3.6
jun II	43	19.5	3.1	2.0			1893	1924		1925	
jul I	85	27.9	6.3	5.0	720.8	21.7	1137.7	111.5	194.6	30	2.7
jul II	77	28.3	5.5	4.0			1894	1911		1890	
aug I	87	27.5	6.2	5.0	764.9	21.7	1637.8	184.1	332.2	22	2.5
aug II	82	28.6	5.5	4.7			1885	1899		1951	
sep I	80	24.4	3.9	3.0	326.7	12.8	1014.0	1.5	212.6	3	2.8
sep II	73	26.0	4.2	3.4			1924	1928		1924	
oct I	68	16.0	1.4	1.1	70.8	3.0	325.4	0.0	137.4	9	3.3
oct II	61	19.0	1.3	1.1			1955			1936	
nov I	70	11.1	0.9	0.2	5.1	0.4	115.6	0.0	78.7	19	3.0
nov II	61	14.0	1.2	0.4			1911			1911	
dec I	76	9.1	2.2	0.8	19.1	1.5	150.1	0.0	108.5	4	2.6
dec II	61	11.5	2.9	1.1			1929			1923	
annual	68	16.1	3.1	1.8	2313.7	85.4	3118.9	1152.4	332.2		3.2

mean	54	16.6	3.2	2.0			1884	1907			
nro	30	30	30	20	30	30	80	80	80		30
years	24	24	24	20							

station: Mussoorie

Month	pressure	Air temperature		mean				extremes			
		dry bulb	wet bulb	daily max	daily min	high mont	lowe mont	high	date year	lowe	date year
	mb	oC	oC	oC	oC	oC	oC	oC		oC	
jan I	798.2	5.7	1.9	10.2	2.5	15.9	-1.4	21.1	14	-5.0	16
jan II	797.2	6.2	4.1						1949		1935
feb I	797.2	7.1	3.6	11.9	3.7	18.2	-1.5	23.3	26	-6.7	10
feb II	796.5	8.0	5.6						1953		1950
mar I	797.7	11.4	6.5	16.2	7.2	21.9	2.2	26.1	31	-2.5	23
mar II	796.8	12.4	8.4						1945		1960
apr I	797.6	16.3	10.0	21.1	11.8	25.9	5.5	28.9	22	-0.6	4
apr II	796.5	18.1	11.6						1956		1944
may I	796.1	19.8	13.0	24.8	15.1	29.1	9.1	34.4	24	5.6	6
may II	794.9	21.6	13.8						1949		1947
jun I	793.6	19.9	15.8	24.1	16.4	28.5	11.0	31.7	3	5.3	8
jun II	792.1	21.4	17.2						1935		1957
jul I	792.8	18.3	17.4	20.8	15.9	24.3	14.1	29.4	7	12.2	1
jul II	791.4	18.6	18.1						1949		1939
aug I	794.0	17.9	17.2	20.2	15.6	23.0	14.0	25.6	23	12.2	15
aug II	792.6	18.0	17.8						1957		1937
sep I	796.5	17.3	16.6	19.9	14.3	25.0	11.2	17.2	11	6.1	30
sep II	795.1	17.1	16.6						1946		1940
oct I	799.8	14.4	10.6	18.7	11.1	22.3	7.4	25.6	18	3.3	29
oct II	798.5	14.3	12.0						1951		1945
nov I	800.3	11.3	6.4	15.8	7.4	19.6	4.1	25.0	17	-2.1	29
nov II	798.5	10.7	7.8						1953		1954
dec I	799.4	8.0	3.8	12.7	4.3	18.5	0.2	21.7	2	-3.9	31
dec II	798.2	7.8	5.3						1953		1954
annual	796.9	13.9	10.2	18.0	10.4	29.8	-2.7	34.3		-6.7	
mean	795.7	14.5	11.5								
nro	30	30	30	30	30	30	30	30		30	
years	26	26	26								

	humidity		cloud amount		rainfall						mean
	rel humid	vapour press	all clouds	low clouds	monthly total	nro rainy days	total in wettest month with year	total in driest month with year	heaviest fall in 24 hours	date and year	wind speed
	%	mb	oktas of sky		mm		mm	mm	mm		km/h
jan I	58	5.0	3.9	1.6	66.4	5.3	200.9	0.0	90.9	6	6.7
jan II	72	6.7	4.6	2.6			1935			1943	
feb I	56	5.5	3.3	1.2	66.9	4.5	220.5	0.0	82.0	4	7.4
feb II	71	7.6	4.2	2.2			1949			1949	
mar I	49	6.3	3.3	1.2	63.5	4.6	182.9	0.0	62.0	24	7.9
mar II	59	8.4	3.8	2.1			1944			1944	
apr I	44	7.9	2.2	0.8	29.5	2.5	106.4	0.0	45.2	17	7.9
apr II	46	8.6	3.6	1.8			1943			1942	
may I	46	10.3	2.1	1.0	45.1	4.1	143.5	5.8	50.0	13	8.4
may II	43	11.9	3.7	2.2			1933	1935		1943	
jun I	68	15.1	3.6	2.0	188.5	8.9	542.5	16.5	139.9	23	7.5
jun II	66	16.1	4.3	3.1			1936	1931		1936	
jul I	93	19.1	6.6	4.5	726.5	22.9	1268.0	381.8	196.9	23	5.6
jul II	95	20.6	6.9	4.8			1942	1951		1942	
aug I	94	18.9	6.9	4.2	754.7	23.6	1217.9	338.3	302.3	3	4.7
aug II	98	20.2	7.4	4.0			1950	1938		1931	
sep I	86	16.2	4.5	3.1	323.2	15.0	1048.0	38.1	199.6	26	5.4
sep II	94	18.5	6.1	4.9			1947	1939		1947	
oct I	63	10.1	1.6	1.1	64.8	2.8	447.0	0.0	198.1	9	6.1
oct II	78	12.8	2.7	2.5			1956			1956	

nov I	49	6.5	1.1	0.2	7.7	0.5	53.9	0.0	20.5	20	6.3
nov II	68	8.8	1.9	0.9			1951			1928	
dec I	50	5.1	2.6	0.9	31.5	1.9	184.4	0.0	111.0	12	6.8
dec II	69	7.0	3.3	1.5			1936			1957	
annual	64	10.5	5.5	1.8	2368.1	94.6	3284.7	1475.7	302.3		6.7
mean	72	12.3	4.4	2.7			1942	1929			
nro	30	30	30	20	30	30	35	35	35		30
years	26	26	26	20							

station: Roorkee

Month	pressure	Air temperature									
				mean				extremes			
		dry bulb	wet bulb	daily max	daily min	high mont	lowe mont	high	date year	lowe	date year
	mb	oC	oC	oC	oC	oC	oC	oC		oC	
jan I	985.1	9.5	8.0	20.1	6.6	24.2	2.8	28.3	24	-1.1	17
jan II	983.0	17.6	12.8						1898		1935
feb I	982.6	11.9	9.9	22.9	8.7	27.9	4.5	31.7	28	-2.2	2
feb II	980.3	21.0	13.1						1956		1905
mar I	980.0	18.0	13.6	28.7	13.1	34.3	7.9	38.9	31	2.8	6
mar II	977.5	26.9	16.7						1945		1945
apr I	976.6	25.3	17.2	35.2	18.2	40.2	12.5	43.3	19	7.2	4
apr II	973.2	33.4	19.4						1897		1905
may I	972.1	30.5	20.4	39.4	23.6	43.7	18.7	46.1	29	14.4	5
may II	968.3	37.7	21.8						1884		1907
jun I	968.6	30.9	23.5	38.5	25.9	43.7	21.0	46.7	13	16.1	14
jun II	964.7	36.8	24.4						1932		1900
jul I	968.6	28.6	25.5	33.3	25.5	38.9	22.3	45.0	1	21.1	11
jul II	965.7	31.5	26.5						1931		1955
aug I	970.4	27.8	25.5	32.3	25.0	36.2	22.6	39.8	14	20.6	5
aug II	967.3	30.4	26.6						1960		1914
sep I	974.2	26.9	24.1	32.4	23.4	35.3	19.8	38.3	10	15.6	29
sep II	971.1	30.6	25.3						1899		1944
oct I	980.4	22.4	19.0	30.9	17.2	34.0	12.1	38.3	7	8.9	31
oct II	977.3	28.4	21.2						1899		1953
nov I	983.7	14.8	12.3	26.5	10.1	29.9	6.2	33.9	1	2.8	30
nov II	981.6	22.9	16.1						1952		1934
dec I	985.4	10.3	8.5	22.0	6.8	25.3	3.3	28.5	5	-0.7	25
dec II	983.0	18.6	13.3						1889		1902
annual	977.3	21.4	17.3	30.2	17.0	44.1	2.2	46.7		-2.2	
mean	974.4	28.0	19.9								
nro	30	30	30	30	30	30	30	80		80	
years	28	28	28								

	humidity		cloud amount		rainfall						mean
	rel humid	vapour press	all clouds	low clouds	monthly total	nro rainy days	total in wettest month with year	total in driest month with year	heaviest fall in 24 hours	date and year	wind speed
	%	mb	oktas of sky		mm		mm	mm	mm		km/h
jan I	84	9.2	3.1	1.3	42.9	3.1	162.8	0.	101.6	26	4.0
jan II	54	10.8	3.3	1.5			1911			1883	
feb I	78	10.2	2.8	0.9	46.8	2.8	202.7	0.	111.0	1	4.8
feb II	43	10.6	3.0	1.2			1954			1930	
mar I	62	11.6	2.6	1.0	28.4	2.0	116.3	0.	109.5	2	5.4
mar II	32	10.4	2.9	1.5			1955			1955	
apr I	41	13.1	2.0	0.6	11.3	1.1	67.1	0.	38.3	12	6.1
apr II	22	10.7	2.5	1.0			1909			1949	
may I	37	16.2	1.8	0.5	17.0	1.8	98.0	0.	57.7	30	7.2
may II	20	12.9	2.0	0.8			1913			1910	
jun I	55	23.6	3.3	1.4	90.5	5.0	438.9	0.3	148.8	29	7.3
jun II	37	20.3	2.7	1.4			1906	1947		1906	
jul I	80	30.5	5.7	3.5	337.2	12.7	621.8	53.1	228.9	7	5.8
jul II	68	30.5	5.2	3.1			1889	1911		1889	
aug I	84	31.0	5.5	5.8	329.0	12.9	777.0	47.2	192.8	3	4.6
aug II	73	29.6	5.0	3.5			1942	1899		1898	
sep I	80	27.3	3.6	2.3	206.4	7.0	745.0	0.	266.7	20	4.2

sep II	64	27.7	3.4	2.5			1924			1888	
oct I	73	19.2	1.5	1.0	39.4	1.5	356.1	0.	231.7	9	5.2
oct II	51	19.0	1.4	1.3			1956			1956	
nov I	74	12.2	1.0	0.2	3.2	0.3	74.2	0.	58.2	19	2.6
nov II	46	12.5	1.3	0.4			1911			1911	
dec I	81	10.0	2.2	0.7	12.5	1.0	97.5	0.	58.2	11	3.1
dec II	51	10.9	2.5	0.8			1894			1923	
annual	69	17.8	2.9	1.4	1164.6	51.2	2299.7	511.6	266.7		4.9
mean	47	17.2	2.9	1.6			1942	1935			
nro	30	30	30	30	30	30	80	80	80		30
years	28	28	28	20							

station: Simla

Month	pressure	Air temperature									
		dry bulb	wet bulb	mean daily max	mean daily min	high mont	lowe mont	high	extremes date year	lowe	date year
	mb	oC	oC	oC	oC	oC	oC	oC		oC	
jan I	781.7	4.9	1.0	8.5	1.9	14.3	-3.3	18.9	14	-10.6	11
jan II	781.1	5.2	2.4						1949		1945
feb I	780.8	6.4	2.0	10.3	5.1	16.0	-2.3	20.6	26	-8.5	11
feb II	780.4	7.1	3.8						1953		1950
mar I	781.5	10.3	4.2	14.4	6.8	20.0	0.2	23.9	31	-5.6	25
mar II	780.9	11.4	6.4						1945		1933
apr I	781.8	15.7	7.8	19.2	11.2	24.4	4.1	28.3	29	-1.1	1
apr II	780.6	16.6	9.2						1941		1905
may I	780.5	19.9	11.2	23.4	15.0	27.7	8.7	30.0	29	4.4	4
may II	779.4	21.1	12.4						1944		1924
jun I	778.0	20.6	14.6	24.3	16.2	28.3	10.6	30.6	15	7.8	2
jun II	776.8	21.8	15.6						1932		1922
jul I	776.8	18.1	16.4	21.0	15.6	25.0	12.8	28.9	6	10.0	2
jul II	775.7	19.1	18.6						1901		1932
aug I	778.3	17.5	16.2	20.1	15.2	23.4	13.3	27.8	26	10.6	1
aug II	777.0	17.9	17.0						1951		1957
sep I	780.8	16.8	14.1	20.0	13.8	22.7	10.8	25.0	11	5.0	29
sep II	779.5	17.2	15.3						1946		1940
oct I	784.3	14.5	8.8	17.9	10.8	21.5	6.7	23.9	1	2.8	29
oct II	782.9	14.5	10.2						1938		1904
nov I	783.9	11.0	4.3	15.0	7.3	18.5	3.8	21.1	17	-1.1	19
nov II	782.9	10.7	5.8						1952		1911
dec I	782.9	7.4	2.1	11.3	4.2	17.0	-0.3	20.4	5	-6.1	22
dec II	782.1	7.2	3.6						1960		1937
annual	780.9	13.6	8.6	17.1	10.1	28.6	-4.3	30.6		-10.6	
mean	779.9	14.1	10.0								
nro	30	30	30	30	30	30	30	65		65	
years	28	28									

	humidity rel humid	vapour press	cloud amount all clouds	low clouds	rainfall monthly total	nro rainy days	total in wettest month with year	total in driest month with year	heaviest fall in 24 hours	date and year	mean wind speed
	%	mb	oktas of sky		mm		mm	mm	mm		km/h
jan I	48	3.5	3.7	1.4	65.2	5.4	255.0	0.	78.7	26	3.9
jan II	62	5.3	4.6	2.4			1911			1888	
feb I	45	3.7	3.2	1.1	47.6	4.2	229.6	0.	63.5	2	4.3
feb II	59	5.8	4.4	2.0			1901			1908	
mar I	37	4.0	3.3	1.0	58.1	5.4	231.4	0.	63.0	24	4.7
mar II	48	6.1	3.9	2.3			1911			1901	
apr I	32	5.4	2.4	0.5	37.6	3.8	197.4	0.5	39.6	26	4.5
apr II	37	6.5	3.7	1.9			1917	1896		1890	
may I	54	7.6	2.0	0.6	53.7	4.8	277.4	2.8	97.8	26	4.4
may II	35	8.2	3.2	1.8			1883	1887		1883	
jun I	53	12.1	3.1	1.7	147.5	9.5	471.9	24.4	122.2	29	3.7
jun II	53	13.3	4.1	2.8			1916	1891		1906	
jul I	86	17.2	6.4	4.3	414.5	20.1	757.9	133.5	167.1	20	2.8

jul II	88	19.0	6.7	5.2			1894	1911		1922	
aug I	89	17.4	6.5	3.8	385.4	19.6	1080.3	119.9	227.1	22	2.4
aug II	92	18.9	7.1	5.1			1906	1939		1901	
sep I	75	13.9	4.3	2.3	195.2	10.3	453.6	11.9	135.9	6	2.7
sep II	82	16.0	5.1	4.3			1924	1899		1892	
oct I	47	7.2	1.3	0.5	45.4	2.8	263.1	0.	113.0	1	3.1
oct II	59	9.6	2.1	1.7			1956			1884	
nov I	31	3.6	1.1	0.2	6.7	0.5	125.0	0.	68.8	5	3.1
nov II	48	6.0	1.7	0.5			1883			1894	
dec I	36	3.3	2.7	0.6	23.7	2.2	106.5	0.	76.5	4	3.5
dec II	55	5.5	3.6	1.3			1893			1923	
annual	51	8.2	3.3	1.5	1480.6	88.6	2786.6	992.6	227.1		3.6
mean	60	10.0	4.2	2.6			1894	1931			
nro	30	30	30	20	30	30	80	80	80		30
years	28	28	28	20							

Station: Dehra Dun City

Month	WEATHER PHENOMENA nro of days with prec)0.3 mm	hail	thun-der	fog	dust storm	squal	WIND nro of days with wind speed)62	20--61	1--19	0	percentage nro of days of wind from N	NE	E	SE	S	SW	W	NW	CALM
jan I	6	0.2	3	0.2	0	0	0	0	15	16	15	17	1	1	2	2	5	6	51
jan II							0	0	19	12	3	2	1	3	4	19	20	8	40
feb I	5	0.1	2	0.3	0	0.1	0	0	12	16	13	14	1	1	0	3	6	5	57
feb II							0	0	23	5	4	3	0	3	8	23	30	9	20
mar I	6	0.3	5	0	0	0.4	0	0	14	17	9	9	1	2	1	6	12	5	55
mar II							0	0	24	7	4	5	1	4	6	24	24	10	22
apr I	3	0.2	4	0	0	0.3	0	0	17	13	5	5	1	2	3	13	21	5	45
apr II							0	0	25	5	5	4	0	2	7	25	33	9	15
may I	5	0.2	8	0	0.2	0.1	0	0	18	13	5	4	1	5	6	16	14	6	43
may II							0	0	27	4	6	4	1	2	8	28	27	9	15
jun I	11	0.5	10	0.2	0.1	0.1	0	0	18	12	5	5	2	11	8	12	10	6	41
jun II							0	0	25	5	6	7	1	4	10	21	22	10	19
jul I	26	0	12	1.1	0	0	0	0	18	13	6	6	3	13	10	6	8	4	44
jul II							0	0	23	8	9	7	2	12	8	11	14	8	29
aug I	25	0	12	0.8	0	0	0	0	16	15	5	5	2	12	7	7	7	4	51
aug II							0	0	22	9	7	7	2	10	9	12	16	6	31
sep I	16	0	10	0.6	0	0	0	0	15	15	7	7	4	9	5	6	6	4	52
sep II							0	0	19	11	6	7	1	5	5	9	18	11	38
oct I	4	0.1	5	0	0	0	0	0	14	17	10	12	1	2	2	4	9	4	56
oct II							0	0	11	20	4	2	0	1	2	6	12	7	66
nov I	0.7	0	0.5	0.1	0	0	0	0	12	18	10	9	0	0	0	4	9	5	63
nov II							0	0	6	24	1	1	0	1	1	4	5	6	81
dec I	3	0	0.7	0.1	0	0	0	0	13	18	13	14	1	1	0	2	6	6	57
dec II							0	0	9	22	1	2	0	2	2	7	10	4	72
annual	111	1.6	70	3	0.3	1.0	0	0	182	183	9	9	1	5	4	7	9	5	51
mean							0	0	233	132	5	4	1	4	6	16	19	8	37
nro	20	20	20	20	20	20	26	26	26	26	28	28	28	28	28	28	28	28	28
years							26	26	26	26	28	28	28	28	28	28	28	28	28

Month	CLOUD nro if days wuth cloud amount (all clouds) oktas 0	1-2	3-5	6-7	8	nro of days with low cloud amount oktas 0	1-2	3-5	6-7	8	fog 8	VISIBILITY nro of days with visibility up to 1km	1-4 kms	4-10 kms	10-20 kms	over 20 kms
jan I	10	7	4	5	5	19	5	3	2	2	0	0	0.5	3	11	17
jan II	5	10	5	6	5	13	10	4	2	2	0	0	0.4	4	12	15
feb I	10	6	4	5	3	20	4	2	1	1	0	0	0.4	2	12	14
feb II	6	9	5	5	3	12	10	3	2	1	0	0.1	0.3	3	12	13
mar I	11	8	4	4	4	22	5	2	1	1	0	0	0.6	3	15	12
mar II	6	10	6	5	4	14	10	3	2	2	0	0	0.6	3	16	12
apr I	14	8	4	3	1	23	4	1	1	1	0	0	1.3	4	12	13
apr II	6	13	5	4	2	13	12	3	1	1	0	0	0.9	4	13	12
may I	16	6	4	3	2	23	5	2	1	0	0	0.1	2	8	14	7
may II	8	13	5	4	1	11	15	3	1	1	0	0	2	8	14	7
jun I	10	6	4	4	6	15	8	3	2	2	0	0.2	3	10	12	5
jun II	5	11	7	4	3	8	14	5	2	1	0	0	3	8	13	6
jul I	1	3	5	8	14	2	7	7	6	9	0	0	3	9	11	8
jul II	1	4	9	10	7	1	11	10	5	4	0	0	1.6	7	12	11
aug I	0	4	5	7	15	1	8	7	4	11	0	0	3	9	11	8
aug II	0	3	8	10	10	1	8	10	6	6	0	0	1.4	7	13	10
sep I	5	8	5	5	7	7	10	5	3	5	0	0	1.4	6	12	11
sep II	1	10	7	7	5	1	13	8	4	3	1	0	1.0	6	12	11
oct I	19	6	2	2	2	21	5	2	2	1	0	0	0.4	2	11	18
oct II	11	15	3	1	1	11	15	3	1	1	0	0	0.5	2	12	17
nov I	21	5	2	1	1	28	2	0	0	0	0	0	0.1	0.9	9	20
nov II	15	11	2	2	0	22	7	1	0	0	0	0	0.1	2	12	16
dec I	13	8	4	4	2	23	5	1	1	1	0	0	0.4	2	12	17
dec II	0	3	16	4	8	8	12	7	0	2	2	0	0.2	5	13	13
annual	130	75	47	51	62	204	68	35	24	34	0	0.3	16	59	142	150
mean	64	112	78	62	49	115	137	60	26	24	3	0.1	12	59	154	143
nro	28	28	28	28	28	20	20	20	20	20	20	28	28	28	28	28

years	24	24	24	24	24	20	20	20	20	20	20	24	24	24	24	24

Station: Mussoorie

Month	WEATHER PHENOMENA nro of days with						WIND nro of days with wind speed				percentage nro of days of wind from								
	prec >0.3 mm	hail	thun-der	fog	dust storm	squal	>62	20--61	1--19	0	N	NE	E	SE	S	SW	W	NW	CALM
jan I	7	2	1.6	3	0	0.3	0	0	24	7	17	13	11	14	13	5	1	5	21
jan II							0	0	24	7	7	7	5	15	27	13	3	3	20
feb I	5	1.7	1.6	1.6	0	0.3	0	0	20	8	19	16	8	8	10	4	1	7	27
feb II							0	0	23	5	5	5	4	15	32	17	3	3	16
mar I	6	1.8	4	0.7	0	0.5	0	1	22	8	21	16	8	9	9	3	1	6	27
mar II							0	0	28	3	8	8	5	15	32	17	3	3	9
apr I	4	1.2	5	0.4	0	0.5	0	1	21	8	18	14	6	9	11	6	2	5	29
apr II							0	1	27	2	7	6	3	15	30	22	4	5	8
may I	6	0.8	8	0.5	0.2	0.8	0	0	22	9	16	9	3	11	19	8	2	5	27
may II							0	0	28	3	9	8	4	13	26	19	5	7	9
jun I	11	0.2	9	6	0.1	0.3	0	0	21	9	10	8	3	12	20	10	2	6	29
jun II							0	0	25	5	6	5	3	12	28	18	6	6	16
jul I	25	0	9	19	0	0	0	0	19	12	9	7	3	9	19	8	2	5	38
jul II							0	0	21	10	4	3	2	10	25	16	3	4	33
aug I	27	0.1	9	17	0	0	0	0	19	12	8	6	3	11	18	8	2	5	39
aug II							0	0	22	9	6	5	2	10	27	16	1	3	30
sep I	17	0.1	9	13	0	0.3	0	0	19	11	11	7	3	11	16	6	1	6	39
sep II							0	0	22	8	7	4	1	11	29	17	2	2	27
oct I	4	0.1	2	3	0	0	0	0	20	11	14	10	3	10	15	6	1	5	36
oct II							0	0	25	6	3	5	1	13	57	19	0	2	22
nov I	0.8	0.1	0.5	1.0	0	0	0	0	21	9	12	10	4	12	16	6	2	7	31
nov II							0	0	25	5	3	2	1	15	38	17	2	5	19
dec I	3	0.7	1.4	2	0	0.1	0	0	23	8	14	11	6	13	17	6	2	6	25
dec II							0	0	24	7	7	4	3	14	29	15	2	4	22
annual	116	9	60	67	0.3	3	0	2	251	112	14	10	5	11	15	6	2	6	31
mean							0	1	294	70	6	5	3	13	30	17	3	4	19
nro	20	20	20	20	20	20	26	26	26	26	28	28	28	28	28	28	28	28	28
years							23	23	23	23	25	25	25	25	25	25	25	25	25

Month	CLOUD nro of days with cloud amount (all clouds) oktas					nro of days with low cloud amount oktas					fog	VISIBILITY nro of days with visibility				
	0	1-2	3-5	6-7	8	0	1-2	3-5	6-7	8	8	up to 1km	1-4 kms	4-10 kms	10-20 kms	over 20 kms
jan I	10	6	3	7	5	22	2	1	2	3	1	1.6	0.6	2	4	22
jan II	4	7	5	7	8	14	5	3	3	3	3	4	1.4	5	3	18
feb I	10	5	3	6	4	21	2	2	1	2	0	0.5	1.4	3	4	19
feb II	4	7	4	7	6	12	7	3	2	3	1	1.8	1.9	6	3	16
mar I	10	7	4	6	4	23	2	2	1	3	0	0.8	1.3	4	5	21
mar II	4	9	5	7	6	13	8	3	4	3	0	0.8	3	5	4	18
apr I	13	8	3	4	2	24	3	1	1	1	0	0.3	1.6	3	5	20
apr II	4	11	6	7	2	8	14	4	3	1	0	0.1	2	6	4	18
may I	15	7	2	5	2	24	3	1	2	1	0	0.7	5	4	6	15
may II	4	12	6	7	2	8	14	3	4	2	0	0.4	6	6	6	13
jun I	9	5	3	6	7	15	4	2	3	3	3	6	6	5	5	9
jun II	2	7	6	8	7	6	8	5	6	2	3	5	8	5	3	9
jul I	2	1	2	7	19	4	3	3	3	6	12	17	4	2	1.5	6
jul II	1	1	2	6	21	1	2	3	5	6	14	18	4	1.9	1.9	5
aug I	0	2	3	7	19	2	4	3	4	6	12	16	4	3	1.5	7
aug II	0	0	2	6	23	1	2	2	4	6	16	21	3	1.5	1.4	5
sep I	4	6	5	5	10	8	6	3	3	5	5	7	3	3	3	14
sep II	1	3	3	7	16	1	3	5	5	6	10	14	3	3	2	8
oct I	17	7	2	3	2	20	5	2	1	2	1	1.5	0.6	3	4	21
oct II	7	12	4	3	5	7	12	3	3	2	4	4	2	4	3	18
nov I	18	7	2	3	0	28	2	0	0	0	0	0	0	2	4	24
nov II	11	11	3	3	2	19	7	1	1	1	1	1.4	0.8	5	4	19
dec I	11	9	3	5	3	25	2	1	1	2	0	0.3	0.1	3	5	23
dec II	7	10	4	6	4	19	5	1	2	3	1	3	0.5	6	4	17

annual	119	70	35	64	77	216	58	21	22	34	34	52	28	37	48	201
mean	49	90	50	74	102	109	87	36	42	38	53	73	36	54	39	164
nro	28	28	28	28	28	20	20	20	20	20	20	28	28	28	28	28
years	28	28	28	28	28	20	20	20	20	20	20	28	28	28	28	28

Station: Roorkee

Month	WEATHER PHENOMENA nro of days with						WIND nro of days with wind speed				percentage nro of days of wind from								
	prec >0.3 mm	hail	thunder	fog	dust storm	squal	>62	20--61	1--19	0	N	NE	E	SE	S	SW	W	NW	CALM
jan I	5	0.3	2	0.7	0	0	0	0	17	14	1	2	1	10	1	3	1	35	46
jan II							0	0	20	11	1	2	0	9	1	3	2	46	36
feb I	4	0.3	3	0.3	0.1	0	0	0	17	11	3	5	1	14	0	3	1	34	39
feb II							0	0	22	6	1	2	1	11	1	5	3	55	21
mar I	4	0.2	2	0	0.1	0	0	0	20	11	2	3	1	17	1	3	1	36	36
mar II							0	1	24	6	1	2	1	12	1	5	2	57	19
apr I	1.8	0.2	1.9	0.1	0.1	0	0	0	19	11	2	5	2	24	1	3	1	23	39
apr II							0	0	25	5	1	2	0	13	1	4	2	61	16
may I	3	0.1	5	0	0.9	0	0	1	23	7	2	3	1	44	1	2	0	23	24
may II							0	1	26	4	0	2	1	18	1	6	1	59	12
jun I	7	0	5	0	1.1	0	0	1	24	5	1	3	1	56	1	1	1	17	19
jun II							0	0	26	4	0	3	1	27	2	5	1	47	14
jul I	15	0.5	8	0	0.2	0	0	1	22	8	1	3	1	60	1	1	0	6	27
jul II							0	1	22	8	1	3	3	44	2	4	1	16	26
aug I	17	0.5	7	0	0	0	0	0	21	10	1	2	1	49	2	1	2	9	33
aug II							0	0	22	9	1	2	1	39	3	4	1	19	30
sep I	9	0.1	3	0	0.1	0	0	0	19	11	2	4	1	43	1	1	1	11	36
sep II							0	0	20	10	1	3	1	21	1	4	1	34	34
oct I	2	0	1.3	0	0	0	0	0	16	15	1	4	1	35	1	1	0	7	50
oct II							0	0	15	16	0	1	1	11	0	1	1	31	54
nov I	0.6	0	0.4	0	0.1	0	0	0	11	19	1	2	1	15	1	2	1	12	65
nov II							0	0	12	18	1	0	0	3	1	1	1	30	63
dec I	2	0	0.4	0.4	0	0	0	0	12	19	2	2	0	11	0	2	1	20	62
dec II							0	0	15	16	0	1	0	7	1	1	2	34	54
annual	70	2	39	1.5	3	0	0	3	221	141	2	3	1	31	1	2	1	19	40
mean							0	3	249	113	1	2	1	18	1	4	1	41	31
nro	20	20	20	20	20	20	26	26	26	26	28	28	28	28	28	28	28	28	28
years							26	26	26	26	28	28	28	28	28	28	28	28	28

	CLOUD nro if days wuth cloud amount (all clouds) oktas					nro of days with low cloud amount oktas						VISIBILITY nro of days with visibility				
	0	1-2	3-5	6-7	8	0	1-2	3-5	6-7	8	fog 8	up to 1km	1-4 kms	4-10 kms	10-20 kms	over 20 kms
jan I	9	7	6	4	5	21	3	3	2	1	1	1.2	5	7	3	15
jan II	7	8	7	5	4	18	6	4	2	1	0	0	3	7	6	15
feb I	8	9	5	3	3	20	3	3	2	0	0	0	4	6	4	14
feb II	6	10	6	4	2	16	8	3	1	0	0	0.1	2	5	6	16
mar I	9	10	6	4	2	23	3	4	1	0	0	0	2	7	6	16
mar II	8	8	8	4	3	15	9	5	1	1	0	0	2	7	7	15
apr I	12	9	5	2	2	25	2	2	1	0	0	0	1.2	7	7	15
apr II	8	10	7	3	2	18	8	3	1	0	0	0	2	8	8	12
may I	13	9	5	2	2	26	2	2	1	0	0	0.1	3	8	11	9
may II	12	10	5	2	2	21	7	3	0	0	0	0.1	4	7	13	6
jun I	7	8	5	5	5	19	3	5	2	1	0	0.2	4	6	11	9
jun II	8	8	7	4	3	17	6	5	1	1	0	0.3	5	6	11	8
jul I	2	3	8	9	9	6	5	11	6	3	0	0.1	4	5	7	15
jul II	0	4	13	9	5	4	9	14	4	0	0	0	2	4	6	19
aug I	1	4	8	9	9	5	6	9	8	3	0	0.2	4	5	8	14
aug II	0	5	12	9	5	2	10	13	5	1	0	0	1.2	4	6	19
sep I	6	8	7	5	4	10	8	7	4	1	0	0	1.3	6	9	14
sep II	4	10	10	4	2	5	12	10	2	1	0	0	0.7	5	8	16
oct I	16	9	3	2	1	23	4	2	2	0	0	0	0.4	6	6	19

oct II	13	13	3	1	1	14	13	3	1	0	0	0	0.3	6	6	18
nov I	18	9	2	1	0	28	2	0	0	0	0	0	1.0	6	5	18
nov II	16	9	4	1	0	25	4	1	0	0	0	0	0.9	7	6	16
dec I	11	10	5	3	2	25	2	3	1	0	0	0.5	3	7	6	15
dec II	9	10	6	4	2	23	4	5	1	0	0	0	3	7	9	12
annual	112	95	65	49	44	231	43	51	30	9	1	2	33	76	83	173
mean	91	105	88	50	31	178	96	67	19	5	0	0.5	26	73	92	172
nro	28	28	28	28	28	20	20	20	20	20	20	28	28	28	28	28
years	28	28	28	28	28	20	20	20	20	20	20	28	28	28	28	28

Station: Simla

Month	WEATHER PHENOMENA nro of days with						WIND nro of days with wind speed				percentage nro of days of wind from								
	prec >0.3 mm	hail	thun-der	fog	dust storm	squal	>62	20--61	1--19	0	N	NE	E	SE	S	SW	W	NW	CALM
jan I	9	0.7	1.3	3	0	0.4	0	0	23	8	8	9	3	25	21	4	1	2	27
jan II							0	0	24	7	6	11	5	19	22	12	1	2	22
feb I	7	1.4	1.8	1.4	0	0.6	0	0	20	8	10	17	3	17	18	3	1	1	30
feb II							0	0	23	5	8	9	2	12	27	18	2	5	17
mar I	9	1.8	5	0.5	0.2	0.4	0	0	23	8	9	16	4	18	19	5	1	2	26
mar II							0	0	28	3	10	6	2	12	28	20	5	8	9
apr I	6	1.6	5	0.2	0.1	0.3	0	0	21	9	9	16	5	15	16	6	1	2	30
apr II							0	0	28	2	9	7	1	9	27	24	6	10	7
may I	8	1.3	7	0.2	0.4	0.1	0	0	23	8	10	17	7	13	14	7	2	3	27
may II							0	0	29	2	12	8	2	5	20	25	9	14	5
jun I	12	0.7	9	2	0.1	0.1	0	0	21	9	10	16	9	8	13	7	3	5	29
jun II							0	0	27	3	11	8	3	5	18	21	8	14	12
jul I	25	0	5	8	0	0	0	0	20	11	12	15	3	8	14	7	2	3	26
jul II							0	0	23	8	12	8	2	6	18	15	5	8	26
aug I	24	0	3	10	0	0	0	0	19	12	10	14	5	7	14	5	1	3	41
aug II							0	0	22	9	12	11	3	8	13	11	4	9	29
sep I	15	0.2	4	4	0	0	0	0	19	11	14	19	5	7	9	3	0	4	39
sep II							0	0	23	7	14	13	4	4	12	14	5	12	22
oct I	5	1.0	2	0.3	0.1	0	0	0	21	10	11	17	4	10	14	5	1	3	35
oct II							0	0	26	5	14	8	2	6	19	19	4	11	17
nov I	1.1	0.2	0.3	0	0	0.1	0	0	21	9	13	18	4	11	14	4	1	2	33
nov II							0	0	23	7	13	15	3	9	17	13	2	5	23
dec I	5	1.0	0.9	0.8	0	0.1	0	0	22	9	12	14	4	17	17	3	1	2	30
dec II							0	0	24	7	10	18	4	16	19	8	1	2	22
annual	126	10	44	30	0.9	2	0	0	253	112	11	16	5	13	15	5	1	3	31
mean							0	0	300	65	11	10	3	9	20	17	4	8	18
nro	20	20	20	20	20	20	26	26	26	26	28	28	28	28	28	28	28	28	28
years							26	26	26	26	28	28	28	28	28	28	28	28	28

	CLOUD: nro if days wuth cloud amount (all clouds) oktas 0	1-2	3-5	6-7	8	nro of days with low cloud amount oktas 0	1-2	3-5	6-7	8	fog 8	VISIBILITY: nro of days with visibility up to 1km	1-4 kms	4-10 kms	10-20 kms	over 20 kms
jan I	10	5	3	6	7	24	1	1	2	2	1	1.3	0.1	3	10	17
jan II	6	5	4	7	9	16	4	3	2	4	2	3	1.0	19	6	2
feb I	9	6	2	5	6	23	1	1	1	2	0	0.1	0	3	10	14
feb II	4	6	5	7	6	16	5	3	2	2	0	2	1.0	20	5	1.0
mar I	11	6	3	6	5	25	2	1	1	1	1	0.4	0.4	4	13	13
mar II	5	8	5	7	6	16	5	4	3	3	0	1.0	1.0	20	8	1.0
apr I	13	6	3	5	3	27	1	0	1	1	0	0.1	0.4	5	11	13
apr II	4	10	5	7	4	15	8	3	2	2	0	0	1.0	15	13	1.0
may I	16	6	2	4	3	26	2	0	1	2	0	0.3	0.7	9	13	8
may II	6	11	5	6	3	14	9	3	3	2	0	0	1.0	18	11	1.0
jun I	11	5	2	5	7	21	2	1	2	3	1	2	2	13	9	4
jun II	3	8	6	8	5	10	7	5	5	2	1	2	2	17	8	1.0
jul I	1	2	3	8	17	7	3	2	4	10	5	10	2	9	6	4
jul II	0	2	3	10	16	4	3	4	6	11	3	9	4	11	6	1.0
aug I	1	2	4	8	16	7	4	3	2	8	7	11	2	7	6	5
aug II	0	1	3	9	18	2	3	5	5	10	6	13	3	10	4	1.0
sep I	7	6	3	6	8	15	4	2	2	5	2	4	0.9	6	10	9
sep II	2	5	6	7	10	3	5	7	6	7	2	6	2	14	7	1.0
oct I	21	4	2	2	2	26	2	1	1	1	0	0.5	0.3	3	9	18
oct II	11	11	3	3	3	14	10	3	2	2	0	1.0	1.0	18	10	1.0
nov I	20	5	2	2	1	29	1	0	0	0	0	0.1	0	0.3	8	22
nov II	14	9	3	3	1	25	4	1	0	0	0	1.0	1.0	21	7	:
dec I	12	7	3	5	4	27	1	1	1	1	0	0.4	0.2	2	9	20
dec II	7	8	4	7	5	22	3	2	2	2	0	1.0	2	21	6	1
annual	132	60	32	62	79	257	24	13	18	36	17	30	9	64	116	147
mean	62	84	52	81	86	157	68	41	38	47	14	39	20	204	91	12
nro	28	28	28	28	28	20	20	20	20	20	20	28	28	28	28	28
years	28	28	28	28	28	20	20	20	20	20	20	28	28	28	28	28

Climatological data for the years 1969-1984

Source: Forest research institute and colleges, New Forest, Dehra Dun
Pamphlet No. 3-18

Station: New Forest (Dehra Dun)

Mon	Av.temperature max. (deg.C)	min.	mean	Av.R.hum 07h (perc.)	14h	Av.Vap.pr 07h (mm of Hg)	14h	No rain days	Rain-fall (mm)	Evaporat. Tot (mm)	av/day	Sunsh/ day (hours)	Av. wind velocity (km/h)
1969													
Jan	19.4	3.5	10.9	96	41	6.2	6.3	7	25.3	43.6	1.5	7.2	1.2
Feb	23.0	5.5	14.0	91	33	6.6	6.4	3	12.7	64.7	2.3	8.3	1.7
Mar	29.6	10.6	20.0	84	30	9.3	8.8	3	36.7	126.8	4.1	9.4	1.9
Apr	32.9	14.5	23.5	70	34	11.0	12.1	6	17.4	185.9	6.2	7.9	3.2
May	34.1	16.7	24.8	67	32	13.6	11.7	12	138.5	177.3	6.3	8.9	2.8
Jun	36.6	21.2	28.1	72	38	18.1	15.6	9	53.0	205.8	6.9	8.5	2.3
Jul	30.4	22.5	26.0	89	69	23.0	21.6	24	476.8	74.6	3.4	4.8	1.5
Aug	29.1	21.9	24.7	95	82	20.9	22.6	26	859.4	50.9	2.8	4.8	2.5
Sep	28.5	20.2	23.8	94	76	18.7	20.6	20	201.5	62.1	2.6	5.9	2.1
Oct	28.6	13.7	20.7	93	57	12.6	15.1	1	32.4	75.9	2.4	9.4	1.9
Nov	25.5	8.6	16.5	98	57	9.0	13.1	0	0.0	57.2	2.0	9.1	1.9
Dec	21.8	4.1	12.5	97	43	6.3	8.1	0	0.0	41.5	1.3	8.3	1.9
Tot.								111	1853.7	1166.3			
1970													
Jan	18.8	3.9	10.7	94	48	6.2	7.0	4	79.6	37.1	1.2	6.5	2.4
Feb	21.2	5.7	13.2	96	57	7.2	10.0	2	32.4	52.9	2.0	8.4	2.8
Mar	25.7	8.9	17.2	91	57	9.0	13.8	1	11.6	96.0	3.1	8.9	3.0
Apr	33.8	13.5	23.7	73	20	11.4	7.4	1	9.2	172.6	5.7	9.6	3.3
May	36.8	17.5	26.4	64	30	13.2	11.6	6	99.2	214.0	6.9	9.6	3.2
Jun	31.4	21.6	25.7	87	65	19.6	19.4	12	291.8	90.0	3.6	6.2	1.7
Jul	31.1	22.5	26.2	91	70	21.4	22.3	15	417.9	76.2	3.3	5.3	1.5
Aug	29.9	22.6	25.6	96	79	21.6	22.2	22	632.1	45.8	2.7	4.1	1.3
Sep	30.0	20.8	24.8	94	74	19.3	20.8	14	447.4	58.0	2.8	6.5	1.0
Oct	28.7	14.8	21.3	92	58	13.7	15.6	3	71.8	67.9	2.4	8.8	1.0
Nov	24.9	6.1	15.0	95	43	7.6	9.5	0	0.0	57.8	1.9	9.0	1.1
Dec	21.7	3.1	11.9	96	45	6.0	8.2	0	0.0	43.1	1.4	7.8	1.1
Tot.								80	2093.0	1011.4			
1971													
Jan	19.2	2.8	10.4	95	48	5.7	7.5	3	45.6	49.1	1.6	7.7	1.5
Feb	21.6	5.1	13.0	95	54	6.9	9.9	4	56.2	60.4	2.3	8.2	2.3
Mar	27.3	8.2	17.8	87	42	8.3	10.8	1	2.8	113.0	3.6	9.4	2.3
Apr	31.7	14.8	23.1	77	44	12.6	14.5	5	54.8	156.4	5.2	8.9	2.6
May	32.1	17.1	23.9	78	49	14.9	16.0	7	114.5	160.3	5.3	8.7	3.4
Jun	30.1	22.3	25.2	90	77	20.7	21.6	19	587.9	53.1	2.8	4.5	1.8
Jul	29.5	22.4	25.4	93	78	21.1	21.9	20	599.5	60.4	2.9	4.7	1.5
Aug	28.1	21.7	24.1	96	81	20.3	21.3	25	1180.6	26.5	2.2	3.9	1.5
Sep	29.4	18.7	23.5	92	67	17.4	19.3	7	136.5	80.7	3.1	8.2	1.2
Oct	27.8	13.7	28.3	93	56	12.9	14.9	5	82.6	80.0	2.8	8.9	1.1
Nov	23.8	8.0	15.4	97	49	8.4	10.3	2	37.4	48.4	1.7	8.4	1.2
Dec	21.2	4.6	12.4	98	45	6.6	8.2	0	0.0	45.5	1.5	8.3	1.2
Tot.								98	2898.4	933.8			
1972													
Jan	20.4	4.0	11.6	97	44	6.5	7.4	3	14.2	42.6	1.4	6.8	1.5
Feb	19.3	3.9	11.4	95	49	6.3	7.7	5	106.6	55.5	2.2	8.8	2.3
Mar	27.5	9.9	18.5	88	41	9.2	10.8	2	48.9	108.7	3.5	8.2	2.4
Apr	30.2	12.8	21.5	82	49	11.4	15.1	5	50.0	152.2	5.1	9.8	2.9
May	37.2	16.9	26.5	62	25	12.7	12.0	0	0.3	239.4	7.7	10.1	2.6
Jun	36.8	21.3	28.1	66	38	16.7	15.1	5	51.1	215.1	7.4	6.9	3.0
Jul	30.8	22.8	26.3	89	73	21.4	22.3	12	278.2	94.8	3.8	5.6	2.1
Aug	29.7	21.7	24.9	94	77	20.4	22.0	19	324.9	71.4	3.1	5.4	1.1

Sep	28.9	18.2	22.9	93	66	17.0	18.9	14	565.9	71.3	3.0	7.9	2.4
Oct	27.8	11.6	19.3	91	49	11.1	12.9	2	10.2	88.9	2.9	8.8	2.3
Nov	24.6	7.9	15.8	96	46	8.7	10.2	1	2.9	60.2	2.0	8.8	2.3
Dec	21.4	4.7	12.5	96	44	7.0	7.9	1	7.6	45.1	1.5	7.4	2.3
Tot.								69	1460.8	1245.2			
1973													
Jan	19.3	4.5	11.3	96	49	6.8	7.5	7	80.4	39.8	1.4	6.5	2.4
Feb	22.4	6.4	14.3	96	43	7.7	8.4	4	26.6	60.9	2.2	7.9	3.0
Mar	26.1	8.4	17.3	88	41	8.7	10.3	4	59.3	105.1	3.6	8.2	3.2
Apr	35.2	14.1	24.6	66	26	10.7	11.1	0	0.0	203.8	6.8	9.7	3.6
May	35.9	17.9	26.1	66	41	14.8	16.9	2	30.1	250.0	8.1	9.7	4.3
Jun	32.2	21.7	26.1	84	62	19.7	19.8	17	228.5	124.9	4.8	5.9	3.2
Jul	30.5	22.5	25.9	90	75	21.9	22.3	17	915.2	78.5	3.9	5.9	3.4
Aug	29.7	21.7	25.0	94	77	20.9	21.8	22	496.5	67.6	3.2	4.6	2.9
Sep	29.8	20.3	24.4	94	72	19.5	20.7	15	346.9	76.7	3.3	6.9	2.9
Oct	27.7	13.2	20.0	94	55	13.0	14.5	4	106.8	86.2	2.9	9.1	2.4
Nov	24.9	6.6	15.2	97	45	8.2	10.1	0	0.0	64.0	2.1	9.4	1.8
Dec	20.3	3.2	11.2	96	47	6.9	7.9	1	12.0	48.4	1.6	7.7	2.4
Tot.								93	2302.3	1205.9			
1974													
Jan	19.8	4.4	11.5	95	44	6.3	7.3	3	52.9	46.8	1.6	7.4	2.6
Feb	20.9	5.0	12.7	91	45	6.4	7.7	1	20.6	67.4	2.5	7.5	2.6
Mar	27.9	10.8	19.2	85	52	9.4	14.0	0	5.4	118.9	3.8	8.4	2.5
Apr	34.3	14.9	24.7	72	37	11.5	14.6	1	8.0	205.2	6.8	10.1	8.1
May	36.6	17.8	26.5	60	31	13.0	13.5	3	40.5	252.9	8.2	9.7	3.6
Jun	35.2	21.2	27.3	73	47	17.8	18.3	6	78.4	190.6	6.8	8.1	3.1
Jul	30.6	22.5	25.9	90	73	20.6	21.4	22	729.4	70.6	3.9	5.3	2.2
Aug	30.0	22.6	25.5	93	73	20.7	21.6	17	452.5	82.1	3.4	5.7	2.0
Sep	30.7	19.9	24.7	90	60	17.7	19.0	6	47.5	118.3	3.9	8.8	1.9
Oct	28.8	13.9	21.0	89	49	12.7	13.9	4	26.3	94.9	3.2	8.7	1.5
Nov	25.7	6.1	15.4	90	36	7.2	8.5	0	0.0	72.0	2.4	9.3	1.2
Dec	19.2	4.0	11.1	92	47	6.2	7.3	4	67.8	39.8	1.4	5.7	1.1
Tot.								67	1529.3	1359.1			
1975													
Jan	17.7	4.6	10.6	93	57	6.5	7.9	6	71.1	36.3	1.3	5.6	1.4
Feb	20.6	6.0	13.1	93	51	7.1	8.8	5	67.1	52.7	2.1	7.7	1.8
Mar	25.7	9.3	17.4	88	42	8.7	9.9	6	119.2	106.6	3.6	8.4	3.6
Apr	33.3	13.3	23.3	73	32	10.9	11.9	0	0.0	165.7	5.7	9.9	3.6
May	36.9	17.0	26.3	62	33	14.0	15.0	2	21.4	243.8	8.1	10.8	4.6
Jun	33.9	20.8	26.5	74	55	17.6	17.7	12	380.1	144.8	6.6	7.4	3.4
Jul	30.0	21.7	25.2	90	75	20.3	20.0	20	430.8	65.3	3.4	5.5	3.2
Aug	29.8	22.0	25.1	93	75	20.4	21.5	21	487.7	61.3	2.8	4.6	2.9
Sep	28.6	20.2	23.8	93	75	18.6	20.0	18	428.2	65.8	2.9	5.3	3.1
Oct	28.7	15.2	21.4	91	57	13.8	15.4	3	48.8	84.6	2.8	8.9	2.7
Nov	24.1	5.4	14.4	95	43	7.4	9.3	0	0.0	63.2	2.1	9.4	2.5
Dec	21.1	2.7	11.4	96	43	6.1	7.8	0	0.0	45.3	1.5	8.1	2.3
Tot.								93	2054.4	1135.4			
1976													
Jan													
Feb													
Mar													
Apr													
May													
Jun													
Jul													
Aug													
Sep													
Oct													
Nov													
Dec													

Tot.

1977

Jan	19.3	4.5	11.4	97	51	6.5	8.1	4	49.4	44.8	1.5	6.4	3.0
Feb	23.2	4.4	13.6	94	38	6.3	8.0	0	1.2	75.0	2.7	9.4	3.4
Mar	30.9	9.4	19.7	81	31	8.4	9.9	1	6.2	139.4	4.5	9.8	3.9
Apr	31.9	14.4	22.9	77	39	12.0	12.7	4	39.4	176.0	5.9	8.5	4.5
May	32.7	17.0	24.3	68	40	14.0	13.7	6	65.9	206.2	6.7	9.7	4.4
Jun	34.5	20.5	26.7	73	54	18.1	18.9	8	285.9	162.1	6.0	7.6	4.1
Jul	29.6	23.4	25.9	94	83	22.1	22.9	24	627.2	54.4	2.6	3.3	3.1
Aug	29.8	22.6	25.5	95	78	21.4	22.8	18	767.1	72.8	3.2	4.7	3.0
Sep	29.1	20.4	24.2	94	73	19.1	20.3	18	513.6	80.3	3.7	6.2	3.0
Oct	27.5	15.7	21.1	95	64	14.5	17.0	1	16.2	84.8	2.7	8.3	2.5
Nov	25.1	10.3	17.2	96	51	9.9	12.1	0	0.0	58.0	2.0	8.6	2.4
Dec	20.3	5.4	12.2	96	49	7.0	8.0	4	58.2	41.3	1.4	6.6	2.6
Tot.								88	2430.3	1195.1			

1978

Jan	18.7	3.4	10.6	96	44	6.1	6.8	1	4.4	46.0	1.5	8.0	2.9
Feb	20.0	5.7	12.6	94	46	7.1	7.8	4	67.6	66.6	2.5	7.2	3.3
Mar	22.7	8.3	15.3	88	53	9.0	10.1	8	171.4	93.1	3.3	7.6	4.3
Apr	30.6	13.2	22.0	83	39	12.4	12.6	3	65.8	142.6	4.9	9.1	3.6
May	36.6	18.4	26.8	65	36	15.3	16.1	1	4.0	230.3	7.4	11.1	3.9
Jun	33.3	23.2	27.3	81	59	20.0	19.6	11	390.0	144.7	6.0	6.5	3.5
Jul	30.0	22.7	25.7	93	77	21.7	22.3	22	656.6	68.5	3.1	4.6	3.2
Aug	29.2	22.7	25.3	95	80	21.5	22.4	21	1094.6	48.9	1.6	3.8	2.8
Sep	29.0	20.1	23.9	92	72	18.9	20.1	14	433.1	83.8	3.4	7.1	2.9
Oct	28.4	13.7	20.7	91	54	13.4	15.2	1	4.6	93.1	3.0	9.8	2.3
Nov	24.1	8.9	15.9	95	53	9.4	11.2	4	69.2	56.4	1.9	8.0	2.5
Dec	21.0	4.8	12.4	98	48	7.0	8.6	1	7.6	41.6	1.3	8.3	2.3
Tot.								91	2968.9	1115.6	39.9	91.1	37.5

1979

Jan	19.9	5.1	12.0	96	48	7.1	8.0	4	48.6	44.0	1.5	7.4	2.8
Feb	19.6	6.0	12.5	93	55	7.5	8.7	4	121.3	48.1	1.9	7.2	3.4
Mar	24.1	8.5	16.3	89	43	8.9	9.3	1	11.9	103.1	3.3	8.0	4.0
Apr	32.6	14.2	23.3	81	41	13.0	14.3	0	7.3	168.8	5.8	9.5	3.7
May	34.5	15.8	24.5	69	38	13.4	14.6	3	65.1	202.7	7.0	9.7	4.0
Jun	35.3	20.6	27.1	73	50	18.6	19.1	9	253.8	174.4	6.5	9.1	3.9
Jul	30.6	22.0	25.7	92	77	21.5	23.2	20	622.3	96.5	14.2	5.4	3.0
Aug	30.9	22.0	25.8	93	73	21.2	23.1	14	408.7	88.6	3.5	6.4	2.9
Sep	31.0	17.1	23.5	91	52	16.2	16.9	1	15.0	119.4	4.0	8.9	2.5
Oct	30.0	13.1	21.2	92	49	12.8	14.8	0	0.0	112.6	3.6	9.3	2.5
Nov	27.0	9.0	17.5	93	48	9.5	12.5	0	0.6	75.0	2.5	7.9	2.5
Dec	21.7	5.5	13.0	96	43	7.1	7.8	1	25.7	47.5	1.6	6.9	2.4
Tot.								57	1580.3	1280.7	45.4	95.7	37.6

1980

Jan	20.5	3.5	11.5	93	43	6.1	7.2	2	11.3	50.5	1.6	7.8	2.8
Feb	22.7	6.3	14.2	92	41	7.5	7.7	2	26.4	69.4	2.5	8.2	3.3
Mar	25.0	9.0	16.9	88	44	9.2	9.7	6	50.4	103.0	3.4	7.0	3.7
Apr	34.7	14.5	24.7	69	28	11.4	11.5	1	8.7	220.7	7.4	10.6	4.4
May	37.5	19.2	27.7	59	37	14.7	17.3	2	7.4	292.7	9.4	10.0	5.0
Jun	32.7	21.8	26.4	83	61	19.8	20.2	12	341.4	142.9	5.5	7.2	3.7
Jul	30.2	23.1	26.1	95	76	22.0	22.6	22	545.5	51.6	2.7	3.9	3.0
Aug	30.1	22.2	25.5	95	76	21.3	22.3	21	890.7	59.7	3.3	5.6	2.7
Sep	30.3	19.8	24.4	91	64	18.1	19.3	8	150.2	87.8	3.4	7.9	2.6
Oct	28.5	14.2	20.9	92	51	13.3	14.1	1	11.7	84.7	2.7	8.4	2.3
Nov	25.0	8.5	16.3	95	45	9.1	10.2	2	17.9	59.3	2.0	8.6	2.3
Dec	21.4	5.1	12.7	98	49	7.2	8.8	1	12.1	42.1	1.4	7.8	2.1
Tot.								80	2083.7	1264.4	45.3	138.3	37.9

1981

Jan	18.0	4.8	10.9	97	57	7.2	8.1	7	90.0	36.9	1.3	6.2	2.6
Feb	22.2	6.8	14.1	95	44	7.8	8.2	0	6.9	57.3	2.1	7.5	3.0
Mar	24.6	9.7	17.1	93	47	9.7	10.4	6	74.1	88.9	3.0	7.5	3.7
Apr	31.5	14.3	23.0	78	33	12.3	11.5	1	6.8	172.3	5.7	9.9	3.9
May	34.3	17.9	25.5	68	37	15.0	14.2	6	79.3	224.8	7.3	10.0	4.2
Jun	35.4	20.6	27.0	69	43	17.1	15.8	9	242.3	170.5	6.8	8.6	3.6
Jul	30.0	23.1	26.0	93	78	22.0	22.6	24	699.2	54.9	3.2	3.7	2.5
Aug	30.6	22.6	25.9	92	74	21.4	22.3	12	467.7	77.1	3.4	5.5	2.6
Sep	30.6	20.0	24.6	93	64	18.5	19.6	11	128.8	99.3	3.3	7.3	2.2
Oct	29.4	12.3	20.5	94	47	12.0	13.4	0	0.0	91.2	2.9	9.8	2.3
Nov	24.0	8.2	15.7	93	51	9.1	10.2	3	75.5	47.1	1.6	8.0	2.1
Dec	21.6	3.0	11.8	94	40	5.9	7.1	1	7.6	45.6	1.5	8.7	2.4
Tot.								80	1879.1	1065.9	42.1	92.7	35.1

1982

Jan	20.1	4.8	11.9	95	51	6.8	7.1	5	88.7	36.8	1.3	6.3	2.5
Feb	19.5	5.9	12.5	94	54	7.7	8.3	4	62.5	43.5	1.6	6.4	2.8
Mar	22.6	8.6	15.6	93	54	9.0	10.6	9	185.9	70.2	2.5	7.4	3.5
Apr	29.9	12.9	21.3	84	41	12.0	12.2	7	56.5	139.2	4.8	9.3	3.6
May	31.9	15.7	23.2	82	41	14.5	12.8	7	104.2	155.9	5.6	9.1	3.3
Jun	34.7	20.5	26.6	80	49	18.1	17.5	7	103.9	162.8	5.4	9.1	3.3
Jul	33.4	22.2	27.1	86	65	19.5	21.1	15	434.1	125.9	4.0	6.1	2.9
Aug	30.7	22.7	25.9	93	77	20.8	22.4	21	652.9	62.3	3.5	4.7	2.5
Sep	31.3	18.4	24.3	93	60	17.6	20.2	4	40.5	109.5	3.7	8.8	2.5
Oct	29.2	12.8	20.5	93	53	12.4	14.9	2	51.7	83.4	2.8	8.4	2.3
Nov	25.3	8.4	16.4	93	48	9.0	11.1	0	0.1	61.2	2.0	7.8	2.2
Dec	21.8	4.3	12.4	94	44	6.4	8.0	2	52.2	47.2	1.6	6.7	2.2
Tot.								83	1833.2	1097.9	38.8	90.1	33.6

1983

Jan	18.6	3.7	10.6	95	55	6.3	8.2	3	78.5	36.4	1.3	6.8	2.3
Feb	20.9	5.0	12.7	94	46	6.7	8.0	3	25.7	57.8	2.1	7.5	2.8
Mar	25.1	8.3	16.6	91	45	8.7	10.1	4	65.3	94.2	3.1	7.4	3.2
Apr	27.5	11.9	19.7	87	47	11.4	11.8	8	97.7	104.6	4.0	7.5	3.3
May	32.0	16.6	23.6	80	50	15.2	15.2	8	113.4	142.5	5.3	9.3	3.1
Jun	35.0	18.9	26.4	72	39	16.2	14.1	5	91.0	191.1	6.6	9.4	3.4
Jul	31.6	22.2	26.4	88	68	23.3	21.5	17	323.2	101.7	4.1	6.0	2.5
Aug	30.4	23.4	26.1	94	76	21.9	22.5	21	689.5	61.6	2.8	3.2	2.4
Sep	30.7	22.2	25.8	93	70	20.2	21.6	13	346.1	69.5	3.0	6.8	2.1
Oct	28.6	14.6	21.0	92	50	12.3	14.2	4	41.8	91.1	3.0	9.3	2.1
Nov	25.5	10.3	17.4	96	46	8.2	10.8	0	0.0	57.3	2.0	9.1	1.7
Dec	20.8	3.8	11.7	95	46	6.0	8.0	1	6.2	44.9	1.4	7.4	1.8
Tot								87	1796.5	1052.7	38.7	89.7	30.7

1984

Jan	19.2	1.8	10.0	95	41	5.2	6.6	2	9.5	46.3	1.5	7.3	2.2
Feb	21.0	3.9	12.2	94	40	6.0	7.0	6	123.4	58.2	2.2	7.7	2.9
Mar	28.3	9.9	19.1	90	36	9.4	10.2	1	3.7	113.1	3.6	8.7	2.8
Apr	32.7	12.9	22.7	76	22	11.7	9.8	1	7.6	184.5	6.2	8.8	3.6
May	38.2	18.3	27.6	60	26	14.3	12.4	0	1.0	259.9	8.4	9.5	3.7
Jun	32.9	23.2	27.1	84	62	20.4	20.3	13	389.5	109.6	4.8	4.9	2.7
Jul	29.9	21.9	25.3	93	75	20.9	21.7	26	687.4	69.8	3.7	4.9	2.4
Aug	30.2	22.6	25.7	93	77	21.4	22.1	18	298.6	69.1	3.0	4.5	1.8
Sep	29.5	18.6	23.5	94	63	17.1	18.7	11	207.1	88.3	3.3	7.8	1.8
Oct	29.7	11.7	20.2	94	39	10.8	11.7	0	0.0	101.7	3.3	9.8	1.8
Nov	25.3	6.3	15.3	96	42	7.5	9.7	0	0.0	64.8	2.2	8.8	1.6
Dec	22.1	3.7	12.4	96	42	6.3	7.7	1	13.1	46.1	1.5	7.0	1.5
Tot.								79	1740.9	1211.4	43.7	89.7	28.8

Temporal distribution of annual rainfall

Year	precipitation (cm)
1865	148.
1866	185.
1867	225.
1868	140.
1869	180.
1870	220.
1871	300.
1872	230.
1873	240.
1874	160.
1875	216.
1876	215.
1877	110.
1878	210.
1879	274.
1880	220.
1881	240.
1882	235.
1883	160.
1884	155.
1885	220.
1886	300.
1887	240.
1888	210.
1889	215.
1890	240.
1891	140.
1892	180.
1893	260.
1894	320.
1895	210.
1896	180.
1897	176.
1898	310.
1899	150.
1900	180.
1901	224.
1902	148.
1903	150.
1904	220.
1905	130.
1906	200.
1907	180.
1908	276.
1909	270.
1910	278.
1911	265.
1912	180.
1913	155.
1914	152.
1915	170.
1916	220.
1917	230.
1918	280.
1919	120.
1920	160.
1921	230.
1922	251.
1923	285.
1924	205.

1925	180.
1926	280.
1927	174.
1928	173.
1929	180.
1930	170.
1931	226.
1932	225.
1933	252.
1934	180.
1935	305.
1936	300.
1937	222.
1938	250.
1939	174.
1940	175.
1941	245.
1942	260.
1943	177.
1944	224.
1945	230.
1946	250.
1947	224.
1948	205.
1949	225.
1950	176.
1951	205.
1952	210.
1953	260.
1954	227.
1955	255.
1956	178.
1957	230.
1958	280.
1959	176.
1960	278.
1961	222.
1962	230.
1963	240.
1964	230.
1965	225.
1966	222.
1967	175.
1968	165.
1969	175.
1970	210.
1971	215.
1972	146.
1973	230.
1974	153.
1975	205.
1976	???
1977	243.
1978	297.
1979	158.
1980	208.
1981	188.
1982	183.
1983	180.
1984	174.

Source: Dept. of Environment
data for years 1972-1984 are from Forest Research Institute, Dehra Dun pamphlets about climatological data for the New Forest Station in Dehra Dun

Monthly average rainfall (60 years) (mm)
(UNDP)

jan	58.9
feb	62.7
mar	32.0
apr	16.5
may	36.8
jun	217.2
jul	668.0
aug	731.3
sep	269.7
oct	32.0
nov	8.9
dec	25.9

Potential temperature differences between
Mussoorie and valley floor (in oC)

Height (100m)	Diifference (oC)
0	0.0
1	0.5
2	1.0
3	1.9
4	1.7
5	4.2
6	3.8
7	7.0
8	1.9
9	3.2
10	4.5
11	7.3
12	6.2
13	7.7

Potential temperature profile measured outside the left front window of a moving automobile, 10.00 - 11.00 LST 9 January, 1986, between the city limits of Dehra Dun and Mussourie.

Expected rainfall (in cm) Dehradun with different percent chance frequency

Month/ period	90%	80%	70%	60%	50%	40%	30%	20%	10%	5%	1%
Jan	0.25	1.35	2.41	3.96	5.87	7.47	8.61	10.13	12.04	15.24	22.73
Feb	0.85	1.35	2.44	3.56	4.32	5.99	7.98	11.51	14.73	18.54	21.29
Mar	0.08	0.64	1.14	1.65	2.82	4.11	4.76	6.27	8.33	10.57	19.66
Apr	0.03	0.20	0.43	0.79	1.09	1.78	2.08	3.12	4.65	6.00	9.68
May	0.56	0.89	1.65	2.29	2.87	3.68	4.72	5.87	6.98	11.66	19.30
Jun	3.51	8.10	10.49	13.51	17.40	21.22	25.96	35.46	40.94	46.00	61.95
Jul	38.00	48.08	58.32	64.90	70.15	76.61	83.69	87.93	99.87	108.89	113.69
Aug	42.80	50.07	57.99	65.53	71.70	77.05	88.21	98.60	104.24	117.48	163.65
Sep	7.72	13.69	17.22	23.06	27.03	32.84	35.08	40.41	56.24	65.99	101.40
Oct	0.	0.	0.13	0.79	1.50	3.20	4.93	8.36	11.33	17.58	32.54
Nov	0.	0.	0.	0.	0.	0.10	0.36	1.24	3.10	3.91	11.43
Dec	0.	0.	0.23	0.51	1.04	1.73	2.54	4.14	8.28	9.93	15.01
Annu	154.94	177.80	190.50	205.74	215.90	226.06	241.30	266.70	284.48	302.26	309.90
Premo	10.90	15.19	17.40	24.03	26.62	30.23	35.92	40.92	50.55	57.86	71.88
Monso	107.57	135.69	150.65	159.31	175.90	186.97	200.66	218.72	231.85	249.86	262.31
Posmo	6.00	7.54	9.75	11.58	13.72	18.11	19.43	23.32	26.75	31.88	40.41

Premonsoon - March, April, May, June
Monsoon - July, August, September, October
Postmonsoon- November, December, January, February

Frequency = 100. / Percent chance

Population during last 12 decades
District Dehradun
(yearbook 1984)

YEAR	total	male	female	rural	urban	% increase during 10 years
1872	117000					
1881	144000					23.08
1891	168000					16.67
1901	177500	102400	75100			5.65
1911	204500	120500	84000			15.21
1921	211900	128000	83400			3.62
1931	229800	137300	92500			8.45
1941	265785	161671	104115			15.66
1951	361689	210860	150829			36.08
1961	429014	242987	186027	231179	197835	18.60
1971	577306	326108	251798	305529	271777	34.57
1981	761668	420465	341203	389527	372141	31.93

Percentage of different workers in main working class:
District Dehradun
(yearbook 1984)

Total main workers	247982	100 %
Farmers	69291	28 %
Agricultural workers	19682	8 %
Family industry	3168	1 %
Others	155841	63 %

Population & area in 1971 according blocks:

	population	area in sq km
block Chakrata	22834	302
block Kalasi	38660	278
block Sahaspur	112709	1229
block Doiwala	112991	1114
block Vangram	8335	0
total rural	305529	2923
total urban	271777	165
Doon valley rural	234035	2343
Doon valley total	505812	2508
Dehra Dun District	577306	3088

Electricity Consumption in District
in kWhours Electricity in use
(yearbook 1984)

	1981-82	1982-83	1983-84
Domestic light & power	46080	58500	139360
Commercial light &power	4097	30258	18176
Industrial capacity	88847	157084	158416
Public lightning	874	798	1133
Agricultural consumption	5372	5113	4846
Sewer & water supply	12205	14347	13997
Total	257475	266600	335928
Per capita use	338	350	441

Percentage of Electrified Villages

1970-71	6 %
1973-74	15 %
1978-79	32 %
1981-82	50 %
1983-84	63 %

Extraction of Forest Product in Dehradun in Cu.M.
Source: Dept. of Environment

Year	Commercial Wood	Commercial Firewood	Free & Concessional Wood	Free & Concessional Firewood	Total
1959-60	26698	9515	6	4376	40595
1960-61	20654	29181	13	2532	52380
1961-62	19514	56056	52	3414	79036
1962-63	13111	62564	150	3166	78991
1963-64	15456	51326	135	3232	70149
1964-65	34772	63490	111	3155	101528
1965-66	37359	62782	0	983	101124
1966-67	32788	76067	2	28	108885
1967-68	26926	54303	n.a.	n.a.	81229
1968-69	36873	187493	115	166	224647
1969-70	41864	141380	125	693	184062
1970-71	45620	176002	175	8	221805
1971-72	51855	125025	129	378	177387
1972-73	34043	115746	108	142	150039
1973-74	31023	91556	35	97	122711
1974-75	31342	83434	126	84	114986
1975-76	40777	89706	50	530	131063
1976-77	34053	85089	85	173	119400
1977-78	39737	n.a.	108	563	40408

Growth of forest revenue

year	revenue Ro.	growth %	expenditure Ro	growth %
1945	1080904	-	165140	-
1946	1235302	12.5	188833	14.3
1947	1389681	11.8	212526	12.5
1948	1543996	12.5	236139	11.1
1949	3484782	25.9	378484	60.2
1950	4392395	23.19	416397	27.9
1951	5506375	27.4	378852	10.0
1952	3216983	38.5	387777	2.3
1953	2678341	21.2	380752	0.2
1954	2660067	0.3	359101	8.2
1955	4079493	12.4	385665	7.4
1956				
1957	5654347	70.9	458915	16.1
1958	4220542	25.2	630508	16.4
1959	4320562	2.2	600292	3.8
1960	4525320	4.7	699980	3.8
1961	5015649	6.3	799039	12.8
1962	5963680	4.3	814556	3.2
1963	6954002	18.5	786156	3.8
1964	8404161	16.9	882447	12.2
1965	11986339	14.5	1306248	48.2
1966	12890035	8.9	890468	37.7
1967	12340018	4.4	1148573	29.3
1968	12450365	0.9	1313332	19.9
1969	13647050	9.5	1411541	3.3
1970	16215524	11.4	1519994	7.2

Remark: values and percentages are not reliable
Source: Dept. of Environment

Runoff versus crop rotation in Dehradun Valley

particulars	Sannhemp-wheat	Iwar fodder-wheat	Maize wheat
Rainfall (mm)	986.8	986.6	986.8
Runoff (mm)	427.8	267.2	179.8
Runoff as %	43.3	27.0	18.2
Rainfall (mm)	1678.3	1678.3	1678.3
Runoff (mm)	1007.4	386.1	680.0
Runoff as %	60.0	23.0	40.0
Rainfall (mm)	1023.0	1023.0	1023.0
Runoff (mm)	409.8	70.6	110.7
Runoff as %	40.0	6.9	10.8
Rainfall (mm)	1018.6	1430.2	833.8
Runoff (mm)	280.0	78.0	36.0
Runoff as %	27.5	5.5	4.3

Runoff and soil erosion
(for monsoon period)

Treatment	Rainfall (mm)	water losses as % of rainfall	soil erosion tons/hour
(for monsoon period)			
Foddergrass	1250	27.1	1.10
Barefollon	1250	71.1	42.40
Bare ploughed	1250	59.6	155.95
Natural grass	1250	21.2	1.00
(for winter rains)			
Fodder grass	173	11.4	1.10
Bare fallon	173	58.7	3.55
Bare ploughed	173	45.6	5.77
Natural grass	173	4.1	0.03

The area in Dehra Dun District in years 1880 - 1980 (in hectares)

	1880	1890	1900	1910	1920	1930	1940	1950	1960	1970	1980
temporary crops	35986	36484	36544	38975	35739	39487	40119	42323	54372	53411	56101
permanent crops	1842	1842	2111	2172	2087	2099	2086	1995	2046	1459	1245
wet rice	9404	9404	10195	9691	9166	10332	9458	11896	13779	13247	12088
fallows	3291	4653	4294	3657	6410	3728	3412	3490	4100	4602	6502
ARABLE	41119	42979	42949	44804	44236	45314	45617	47808	60518	59472	63848
conifer	20446	20065	19760	19332	19139	18818	18512	18036	16826	16628	15949
trop. B/L humid forest	38821	38328	37980	37393	37257	36874	36517	35822	33652	33256	32361
temperate B/L forest	29504	29068	28741	28235	28071	27719	27388	26804	25120	24941	24039
mixed woods	27174	27010	26945	26709	26795	26702	26627	26303	24884	24942	24271
trop. dry forest/woodland	56937	56335	55944	55200	55121	54675	54268	53358	50240	49884	48541
FOREST/WOODLAND	172882	170806	169370	166869	166383	164788	163312	160323	150722	149651	145161
swamp/marsh	21481	21094	20786	20350	20160	19835	19526	19038	17773	17540	16874
MAJOR WETLANDS	21481	21094	20786	20350	20160	19835	19526	19038	17773	17540	16874
SURFACE WATER	7720	7720	7720	7720	7720	7720	7720	7720	7720	7720	7720
wood/field mosaics	3907	4012	4131	4222	4363	4475	4590	4659	4526	4625	4646
woods/shrub/grass complex	35172	36117	37185	38004	39274	40282	41310	41935	40739	41627	41815
INTERRUPTED WOODS	39079	40129	41316	42226	43637	44757	45900	46594	45265	46252	46461
grassland/shrubland	21223	20607	21129	21120	20881	20475	20536	20406	19567	19817	18954
GRASS/SHRUB COMPLEXES	21223	20607	21129	21120	20881	20475	20536	20406	19567	19817	18954
deser & semidesert	4140	4116	4106	4049	4083	4066	4056	4008	3792	3716	3698
TOTAL WASTELAND & DESERT	4140	4116	4106	4049	4083	4066	4056	4008	3792	3716	3698
SETTLED, BUILT-UP, RR & ROADS	1156	1349	1424	1642	1700	1845	2133	2903	3443	4632	6084
AREA FROM AGGREGATE SOURCE	308800	308800	308800	308800	308800	308800	308800	308800	308800	308800	308800
TOTAL POPULATION	144070	168135	177465	204534	211877	229850	265786	361689	429014	577306	758241

compare 1980 - 1880	change	% change
temporary crops	20115	55.9
permanent crops	-597	-32.4
wet rice	2684	28.5
fallows	3211	97.6
ARABLE	22729	55.3
conifer	-4497	-22.0
trop. B/L humid forest	-6460	-16.6
temperate B/L forest	-5465	-18.5
mixed woods	-2903	-10.7
trop. dry forest/woodland	-8396	-14.7
FOREST/WOODLAND	-27721	-16.0
swamp/marsh	-4607	-21.4
MAJOR WETLANDS	-4607	-21.4
SURFACE WATER	0	0.0
wood/field mosaics	739	18.9
woods/shrub/grass complex	6643	18.9
INTERRUPTED WOODS	7382	18.9

grassland/shrubland	-2269	-10.7
GRASS/SHRUB COMPLEXES	-2269	-10.7
deser & semidesert	-442	-10.7
TOTAL WASTELAND & DESERT	-442	-10.7
SETTLED, BUILT-UP, RR & ROADS	4928	426.3
AREA FROM AGGREGATE SOURCE	0	0.0
TOTAL POPULATION	614171	426.3

Table prepared by John F. Richards

Fertilizer distribution in Dehradun District
(yearbook 1984)

	nitrogen		phosphat		potash		all fertilizer	
	total tonn	per ha kg	total tonn	per ha kg	total tonn	per ha kg	total tonn	per hectar kg
1980-81	1224	13.85	305	3.45	97	1.10	1626	18.4
1981-82	1428	16.16	421	4.76	138	1.56	1987	23.31
1982-83	1441	16.31	298	3.37	104	1.18	1843	20.96

annual applications of chemical fertilizers
for Dehra Dun District
(source: Gazetteer)

	Kharif	tonn	Rabi	tonn	Annual	tonn	kg/ha	
	1969-70	70-71	1969-70	70-71	1969-70	70-71	1969-70	70-71
Nitrogenous	331	371	459	540	787	911	14.1	16.4
Phosphatic	87	70	151	217	238	287	4.3	5.2
Potasic	36	36	101	118	137	154	2.5	2.8

annual applications of insecticides & pesticides

for Uttar Pradesh

organo-chlorine	1238.0	cons	tonn/year	0.204	kg/hectar	applic
organo-phosphorus	24.0	cons	tonn/year	0.004	kg/hectar	applic
others	107.0	cons	tonn/year	0.018	kg/hectar	applic
N fertilizer	67088	cons	tonn/year	11.3	kg/hectar	applic
P fertilizer	15747	cons	tonn/year	2.7	kg/hectar	applic
K fertilizer	7394	cons	tonn/year	1.2	kg/hectar	applic

Data about land use
(source: Yearbook 1984)

Net cultivated and irrigated land in hectares

	net cultivated	net irrigated
1970-71	55647	18386
1973-74	54652	17536
1978-79	58336	22673
1981-82	56469	23697
1982-83	57348	23542

Area in hectares of main crops
(1982-83)

wheat	28305
barley	2278
rice	16090
maize	12701
sugarcane	5037
potato	971
total main crops	65362

Use of land in hectars in Dehra Dun District (*)

	total area under cultiv.	forest	fallow	present land	other land
1980-81	322786	226086	11938	2848	3250
1981-82	319151	222514	11879	2823	3035
1982-83	320189	222391	11821	3061	3241

Land in District under cultivation of various crops
(in hectares)

	Rice		Wheat		Barley		Maize	
	total	irrig	total	irrig	total	irrig	total	irrig
1980-81	17477	13545	27735	12576	2257	123	12200	706
1981-82	16185	12655	27902	11700	2330	172	11923	521
1982-83	16090	12088	28305	11828	2278	99	12701	454

(*) Headings for these tables were taken from translation from original language

Livestock population, 1890-1966

	1890	%	1898	%	1908	%	1914	%	1929	%	1934	%	1966	%
bulls/bullocks	30328	18.2	37366	18.8	43999	17.4	44271	16.8	47271	16.6	47273	16.6	57890	18.4
other bovines	65524	39.2	84546	42.6	107848	42.6	119938	45.6	116375	40.9	122665	42.8	138089	43.8
total bovines	95847	57.4	121912	61.4	151847	60.0	164209	62.4	163646	57.5	170388	59.4	195979	62.2
sheep/goats	68813	41.2	73078	36.8	96832	38.3	94546	35.9	115609	40.6	111915	39.0	115900	36.8
horses/mules/donkeys	2387	1.4	3463	1.7	4193	1.7	4433	1.7	5139	1.8	4400	1.5	3052	1.0
camels	0	0.0	3	0.0	179	0.1	96	0.0	116	0.0	175	0.1	1	0.0
total	167047	100.0	198456	100.0	253051	100.0	263284	100.0	284510	100.0	286878	100.0	314932	100.0
human pop	168135		177465		204534		211877		229850		265786		429014	
ratio of livestock to human pop	99:100		112:100		124:100		124:100		124:100		108:100		73:100	
forage/grazing area	60736		62445		63346		64518		65232		66436		64832	
fallow	4653		4294		3657		6410		3728		3412		4100	
total	65389		66739		67003		70928		68960		69848		68932	
hectares per animal	0.39		0.34		0.26		0.27		0.24		0.24		0.22	

Table prepared by John F. Richards

Annual values of water need, precipitation, actual water utilized, deficiency and surplus of the stations
(computed acc. to 1955 scheme of Thornthwaite)

Station	Lat	Long	Elevation (mts)
Mussoorie	30o 27'	78o 05'	2042
Dehradun	30o 19'	78o 02'	682
Roorkee	29o 51'	77o 58'	254

TABLE 1a/

Station	water need (cm)	Precipitation (cm)	water utilized (cm)	deficiency (cm)	surplus (cm)
Mussoorie	72.3	236.1	70.8	1.5	166.1
Dehradun	116.4	231.4	107.9	8.5	123.5
Roorkee	133.4	116.3	160.1	27.3	10.2

TABLE 1b/

Station	P.E. (cm)	S.C %	Im %	Ia/Ih %
Mussoorie	72.2	41.9	222.4	0.2
Dehradun	116.5	44.8	101.7	7.3
Roorkee	133.7	44.4	-46.0	1.7

P.E potential Evaporation
S.C Summer concentration of thermal efficiency
Im Moisture index
Ia/Ih Index of aridity / Index of humidity

TABLE 1c/

Water balance acc to 1955 scheme of Thornthwaite (cm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	YEAR
PE	1.7	2.5	6.2	12.1	17.1	18.6	16.4	14.8	12.6	8.2	4.0	2.2	116.4
P	6.2	5.9	4.0	1.7	4.2	18.6	72.1	76.5	32.7	7.1	0.5	1.9	231.4
AE	1.7	2.5	6.2	9.9	11.7	18.7	16.4	14.8	12.6	8.2	3.7	2.2	107.9
WD	0.0	0.0	0.0	2.2	6.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	8.5
WS	0.0	3.3	0.0	0.0	0.0	38.0	61.7	20.1	0.0	0.0	0.0	0.0	123.5

PE - Potential evapo-transpiration
P - Precipitation
AE - Actual evapo-transpiration
WD - Water deficit
WS - Water surplus

GRAPHICAL PRESENTATION OF MAPS OF DOON VALLEY

This system is planned to be used as a core for presentation of dynamic changes in the region in graphical form. These can be either forest cover changes during the time, or changes in area of arable land, pollution areas, etc. In all of these cases, input data must be digitized to get the areas in use. To use this system with different display possibilities (e.g., on the SUN computer which has the display 1024 x 1024 pixels), one has to recompute all coordinates for the new display mode.

Here we have a hardcopy of some maps. Because of technical problems, we cannot produce these maps in color as they are displayed on the AED terminal. This is why some maps seem to be overloaded by various lines and characters.

Technical description:

Necessary hardware: present version of programs works with AED 512 graphical terminal. The display has 512 x 512 pixels.

Necessary software: WAED package with graphical subroutine support. WAED is a set of subroutines written in fortran 77 for the VAX 11/780 computer under the operating system Unix.

You can display maps consisting of several layers and their sequence can be chosen from the menu. You have the following possibilities:

- to display the basis map (region boundaries with rivers and legend)
- to add river names
- to paint urban areas
- to add names of urban areas
- to paint geographical coordinates and scale of the map
- to add district names
- to display main roads and railway
- to display isolines
- to display wind roses for Dehra Dun City and Mussoorie for every month

You can start with displaying the basis map and later you can add any other layer, if the picture is full, you can start again from basis map.

There is a possibility to zoom any part of the picture (but of course the number of pixels remains the same). This can be done using keyboard and special stick on the AED graphical terminal.

The package consists of several subroutines written in 2 files: 'waed.f' and 'opengr.f'. Except this file 'colcom' is necessary. This file contains 'common /color/' which is used in several subroutines (with a help of 'include' command). The system libraries with graphical subroutines are necessary, too.

To start the work with this system you have to have the executable file WAED ready. This file can be prepared using following command:

```
xf77 -g waed.f opengr.o -lxaed -lxhash -lxU77 -o WAED
```

Then you type WAED and the system starts his work. Follow the dialog through your terminal.

Besides programs you need data files, which contain coordinates of different objects (boundaries, rivers, roads, isolines etc). All coordinates (data in the files and also values of variables in the subroutines) are in absolute values (pixel coordinates), e.g. between 1. and 512.

From the total available system subroutines for graphical support only these were used:

gropen - init graphics
wendgr - terminate graphics
wscald - define scaling
wclut - define the particular color
wcolor - change the current color
wmove - move the cursor
wmover - move relative
wdraw - draw the line
wdrawr - draw relative
wfrect - draw the rectangle
txtbox - display the text
wifill - fill the closed polygon with given color
wlstyl - set line style
wflush - paint the picture (empty internal buffers)
wthick - define thickness of the line

Necessary data files are:

basis - with coordinates of boundaries and rivers
coord - with coordinates of geographical coordinates
isolines - with coordinates of isolines
roads - with coordinates of roads and railway
urban - with coordinates of urban areas
winds - percentual number of days of prevailing wind for every month

REFERENCES

B. Schweeger, Nov 1982, IIASA LS-6, Description of the library of graphics subroutines

B. Schweeger, July 1983, IIASA, LS-13, Supplement to the description of the library of graphics - subbroutines color graphics extentions

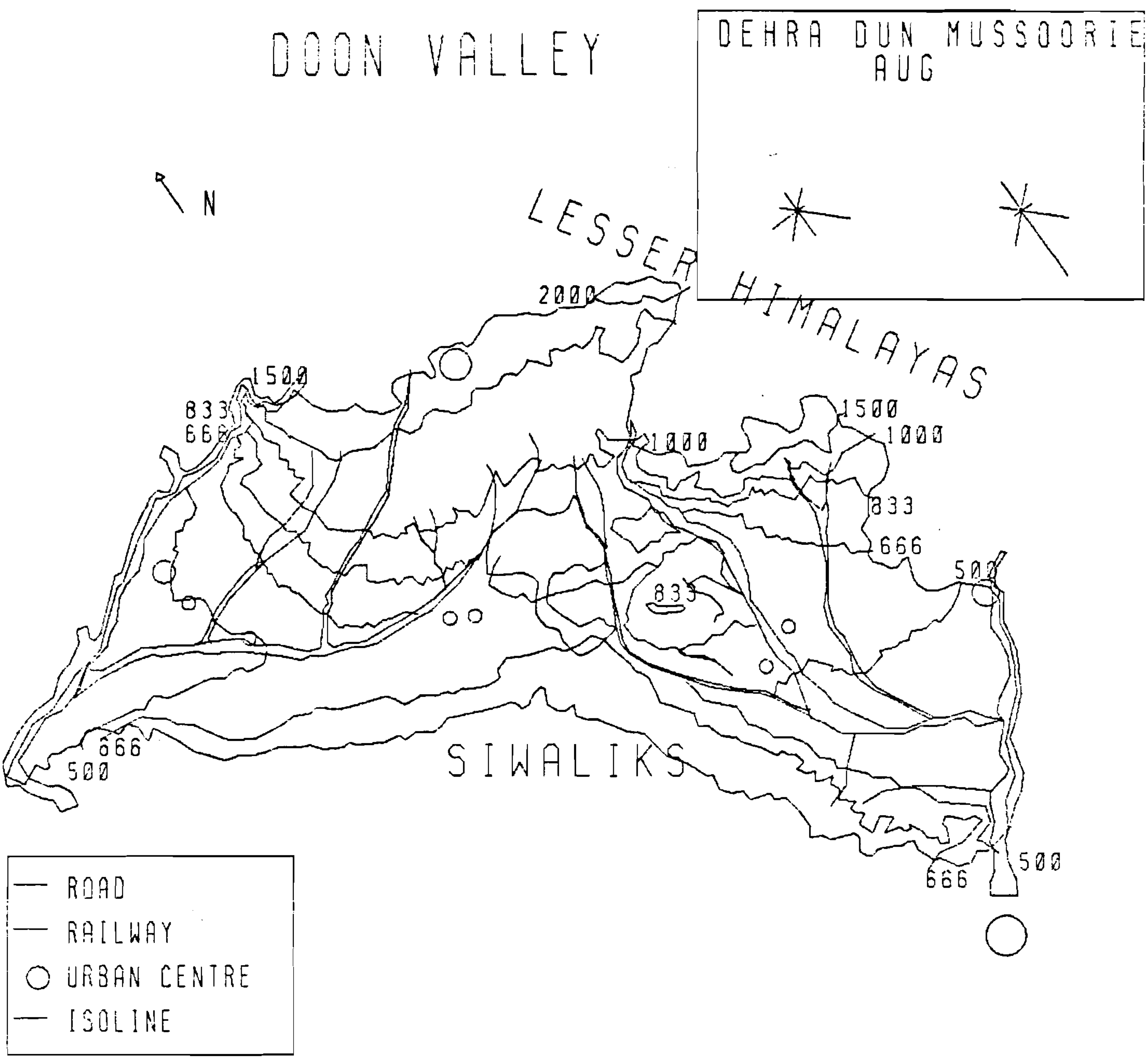

Figure 9 Dehra Dun - isolines and wind roses

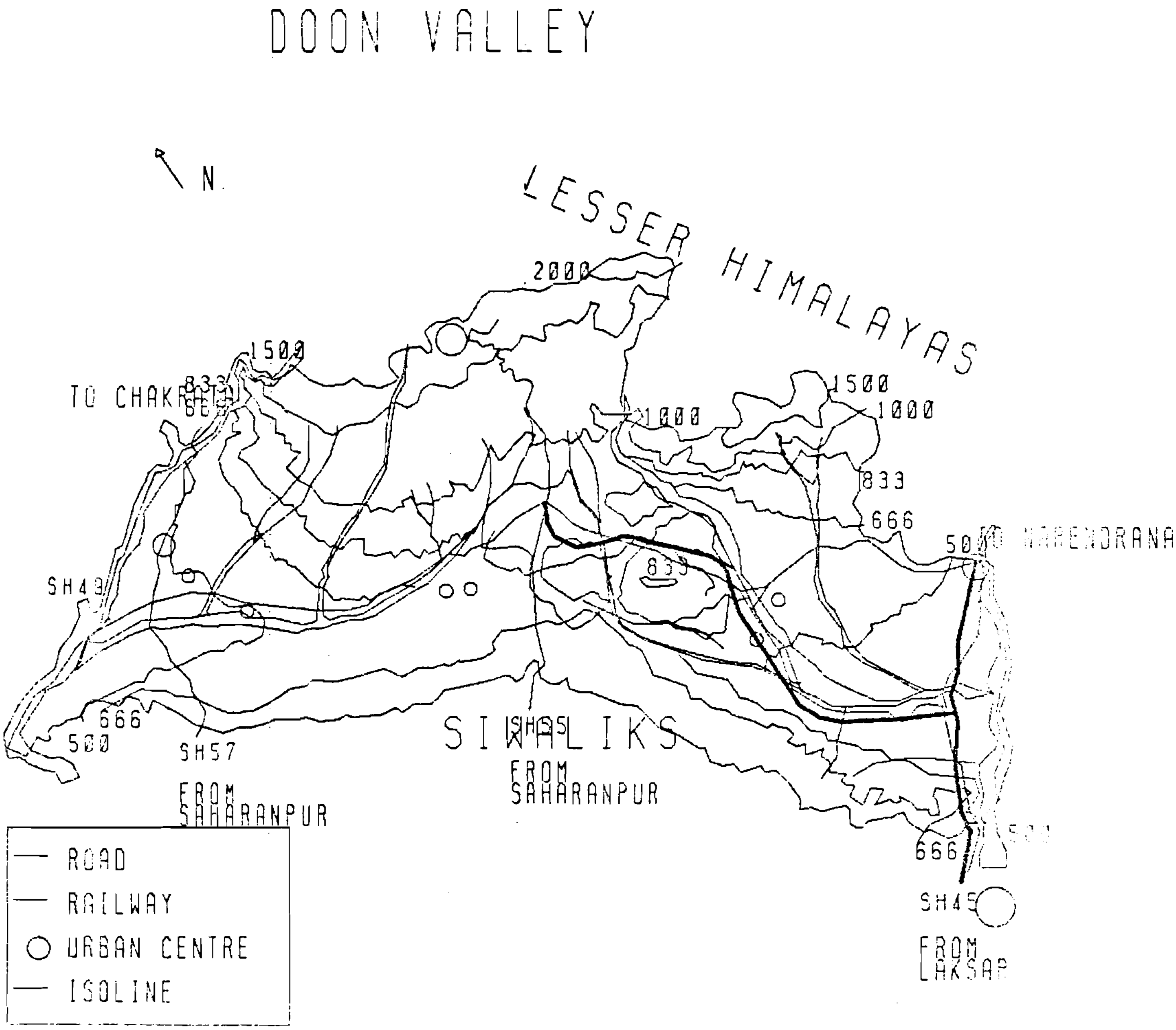

Figure 10 Dehra Dun - roads, railways, isolines

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AN ASSESSMENT OF ENVIRONMENTAL IMPACTS OF INDUSTRIAL DEVELOPMENT

With Special Reference to the Doon Valley, India

Phase I

VOLUME III

REPORTS BY COLLABORATORS

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UNIDO Contract No. 85/82 (US/GLO/85/039)

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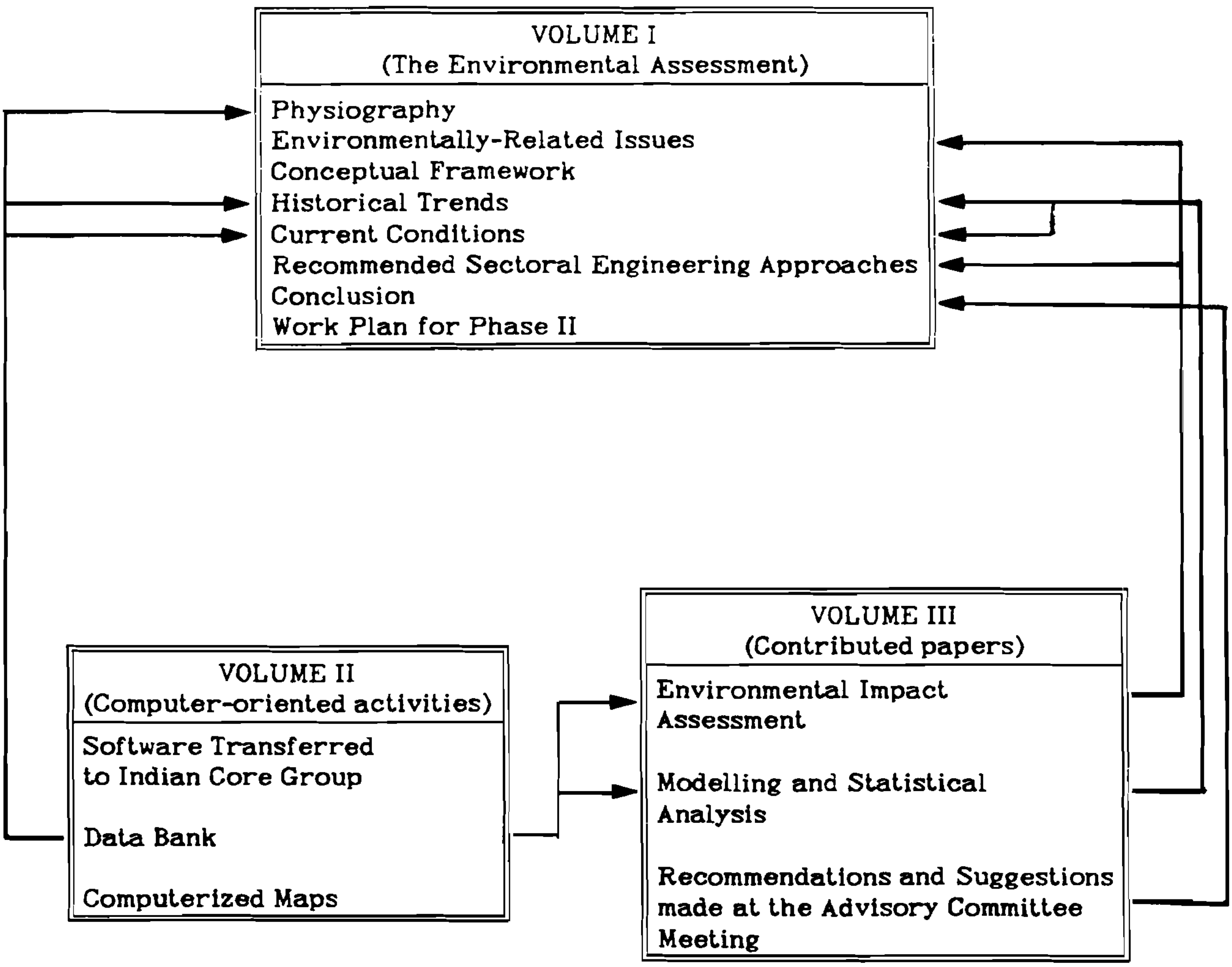
THE STRUCTURE OF THE REPORT



FOREWORD

The present report (Phase I) contains three parts.

Volume I covers a conceptual framework for environmental impact assessment of the Doon Valley, a description of present environmental conditions and past trends in the region, and a comprehensive work program and recommendations for Phase II of the project. To a great extent, Volume I summarizes the main findings of Phase I of the Project, reserving the presentation of details for the two other volumes.

Volume II is devoted to computer-oriented results of Phase I, including a data bank. The potential users should be equipped with elementary computer knowledge: this volume contains tools (more accurately, the instructions on how to use them) but not any final results.

The present volume contains a collection of contributed papers which were presented at the Advisory Committee Meeting (March 1986, IIASA) and some proposals on future activities made by participants of this meeting. Some of the papers are rather general but the majority of them are devoted to specific aspects of the environmental assessment of the Doon Valley and supplement Volume I.

CONTENTS

I ENVIRONMENTAL IMPACT ASSESSMENT

COMMENTS ON DOON VALLEY

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Initial Impressions

One cannot help being struck by the complexity of the problems posed by developments in the Doon Valley. Any approach to dealing with the complexity of issues involved would not reflect the conventional approach to project- specific environmental impact assessment (EIA) as practiced in most developed countries. On the contrary, the Doon Valley situation is more representative of the problem with cumulative environmental effects - a problem which we are only beginning to seriously address in the industrialized world.

Nevertheless, in my experience the problems of development in the Doon Valley are not unique. I have seen and heard of numerous other examples in other parts of the developing world. What makes these situations very difficult to deal with is (1) the direct dependence of the majority of the population on the natural resource base, (2) the degree of competition for resources brought on by the density of population, and (3) the lack of adequate control systems available to those responsible for resource management. Attempts are being made to deal with these situations through the application of EIA; however, it is difficult to make the model fit. EIA, as originally perceived, was a forward-looking mechanism designed to support important development decisions yet to be taken. Here it is being applied to unravel an environmental mess that has resulted from a lack of planning over the years.

It is also clear to me that any approach to resolving the problems in the Doon Valley must give equal weight to the natural (ecological) system and the social system, i.e., public aspiration, administrative difficulties and jurisdictional conflicts. In other words, a focus on an "ecological audit" without similar attention to the social dimension of the problem will not resolve the issues involved.

In short, I see the Doon Valley as a challenge - can we demonstrate that the underlying concepts and principles of environmental impact assessment are flexible enough to be applied to complex environmental problems currently facing the developing world? If we can make it work in the Doon Valley, it could be a model for application elsewhere.

The Objective for Phase I

As I understand it, Phase I of the project is to produce a detailed proposal (action plan) to guide the actual conduct of Phase II. An important component of Phase I will be a conceptual framework or model which will provide the basis for synthesizing or integrating the diverse sectoral problems which characterize the overall situation.

Following on the above-noted theme, I think it is important to develop such a conceptual framework which will take account of the socio-economic and political problems as well as those stressed in the resource sectors - agriculture, forestry, mining, etc. The conceptual framework should not be limited to the ecological "connectivity" but address the human ecology aspects as well.

Approaching the Problem

If we try to adopt the six "requirements" advocated by Beanlands and Duinker (1984), it seems to me that Phase I should deal with the first three, i.e., identification of valued ecosystem components, definition of unacceptable changes to these components and the establishment of boundaries in space and time. If we are successful in defining these for the Doon Valley, it should provide the basis for implementing a study strategy, predicting changes and defining monitoring requirements in Phase II - the remaining three "requirements." A major extension from the original "requirements" would be the inclusion of the socio-political and institutional/administrative components of the problem.

To put it in other words, the Phase I report should indicate the natural and social amenities that are valued by the residents of the Doon Valley, demonstrate that these amenities have "significantly" deteriorated in recent times and rationalize the selection of space and time boundaries to place some limits on the problem and subsequent analysis. The Phase I report should end up with a clear indication of how this information will be crucial in the design of the detailed assessment in Phase II.

Getting Started

Scoping is the term currently used to refine the focus of the problem in assessment. In the social sense, this is equivalent to the identification of the valued ecosystem components under the first "requirement." As mentioned above, if we include the human dimension under our definition of "ecosystem", the valued components in the Doon Valley might (for purposes of discussion) be listed as:

- agricultural production
- reliable source of fuelwood (energy)
- reliable source of clean water
- clean air
- aesthetically pleasing countryside

However, Beanlands and Duinker also urged that an ecological scoping be undertaken. This is in recognition of the need to link the social concerns to some measurable natural variable(s) which can be studied in a more quantitative manner. In the Doon Valley case the question would be "What variable would best reflect the changes in agricultural production which is of concern to the local residents?" Would it be decreased growing rates, changes in soil fertility, loss of arable land, etc.? In this manner, ecological scoping would provide a list of measurable variables linked to each of the valued ecosystem components identified in the social scoping exercise. The results of the ecological scoping would provide the basic direction required in subsequent baseline studies.

While the scoping exercise is underway, Beanlands and Duinker also recommended that an "ecological reconnaissance" be undertaken. This is a summary of the main driving forces at work at the regional level - to quote from the publication:

> The objective should be to gain an appreciation for such features as the biological resources important to man, and important components of their habitat, the key biological processes such as major trophic relationships, and driving forces such as climatic conditions and transport mechanisms.

This information serves as the "backdrop" to more detailed studies undertaken in the assessment itself.

The Significance of Change

Once the ecological scoping has provided the basis upon which changes in valued ecosystem components will be measured, there should be some definition of an unacceptable change. This, of course, is derived from the model in which a significant change is used as a reference against which predicted changes can be tested. In the case of the Doon Valley, however, I suggest that "significance" be more appropriately dealt with in terms of trend analysis or time series studies. Obviously the valued ecosystem components have been under pressure for some time and it may be sufficient to demonstrate that if current trends continue sooner or later the results will be socially, economically and politically significant. This is what happened with Atlantic salmon stocks in eastern Canada - a demonstrated long-term continuous decline eventually forced politicians to act, even though no specific "significant" reduction was ever stated.

In the Doon Valley case, the data required to show the significant decline in agricultural production, the availability of water, air quality, etc., could also from the basis for the more detailed baseline studies which would be required in the comprehensive EIA as envisaged in Phase II.

Bounding the Problem

Beanlands and Duinker recognize four classes of boundaries - administrative, project, ecological and technical. Each of these is considered from the perspectives of time and space.

The administrative and "project" boundaries for the Doon Valley should be fairly easy to establish from a geographical point of view. The ecological boundaries may be more difficult due to the potential effects of development in the valley on downstream resources. The technical boundaries may be the most difficult. This simply means that it may not be possible to definitively demonstrate the cause-effect linkage between specific human activities, like limestone quarrying, and changes in valued ecosystem components, like agricultural production or water supplies.

The time element may be the most crucial boundary. By this I mean that it has taken a number of years for the natural systems to react to various perturbations in the valley and it will certainly take a number of years for positive adjustments to be achieved. The operative words here are patience (it will require time to demonstrate progress) and commitment (all actors must be prepared to abide by the new rules for the long run.)

Projection for Phase II

The results from Phase I should provide the information and data to undertake a full-scale assessment in Phase II. Such an effort could focus on:

- Study strategy: the development of an analytical framework
- Predictions: applying the analytical framework to various development scenarios and predicting effects on the valued ecosystem components
- Monitoring: the design of monitoring programs to test the effectiveness of proposed mitigation (planning) measures

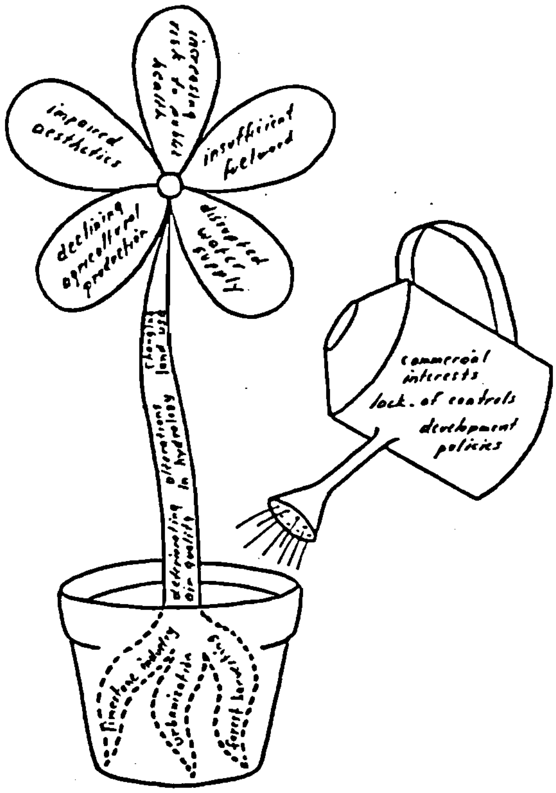
I have not taken my thinking too far in this area so I cannot offer any specific suggestions. However, the study strategy is the single most important component. Will it be based on a quantitative model; will it be based on consensus-seeking among professionals; will it be based on extrapolation methodologies within sectors, etc.?

The study strategy to be adopted as the analytical basis for the assessment should be outlined at the end of the Phase I report.

Communications

My experience in a number of developing countries emphasizes the utility of the old saying "A picture is worth a thousand words." If I was given the responsibility of communicating the complexity of the Doon Valley problems to the masses, I would be tempted to portray it as shown in the drawing below - The Doon Valley Weed.

The roots of the problem are the limestone industry, escalating urbanization and excessive forest harvesting. These lead to changes in air quality, water quality and availability and land use - the stem (or integrator) of the problem. The "flower" which grows is made up of negative effects on the valued ecosystem components: declining agricultural production, negative effects on aesthetic resources, increased risk to human health, insufficient fuelwood supply and disrupted water supplies. The entire system (weed) is being fed by overriding commercial interests, a lack of effective control mechanisms (bureaucratic and legal) and a lack of appropriate long-term development policies. Ultimately the "fertilizer" will have to be reduced, but for the immediate future it might be possible to control the root structure!!



The Doon Valley Weed

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ON THE POSSIBILITIES OF OBTAINING BACKGROUND DATA FOR THE EVALUATION OF SOME CLIMATOLOGICAL PARAMETERS IN THE DOON VALLEY

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1 Introduction

For many environmental, hydrological, ecological and agronomical problems, a knowledge of selected climatological parameters, indicators of the meteorological and topographic conditions of the region under investigation, is of considerable importance. Various models have been developed and applied using simple climatological data as well as satellite data to evaluate these parameters. A considerable improvement for model application can be achieved by applying digital height grid techniques in conjunction with objective interpolation methods (Gandin 1963, 1968, or more recently "Kriging") to "snap" the data to the next grid point. Monitoring sites are usually distributed irregularly across a region.

These "objective interpolation methods" must take into account some fundamental relations for the areal distribution of the basic climatological data as there is a height dependence of air temperature; the amount of insolation on mountain slopes is dependent on aspect, slope inclination and ground albedo; and the surface temperature is dependent on surface properties such as roughness, albedo, and vegetation coverage. Thus, there is a clear need for detailed knowledge of the physical properties of the surface being studied. There exists a rather sparse network of climatological stations in the Dehra Doon Valley. The possibility of obtaining additional information must be considered. Several approaches are possible, with very different costs and manpower requirements.

2 Data and Methods

One approach widely used to get information about the mentioned climatological properties is to establish the heat budget of the ground surface. Because ground-based data are the most readily available, a vast variety of models have been applied to evaluate the main components of the heat budget equation, viz., evapo-transpiration, sensible heat flux, long- and short-wave radiation, and the heat flux into the ground. Since precipitation data are available in most cases, the water budget may also be established, involving evaporation and precipitation as its main components. In this case, the time scale is usually a month, whereas for the heat budget, the time scale is daily to monthly (e.g., five to ten-day means for agrometeorological applications.)

The crucial problem is to get the maximum information out of the available data and consequently to apply adequate models. Since ground-based data networks give good information only for the immediate surroundings of the measuring site, some regionalization procedures should be applied to get at least crude information about other parts of the region under investigation.

The use of satellite data must be considered in a somewhat different manner. For climatological purposes, this information consists mainly of the surface temperature, since remote sending of vegetation-covered surfaces is limited to two wave bands: the thermal infrared and the microwave.

Concentrating here only upon the thermal IR in the window of 10.5 to 12.5 m, the basic technique is to estimate thermal inertia from the diurnal temperature range which is closely related to the volumetric water content of the first few cm below the surface.

The model of Carlson et al. (1981) is widely used to estimate both the thermal inertia and soil moisture availability using data from polar-orbiting satellites (e.g. TIROS) which view the same area twice a day near the times of maximum and minimum temperature. An improvement could be achieved (e.g., Wetzel et al., 1983) by using data obtained from geostationary satellites (GOES, INSAT) with more sophisticated algorithms to remove the effects of horizontal variations in vegetation biomass, surface roughness, wind speed and other atmospheric and surface properties.

The basis for these ideas is as follows: Surface heat flux and surface temperature are closely related; thus the partitioning of energy into sensible and latent heat is directly proportional to the amplitude of the surface temperature wave. So the greatest amplitude of temperature occurs immediately at the ground-air interface, decreasing rapidly upward in the air and downward in the ground. Well away from the surface, the daily amplitude is much smaller and is greatly modulated by advection and other meteorological influences.

The surface temperature response is a very sensitive measure of surface character. Along with other parameters such as ground-albedo or emissivity, surface roughness and assumptions concerning an appropriate boundary-layer model, a reasonable estimation of surface temperature with a relative accuracy of + or - 2 ° C can be achieved.

Up to this point, we have been considering "synoptic satellites" which provide data at least twice a day with a resolution of 4-7 km. As for information from the LANDSAT-3 thermal IR channel (which has a resolution of about 240 meters and repetitive coverage every 18 days), appropriate data processing facilities have to be provided (see Appendix: IMAGE PROCESSING) as well as some ground-based points for control measurements in order to calibrate the pictures. It is then possible to get a snapshot of ground temperatures which may be useful to test the model under consideration.

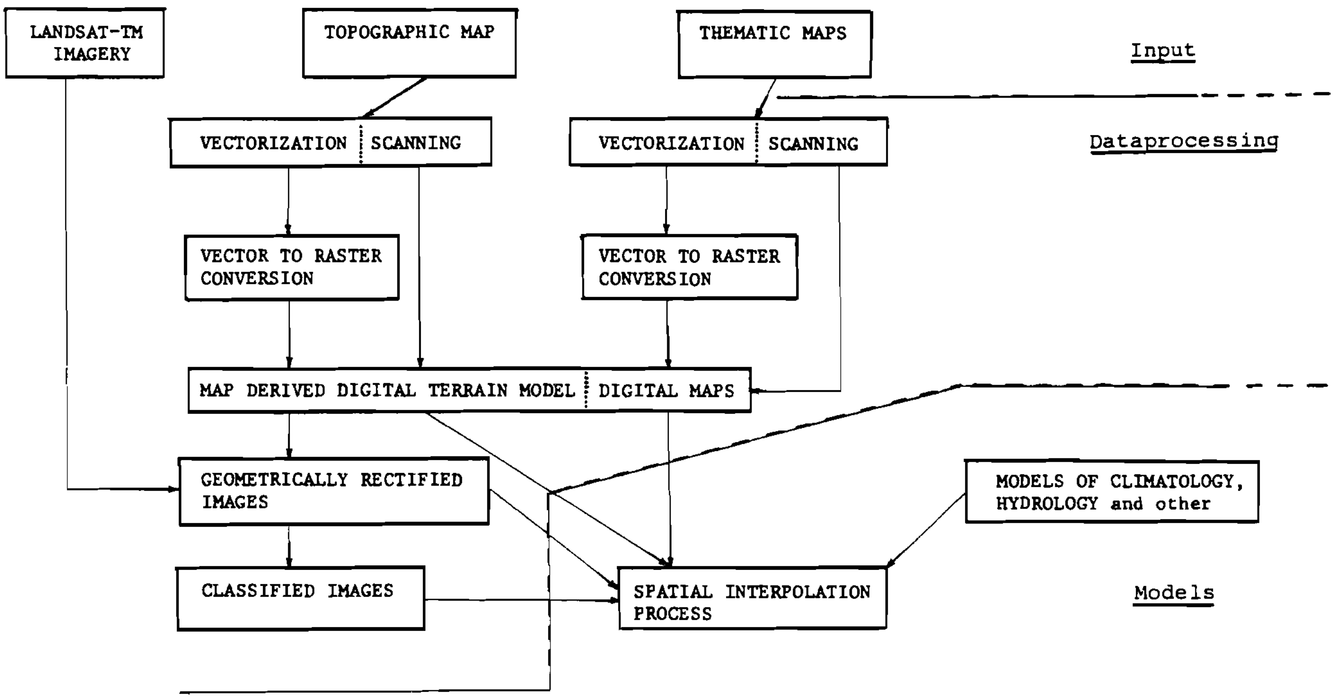
3 Conclusions

An analysis of climatological conditions in Doon Valley especially for agricultural purposes should involve gathering of additional data. By applying a height-grid model there is the possibility to infer such information from the physical properties of the soil, vegetation coverage, land use, etc. in the region under investigation. So if Landsat data are processed, valuable information about the above mentioned properties can be achieved.

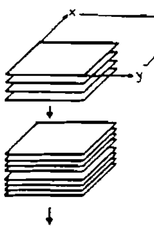
There are some other simpler possibilities to qualify the characteristic climatological features through ***phenological*** observations (if there exist any) and ***crop-yield*** records as a function of weather conditions, including meteorological hazards.

Inquiries for such data should be initiated. If appropriate information is obtained, it might be possible to increase crop yields (as has been done, e.g., by JEANNERET (1977) for Switzerland). Since there are numerous models which make different demands on the data for the Dehra Dun Project, it should be clarified first if there is a necessity to evaluate more complex climatological parameters, and if a need is found, which data and which model should be on the short list.

SUGGESTIONS FOR DATA PROCESSING



DATA SET



Coordinates of the given map-projection (for example UTM) *
all images on the same scale

7 Bands Landsat-Thematic Mapper (multitemporal)

Digital Terrain Model -elevation
-slope
-aspect

digital thematic maps and/or

classified satellite imagery

thematic maps derived from the geoscientific models and the above mentioned sources

* UTM = Universal-Transversal Mercator

Appendix IMAGE PROCESSING

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ON GROUNDWATER CONDITIONS IN THE DOON VALLEY, U.P.

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This paper highlights the hydrogeological setting of the Dehra Dun Valley, and the groundwater conditions therein. Recent trends in groundwater exploration in the valley and the effect on groundwater conditions are enumerated. Implications of industrialisation, deforestation and possible effects on groundwater quality are cited. Suggestions for further groundwater resource assessment and future pattern of exploitation of groundwater are made. It is imperative that proper monitoring and assessment of the water resources of the Doon Valley be made for optimal water utilisation and conservation, to forestall detrimental environmental effects.

INTRODUCTION

Water is a natural resource. It is vital for sustenance of life, as well as for industrial and agricultural development. With the increase in population and human activities in the form of hydrologic works, industrialisation and agriculture, no natural resource has perhaps given rise to deeper concern about its optimal exploitation and conservation than good, clean water.

Underground water is a unique, renewable natural resource in the sense that it is a "reserve bank" of generally pure and abundant water wherever good aquifer materials exist; on the other hand, surface water can become polluted more directly and can also cause damage by flooding during excess run-off. During the process of percolation through porous materials and deposits, rain and surface waters are "filtered" while being stored in the pore spaces of underground layers of porous deposits such as sands and gravels, known as "aquifers" (water-yielding deposits). Deep underground waters are generally free of bacteria and other pollutants, unless artificially polluted by human activities.

Dehra Dun city and its surrounding Doon Valley area is endowed with very good, coarse aquifer subsurface materials, known as "Doon Gravels" geologically. The Doon gravel beds occur at several different depths below the surface. They are separated by reddish clay lenses and beds. These gravel-sand- boulder aquifers are annually recharged by rain, but some of the underground waters leak out of the two ends of the valley along the Suswa river in the east and the Asan river in the west. The lower reaches of the Doon Valley provide good groundwater, and are tapped by many tubewells. Tapping of underground water must be optimally done.

HYDROMORPHOLOGICAL SET-UP

The salient hydromorphological zones/units are depicted on the attached map.

The Doon Valley is bounded on the south by the Upper Siwalik "Structural Hills" comprising "boulder beds" of Tertiary age. These beds dip northwards and have silty-clayey matrix-binding gravel, pebbles and boulders of quartzite, sandstone, etc. The hills are highly dissected, variably forested, and form a surface run-off zone. The Upper Siwaliks are underlain by Middle Siwalik sandstone and clay beds forming hills at the south towards the plains. To the north of the Doon Valley occur the "Structural Hills" in the Middle Siwaliks in an overturned sequence forming the northern limb of the syncline underlying the Doon Valley. The northern structural hills also forming a run-off zone, extend from north of Dehradun westward to the Katapathar area along the Yamuna River. Along this stretch, overturned anticline also occurs in the hilly belt with patchy exposures of Upper Siwaliks below the Krol Thrust zone at the base of the Mussoorie "Dendudational mountains" comprising pre-Tertiary rocks. Upper Siwalik beds also underlie the Doon Valley deposits ("Doon Gravels") and form the Doon Syncline. They are exposed in places along stream cuttings in the northern part of the valley. Towards the western part of the northern flank of the Doon Valley Subathu (Older Tertiary), beds of reddish-purple shales form structural hills and juxtapose pre-Tertiary rocks of Mussoorie mountains above the Krol Thrust (KT), as well as lie over the Middle Siwalik beds along the Main Boundary Fault (MBF) extending NW - SE South of the Krol Thrust zone between Katapathar and Rajpur.

Eastward, in the northern flank of the Doon Valley, the Krol Thrust and MBF appear to coincide, cutting off the subathu beds. The Krol Thrust is intermittently concealed by the Doon Valley deposits, and the Middle Siwalik and related beds are not exposed in the eastern part of the valley. The hills and mountains are prominent run-off zones as mentioned earlier. In the Krol (Mussoorie) mountains, springs occur in the limestones.

A major part of the Doon Valley consists of "Doon Gravel" deposits and related alluvial deposits of Late-Pleistocene to Sub-recent age. The Doon Gravels are subdivided into older and younger (Sub-recent) units. These deposits are of considerable thickness (approximately 200 m in the deepest part) and contain gently inclined unconsolidated layers of silts, gravels, sands, pebbles, boulders, etc. with interlayers of reddish clays. They form geomorphic units as Intermontane piedmont plains with land forms such as alluvial fans (both northern and southern aspects) and fan-cut terraces, as well as flood plains (present) along major rivers and river terraces, fan-cones (recent), etc. Isolated Denudo-Residual Hills of relatively Older Doon Gravels also occur (ODG). These isolated hills are also run-off units.

The alluvial fans of the Doon Valley are subdivided as follows:

a) The southward sloping (8o - 10o slopes) fans orig- inating from the northern hills/Mussoorie mountain belt. These are the Principal Doon Fans, and can be further subdivided into 2 or 3 sub-units from their apexes downward.

b) The northward sloping (about 10o) fans (fanglomerates) originating from the southern Siwalik hills. The above two terminate along the Asan river in the west and the Suswa - Song river in the east. Dehradun forms a local surfacewater divide in the valley for the Asan and Suswa - Song drainage systems.

c) Recent fan-cones of localised extent, occuring at the base of hills (not shown on map). These act as local rechargers to groundwater.

d) Isolated high level fans attesting to tectonic activity occurring on the top of structural hills near the Krol Thrust zone (not shown on the map since they are of limited Hydromorphological significance).

The alluvial fans and terraces are major rainfall rechargers to groundwater, and the valley deposits harbour potential aquifers at depths specially in the lower reaches of the valley between the limits of the aquifer zone shown in the attached map. The upper reaches of the valley act as a recharging zone mainly, and the groundwater moves down the valley to provide good groundwater potential therein. In places the circulating groundwaters of the lower parts of the valley also seep out as base-flow along the Asan and Suswa-Song rivers in the lowest parts of the valley. These rivers join the Yamuna and Ganga rivers, respectively. The thickness of the Doon gravels (fanglo- merates) reduces appreciably towards the bounding structural hills. Generally, the water table in the valley is affected by these semi-confined groundwater conditions. Water-table depths range from about 20 to 90 m. At the lowest valley point, the water table is shallower. Seasonal water-level fluctuations range from 20 to 50 m in different parts of the area. Tubewells yield around 60,000 to 150,000 litres per hour or more for nominal drawdown around 20 m. Locally, shallower perched water levels also exist, but are not reliable, since they dwindle in the dry season. In the lowest parts of the valley where seepages occur, deep drilling could possibly provide weak artesian to semi-artesian groundwater conditions. One tubewell at Clement Town is reported to have a free flow of about 0.4 m above ground surface. A number of seepages/springs also occur in the upreaches of the valley along formational contacts adjacent to recent faults, e.g., near to and north of Manduwala, along Darer Nadi.

A number of tubewells have been constructed in the rapidly growing Dehra Dun City Campuses and Colonies in recent years, and more are being constructed every year. Most of these tubewells tap aquifers up to a maximum depth of about 120 - 140 m. Some of the recent tubewells are closely clustered, for example in the Kaulagarh estate area and are likely to interfere with each other's functioning. Since most of the tubewells in Dehra Dun tap more or less the same existing aquifers up to 140 m depth, they are beginning to strain the water resources in these aquifers. This is reflected in a general decline (15 m or so) in water table level, in Dehradun, in recent years. If further tubewell construction proceeds without proper groundwater resource assessment and optimal utilisation, further deterio- ration in groundwater yield will occur, to the detriment of the valley's development and ecological balance.

There is thus a great need for proper monitoring of water resources of the Doon Valley. The tubewells should be properly spaced, based on standards that ought to be set, and should also tap the available aquifers at different depths in a staggered way. Future tubewells should also tap still deeper aquifers, after suitable exploration so that these aquifers are also utilised and pressure on the upper aquifers is somewhat decreased. Suitable plans for future drilling sites should be prepared. A battery of properly spaced tubewells in the Jhaira sector or the Doon Valley is suggested for future development of the water supply to Dehra Dun. This recommendation is based on analysis of available data for the valley, and needs to be elaborated.

Another important question is environmental degradation and water pollution. Environmental degradation of land is a serious concern, since deforestation tends to increase surface run-off of rain waters, as well as erosion and sediment supply. In the valley basin of Dehradun, further unplanned land degradation due to developmental activities would reduce groundwater recharge possibilities by attendant increases of run-off, and siltation which would tend to partially choke the recharging pores of the surfacial deposits of the valley. The long-term effects have to be studied and weighed, so as to evolve a more rational land-use plan for Dehra Dun and environs, keeping a balanced mix between development and environmental conservation.

With more industries expected in Dehra Dun and neighbouring places, it has to be kept in mind that the valley aquifers are directly recharged by surface water after rains. Thus any industry discharging poisonous effluents into the valley would pose a serious groundwater pollution problem. Hence, chemically polluting industries should not be built in the Dehra Dun valley. Even smoke pollution should be controlled to a tolerable level in such a closed valley. The introduction of non-polluting industries is the only answer to development of the Doon, although it is recognized that one or two vital major industries may be inevitable. Already a Cement and Carbide factory exists just north of Dehradun, near a recreational centre, which is a pity. There must be a stop to unplanned development. There is also a paramount need for creating public awareness towards environmental protection side by side with development.

CONCLUSIONS AND SUGGESTIONS

The Doon Valley is a unique Intermontane valley basin forming piedmont alluvial fan plains, fan-cut terraces and river terraces. It consists of "Doon Gravel" deposits of gently- sloping (southwards and northwards - northern and southern aspects) silts, sands, gravels, pebbles, boulders etc. with inter-layers of clays. These deposits are quite thick in the lower reaches of the valley and form major aquifer systems with high groundwater potential.

The groundwater conditions have been broadly enumerated in the paper. Water level is generally deep, but the aquifers support heavy-duty tubewells. Water levels in Dehradun have reportedly lowered by about 15 m in the last 7 years or so.

The valley is bounded by hills and mountains to its south and north sides, enclosing the valley. Antecedent rivers, namely the Yamuna and Ganga cut across the foothills to drain into the gangetic plains further south, beyond the valley. The hills are composed of pre-Tertiary and Tertiary rocks consisting of phyllites, quartzites, shales, limestones; and sandstones, clays, boulder beds, respectively.

The main geomorphic units mapped are:

Intermontane valley - piedmont plains
Denudo-Residual Hills in Older Doon Gravels
Structural Hills in Tertiaries
Denudational Mountains in pre-Tertiaries

The environmental and groundwater aspects have been briefly discussed. Suggestions for future development are made. Caution is expressed regarding environmental degradation due to future development activities around Dehra Dun. A balance should be maintained between development and environmental preservation.

Keeping in view the growth of Dehradun and environs and the increasing demands for water supply, it is suggested that a detailed groundwater resources assessment and associated monitoring should be carried out, and future tubewells should be properly located, spaced and designed so as to tap deeper aquifers in a staggered manner. For future water supply to the growing Dehradun city, a "nest" of properly spaced tubewells should be constructed along the terraces of Tons Nadi in the Jhajra sector, beyond Premnagar, and the water should be piped in. This is essential so as not to congest Dehradun city proper with too many tubewells, as is the case presently, causing a strain on the aquifers in Dehra Dun.

Measures to conserve the water resources of Doon Valley, and their optimal utilisation as well as artificial recharge should be considered.

ENVIRONMENTAL IMPACT ASSESSMENT WITH SPECIAL REFERENCE TO DEHRA DUN

Prem Thadhani

Mussoorie, India

1 The Area Under Study

The Dehra Dun watershed is bounded by the first range of the Lesser Himalays to the North East, ther Siwalik hills to the South West, the Yamuna river to the North West, and the Ganges river to the South East.

Mussoorie is the highpoint of this watershed.

The saucer-shaped Doon Valley covers an area of approximately 20 km by 70 km and has an annual rainfall in excess of 200 cm. The valley is made up of dolomite rocks above krol limestone, with shale and mud below. Above the limestone is a thin layer of black phosphatic rock.

The population of Dehra Dun and Mussoorie is 762,000. This valley is the gateway to the rural Tehri Garhwal hinterland with a population of 498,000. The two towns of Mussoorie and Dehra Dun have many residential schools with a student population of over 20,000, and several Government institutes like The Indian Military Academy, The Oil and Natural Gas Commission, The Forest Research Institute, The Lal Bahadur Shastri National Academy of Administration, and the High Altitude Defence Services Academy of the Indo-Tibet Border Police.

2 History

According to legend, Garhwal was formed by the merger of 52 Chieftanships. Garh means Fort and Garhwal, the land of Forts. Garhwal had a barter system till the 18th Century and in the 19th Century 'Rajah' Wilson, a forest contractor, minted his own i.o.u. coins near Harsil. Traditionally, this area has had a money-order economy, with women toiling on the land, and the men joining the army and sending money home to support the family.

After the Gorkha war of 1814, Pauri or British Garhwal was annexed by the British and Tehri Garhwal was awarded to Ajaz Pal of the Chandpur Dynasty, for helping the British in driving out the Nepalese. At this time, Mussoorie was also annexed as a British territory. In the eighteen-thirties the British began to encourage people to settle in the Mussoorie hills, as a kind of sanitorium for British troops and expatriates keen to get away from the summer heat of the Indian plains.

G.R.C. Williams of the "Imperial Gazetteer" recorded in his memoirs of 1874: "The scenery of these mountain dales can hardly be surpassed for picturesque beauty."

Villagers dependent on forests for fodder and firewood preserved them in their own interests. In the early 19th Century, felling of trees by Zamindass (landowners) had led to a reduction of forest cover. Agriculture supported staples like the famous Basmati rice, grown on drained swamp land, wheat, lentils, and oilseeds like mustard. Plantations grew some of the finest green tea exported to Afghanistan and sericulture flourished for a while.

The railway came to Dehra Dun in 1900. However, no great harm was done to the valley till 1947 when refugee miners settled in Dehra Dun and recognised the potential for making quick money from limestone quarrying on a large scale.

Traditionally, parts of river beds had been leased out by the District Magistrate by the grant of permits for a short period to local residents, who cleared the rivers of debris brought down by the monsoons and crushed and fired the boulders on site to meet their local needs, such as whitewash for painting their houses. Till about 1947, the entire quantity of limestone required by a few industries in India was imported from Pakistan.

In 1975 the forest contractor arrangement was ended by the Government and the price of minerals started to go up.

3 Legal History

For the first time in 1949 an act named "The Mines and Minerals (Regulation and Development) Act 1949" was passed by the Government and the Mineral Concession Rules 1949 were published by Notification No. M-11-155 (24)-2 dated 18 October 1949. This act did not serve the purpose of development and conservation of mineral resources and therefore in 1957, the Government substituted this act by Act No. 67 of 1957. The main objective of this act was to provide for the regulation of mines and the development of minerals under the control of the Union. Petroleum products which were earlier included in the act of 2949 were now excluded.

In 1952, the Mines Act 2952 was enacted, superseding the 1923 Act, with the purpose of removing a number of defects and deficiencies which hampered effective administration.

The Government of India vide notification No. VSR-1398 dated 11 November 1960 published the Mineral Concession Rules 1960 by virtue of the power conferred on them under section 13 of Act 67 of 1957. These rules apply to all the major mlinerals which are specified in Schedule I and II of Act No. 67 of 1957. The Mines and Minerals (Regulation and Development) Act 1957 also empowered the State Government under section 15 of the Act to make rules in respect of minor minerals. Accordingly the Government of Uttar Pradesh vide notification No. 1575-M-XVIII-BM-96-58 dated 26 August 1963 made the rules known as "U.P. Minor Minerals (Concession) Rules 1963."

Under the provisions of Act 67 of 1957, the State Government is empowered to sanction a lease of a mineral which is specified in Schedule II but it has to take prior approval of the Central Government in respect of a mineral which is specified in Schedule I. In the district of Dehra Dun all the minerals which are available are listed in Schedule II except for gypsum. Section 8 of the Act says that the maximum period for which a lease can be granted for the minerals available in Dehra Dun district is 20 years, and the maximum period for which such leases can be renewed is also 20 years.

Consequently, leases were granted around 1962/3 for 20 years with a clause stating that, should the leasee so wish, his lease would be automatically renewed for an additional 20 years.

In the beginning of 1982 the position of leases was as follows:

Serial No.	Name of Block	Under MCR 1960	Under MMCR 1963	No. of leases which were to expire in 1982/83
1	Kiarkuli	5	6	5
2	Banog-Nun	7	7	2
3	Bhittarli	9	5	3
4	Maldeota	2	-	-
5	Song Valley	5	1	-
6	Sahastradhara	6	2	2
7	Arnigad	7	1	5
8	Kairwan	3	1	1
9	Barkot	3	-	1
		47	23	19

With the growing demand in many circles for the closure of limestone quarries on ecological considerations, the Government of U.P. formed a committee under the chairmanship of the special Secretary of Industries to advise it on the sanction and renewal of leases. Subsequently, the Industries Department issued a General Order No. 6013/18-12/82 dated 17 September 1982 saying that the Kiarkuli and Song Valley Blocks were unsuitable for mining. In Sahastradara Block, the Government directed that leases should not be sanctioned or renewed close to sulphur streams directly connected with the Sulphur Spring. The Government also directed that in other blocks, action should be taken on the individual merits of each case. In February 1983, the Government of U.P. rejected all renewal applications, mainly on the grounds that quarrying had an adverse effect on the environment, ecology, and scenic beauty of the Mussoorie hills. In some cases the grounds for rejection were stated to be that the leased area formed part of reserved forests or other forests which came under the purview of the Forest Conservation Act 1980. This act prohibits use of forest land for non-forest purposes, and in all such cases where forest land is involved, prior permission of the Government of India is required.

It is unfortunate that the Forest Department has not been more alert in protesting against the grant of leases on forest land. In any case, the State Government's action did not go far enough, as it did not touch those mining leases which had not expired in 1982/83. Further, it created a contradictory legal position which it did not tackle or resolve. The steps taken by the State Government were skin deep and merely paid lip service to the cause of preserving the environment and its ecology, without any real, in-depth appreciation of the general and specific factors involved in this particular Himalayan, micro-watershed.

Almost all persons whose renewal applications had been rejected by the State Government, approached the Honorable High Court under Article 226 of the constitution of India and some of them filed civil suits for injunction under the specific performance Act for renewal of their leases for an additional 20 years.

The first case, decided by the High Court on 9.3.83, directed the Government to dispose of the renewal application after giving reasonable opportunity under Article 14 of the constitution, and did not agree with the Government that if a renewal application is not disposed of within a stipulated time, the application is deemed to have been rejected as is provided under sub-rule 3 of rule 24 of the Mineral Concession Rules 1960. Other cases were also decided on similar lines.

Some lease holders had filed civil suits before the Civil Judge, Dehradun and on 28.5.83 they were joined by others whose writ petitions had been disposed of by the High Court. On 8.6.83 the Civil Judge, Dehradun granted an ad interim injunction against the State of U.P. until disposal of the suit. However, the High Court had already directed the Government to consider renewing the applications, but before this could be done, the Civil Judge, Dehra Dun, a lower court, by its ad interim injunction, in unseemly haste preempted the action of the State Government under directions of the High Court.

In some cases, the State Government prematurely determined the leases on the grounds that certain provisions of the Metalliferous Mines Reputation Act 1981 were not being followed. Three leases moved through the Civil Court and one went up to the High Court against these orders. All four leases were granted stay orders on the technicality that the Director, Geology and Mining, who had prematurely terminated the leases, was not empowered to do so, and that the only authority who could enforce the Mines Act, the M.M.R. 1961 was the Director, Mines Safety.

Subsection 3 of Section 5 of the Mines Act reads as follows:

> The District Magistrate may exercise the powers and perform the duties of an inspector (of mines) subject to general or special orders of the Central Government. Provided that nothing in this subsection shall be deemed to empower the District Magistrate to exercise only of the powers conferred by section 22 or section 61.

Section 22 of the Mine Act 1952 states the powers of the Inspector of Mines when the cause of danger is not expressly provided against or when employment of persons is dangerous. Section 61 relates to the bye-laws for working of mines. Non-compliance of an order issued under section 22 or 61 is punishable on complaint but section 75 provides that when an offence is committed in the course of the technical direction and management of a mine, the District Magistrate shall not institute any prosecution against an owner, agent, or manager without the previous approval of the Chief Inspector.

The Mine Rules 1955 were framed under section 58 and the Metalliferous Mines Regulation 1961 were framed under section 57 of the Mines Act. These rules do not spell out the functions of the District Magistrate with regards to the technical aspects of the management of mines. The conclusion derived is that it is only the Director of Mines Safety who is empowered to prosecute under these Acts and Rules which, in any case, are largely confined to the safe working of mines and the safety of mine labour, with little or no emphasis on ecological considerations. Where ecological considerations are mentioned in passing, they appear to relate to the plains and not to hilly terrain. For instance, restrictions on mining within certain distances from tube wells are mentioned, but no thought has been given to contamination and silting of mountain streams and the damage to terraced fields from scree from mines situated above the fields.

A unit of the Directorate of Mines and safety is at Dehra Dun and the Regional Office is at Ghaziabad. The quarry office is directly concerned with the recovery of royalty, etc., and the work of on-the-spot demarcation is done by the geologist directly under the control of the D.G.M. Lucknow and the State Government.

4 Citizens Initiative

While this legal wrangle was going on in the context of badly framed, ill thought out, and uncoordinated laws, the Save Mussoorie Society, a citizens group of ecologically conscious people, filed a petition in July 1983 before the standing committee on Petitions of the Rajya Sabha (the upper House of Parliament or the Council of States) requesting an end to mining in and around Dehra Dun. In its findings, this committee of Parliament, while sympathising with the petitioners on the grounds of ecological damage to the environment, felt itself to be in a dilemma as wholesale closure of mines would, in its opinion, lead to the loss of jobs and cause economic hardship. No action was taken by Government on the report of this Committee, which sat on the fence.

5 The Supreme Court

The scenario then shifted to the Honorable Supreme Court of India. Justice P.N. Bhagwati, now the Chief Justice of India, had introduced a scheme of Public Interest Litigation. Under this scheme, anyone could approach the highest court of the land for social justice and ask for free legal aid.

Mr. Avdesh Kaushal, head of the Rural Litigation and Entitlement Kendra, Dehra Dun, and also the Youth Coordinator of The Nehru Yuvak Kendra, Dehra Dun, submitted public interest litigation before the Honorable Supreme Court. Other interventionists included ecologically minded public groups such as "The Friends of Doon" and "The Save Mussoorie Society."

This case was strongly contested by both sides during 1984/85. The Honorable Supreme Court of India permanently closed about 54 open-cast limestone mines which fell within the municipal limits of Mussoorie and Dehra Dun; allowed 7 mines outside municipal limits to continue to operate, including the U.P. State-owned U.P.S.M.D.C. mine at Lambhidhar, Mussoorie; and temporarily closed the balance of mines falling in a grey area. About 13 mines of 15 lessees, which had divided themselves into two rival groups, the Marwah Group and the Oberoi Group, submitted revised mining schemes to the Bandhopadhaya Committee set up by the Supreme Court vide order dated 12 March 1985. This committee visited all mines on 26,27 December 1985 and the final outcome is awaited.

6 The Negative Impacts of Limestone Quarrying on the Ecology of the Doon Environment

At this point, it will be useful to enumerate, in some detail, the negative impacts of limestone quarrying on the ecology and environment of the Doon, and hence on its economy and the quality of life.

Opencast limestone quarrying and associated industrial operations for its processing in the Dehra Dun-Mussoorie region have resulted in the following adverse environmental effects:

(a) Denudation of forested slopes. Of the total mining area of 1043 hectares in the Mussoorie hills, 803.6 hectares fall under the category of reserved forests. Denudation of forested slopes and the valuable soil cover is further compounded by the construction of access roads to mine sites and by the vast quantities of scree sliding down hillsides. With the erosion of hillsides, the monsoons have washed away top soil with the result that there is no leaf mould, a valuable organic fertiliser, left for the fields. For instance, in the Baldi river catchment area, food grain production fell by 28% in the last 2 decades, according to a study carried out by Dr. Jayanto Bandhopadhaya for the Department of Environment, Government of India.

(b) 30% of the limestone mined is dumped into river beds, polluting the water and raising river bed levels which have led to the inundation of low-lying farm land. For instance, in the 1982 monsoons, the debris inflow into the Tons river was measured as five feet in height.

(c) Without water, there can be no civilization. The water supply to Dehra Dun and Mussoorie is dependent on perennial, rainfed streams. The Himalayas range effectively blocks these settlements from snow-fed river sources which skirt the Doon. Some of the important rainfed streams and canals which feed these two townships are: the Rajpur Canal, the Bijapur Canal, the Kalinga Canal, the Jakhan Canal, the Aswan, Song and Sukswa rivers, the Arnigad Nala, the Bhitarli Nadi and the Kandighat stream. The limestone strata is an aquifir which stores rainwater in its cavities and allows it to percolate to feed streams and rivulets in the dry season. In the four years from 1979 to 1982, the water level in the Rajpur Canal has dropped by 80%, in the Bijapur Canal by 40%, and in 18 springs in the Baldi Catchment area by 50%.

(d) Owing to the loss of forest cover, the ambient temperature of Mussoorie has risen from 25.8 ° C in 1950 to 32.2 ° C in 1980.

(e) Schock waves from gelignite blasts have further weakened the limestone strata near tectonic faults in Mussoorie, causing landslides. In 1985, the only Mussoorie-Dehra Dun link road was closed for one week by a major landslide.

(f) The destruction of scenic beauty is detrimental to tourism, an important economic activity of the region.

(g) Short trucks known as "guttuo", which are paid by the truck load, are a traffic hazard on narrow hill roads.

(h) Limestone dust particles from quarries and factories such as ARC Cement, Aditya Chemicals, and the UPSMDC Calcium Carbide plant, hang like a pall over the valley. Air-borne pollutants cannot escape from the Doon because of the prevailing weak air current patterns and the temperature inversion, which traps limestone dust in this enclosed valley. This leads to an ever increasing concentration of air pollution which is responsible for respiratory diseases. Dust particles in the Rispana area have been measured as 360 microgrammes per cubic meter as against the safe level of 100. This poses a direct danger first of all to over 2,000 children in 3 residential schools in the area. White limestone dust has settled on vegetation around factories, spot zoned in rural areas. Consequently, milk production has dropped from an average of 30 liters per cow to 10 liters and major crops which gave a yield of 19 quintals per acre 20 years ago, now give a yield of 10 quintals per acre. A meeting of 500 villagers in November 1985 near the ARC factory, did not demand more jobs for local villagers but asked for compensation to every household where traditional means of livelihood had been adversely affected by air pollution from this factory.

(i) Quarrying has also led to a loss of grazing land with the result that in the Baldi Catchment, livestock population dropped by 35% as compared to a rise of 15% in the Kalapathar area unaffected by quarrying activity in the last two decades.

(j) The resultant loss of manure has affected productivity of wheat by 40% and of rice by 33% in the Baldi valley over the last two decades.

The plea of conservationists for a total ban on quarrying in the valley is also based on the facts that:

(a) The limestone reserves of the valley are 3% only of the total reserves in the country; and cater to only 54 out of 315 sugar mills, 2 out of 50 cement plants, 2 out of 121 paper mills, 1 out of 6 major steel plants, and nil out of 147 minor iron and steel factories, which all have alternative sources of supply from less ecologically sensitive areas in the plains.

(b) The 99.8% purity of the Mussoorie limestone, perhaps equalled only by sources in Japan, may be necessary for the manufacture of defence grade steel. However, the TISCO plant could obtain lower grade limestone from less ecologically fragile zones and install a new plant in order to upgrade it.

(c) The bogey of "loss of employment if quarrying is stopped" is false as the Labour Department records show that 1366 persons only were employed in quarries, as against the Industry's claim of about 20,000 people. The migrant Nepali and Bihari labour force has already moved on.

(d) In fact, traditional skills like farming and dairying have been destroyed. Displaced farmers have taken to occupations like illicit brewing of liquor and timber smuggling, or have migrated to slums in cities as unskilled labour.

(e) De-silting of Calans costs the Garhwal Jal Sanathan Rs.300,000 to Rs. 500,000 annually.

(f) If the whole subject was not under review by several agencies, then the 26 proposed cement and chemical plants would have needed 32 MW of electricity, while Dehra Dun consumes only 40 MW today.

(g) Similarly, limestone-based industries would have consumed 32 cu metres per sec of water, which is almost as much as the rest of the valley.

(h) 20 more years of mining will lead to a water famine and mineable reserves of limestone will be exhausted in 50 years. (Source: U.P. Government special committee report dated July 1982 and Information and Broadcasting Ministry publication "India 1982").

7 Sabotage by Vested Interests

Meanwhile some other developments have taken place which have a bearing on the problem.

Entire villages, like Jhandukhala have been wiped out by landslides caused by blasting associated with mining activity. No compensation was paid to the lone survivor. While this was brought to the attention of The Rajya Sabha Committee on Petitions during their site visits, their report does not document this fact.

Most of the temporarily closed mines under review by the High powered Bandhopadhaza Committee of the Honorable Supreme Court of India are situated on hills, the slopes of which are directly connected to streams which supply water to Dehra Dun and Mussoorie. These streams are Arnigad, Bhitarli and Kandigad.

Funds sanctioned under The National Rural Employment Programme were effectively blocked by the District administration for 6 months, delaying construction of an absolutely essential minor irrigation Canal in Kiaskhuli Village, estimated to cost lRs. 5 lakhs; but in nearby Basa Gad Village, a similar Canal, estimated to cost Rs. 9 lakhs, has been partly built at an expenditure of Rs. 4 lakhs, to feed terraced fields which proved to be non-existent.

While the U.P. Government's own figures show that Dehra Dun district is the second most developed district in U.P. in terms of manufactured goods taken as a percentage of agricultural produce, this district was declared a "backward district" and became eligible for Government subsidies for industry. This was avowedly done to offer incentives to attract the non-polluting electronics industry. In fact, limestone-based industries, in which politicians probably have an interest, have developed.

In this district a Cess Trust Board was constituted in 1976 and some quarry owners agreed to pay a Cess of Rs. 0.45 per M. ton which was to be used for works of public utility within a radius of 5 km from the mine. There is no provision in law to realise this cess and in 1982 about Rs. 1,200,000 was outstanding in the account. As mine owners have to deal with the District Administration on many matters, perhaps District Magistrates could have used greater powers of persuasion to realise outstanding cess money.

The Honorable Supreme Court in the order dated 12th March, 1985 directed "the workmen who were thrown out of their job, in consequence of this order shall as far as practicable and in the shortest possible time, be provided employment in the afforestation and soil conservation programme to be taken up in this area." The Government released Rs. 2,000,000 on 18 March 1985 for providing employment through the National Rural Employment Programme to the dis-employed quarry workers. However, the District Magistrate of Dehradun did nothing till October 1985 when on the complaint of "The Friends of Doon", this inaction was investigated by The Bandyopadhyay Committee of The Supreme Court.

The Supreme Court in their orders dated 12 March 1985 and 24 April 1985, directed that public spirited individuals be associated with representatives of the District Magistrate, Dehradun and a gazetted officer of the Mining Department of the Government of U.P. to supervise the removal of minerals already mined but lying at the site of closed mines. This was done. Subsequently, however, the District Magistrate, Dehradun issued mining permits/leases for removal of material from river beds adjoining the closed mines. This led to illegal quarrying. The Bandyopadhyay Committee also investigated this matter on receiving a complaint from "The Friends of Doon". The committee's findings were as follows:

> Fresh mining activities were noticed... As regards the complaint about the dislodging of material from the closed mines and subsequent removal from the river-beds, this complaint was found to be absolutely correct... From the foregoing it would be clear that the collector did not act with circumspection and care in the issue of an auction/mining permit. Due attention and regard was also not paid to the spirit of the directions of the Honorable supreme court. I feel it is skating on dangerously thin ice by giving a permit which touched the boundaries of closed mines...
>
> I cannot say whether this has been done because of mala fide intention, carelessness or foolishness...Since it may amount to a violation of the clear order of the Honorable Supreme Court on the issue, I am bringing this matter to the notice of the Honorable Court.
>
> The summary record of the fifth meeting of the "Board for Doon Valley and the Adjacent Watershed Areas of Ganga and Yamuna" held on 5th November 1985, states: "The U.P. authorities would take appropriate legal powers if need be through an ordinance for declaring Doon Valley as an ecologically fragile zone within one month."
>
> Since the notified Master Plan deviates from the recommendation of the Expert Group, the Board directed that the Department of Environment should study the reports...a final view...should be communicated...for recasting the Master Plan.
>
> Serious concern was expressed that some of the industrial units like ARC Cement continued to be a source of serious pollution in the Valley despite the fact that everybody from the Prime Minister to the citizens of Dehradun have called for closure of the units.
>
> The State Government did not declare the Doon Valley as an ecologically fragile zone in one month but its Industries Department pushed through trial production of the spot zoned Calcium Carbide plant of the U.P.S.M.D.C. which went on stream for the first time after the Doon Valley Board recorded: "the siting of industries should be done in a composite manner."

8 Benefits of Tourism

As against the negative impact of the limestone industry, well planned tourism can make a large positive contribution to this region.

The tourist industry is a catalyst which revitalises other sectors of the economy because of its multiplier effect.

A survey of the International Union of Official Travel Organisations summarises tourist expenditure as 42% on board and lodging, 55% on internal travel and shopping, and 3% under other miscellaneous heads of expenditure.

By encouraging direct and indirect employment, particularly in less favoured backward districts, it alleviates unemployment. For instance, the staff-to-room ratio for low priced hotels alone is 1.5 people per room.

An ad-hoc committee under the Director General of Tourism had estimated that 15% of all expenses incurred by tourists accrued to the Government in the form of taxes in 1979. Recent trends indicate this figure may now be as high as 20%.

> Apart from its direct contribution to the growth of hotels, restaurants and other tourist orientated schemes, it has significant linkages with many other sectors of the economy such as agriculture, fruit growing, poultry, horticulture, handicrafts, etc., with a multiplier effect in these sectors. Tourism is also significant in having a direct spin-off of income among sections of society which are traditionally considered to be backward and sometimes rural. (Source: Seventh Five Year Plan of Department of Tourism, Chapter 1, para 2).

Tourism is also India's second major foreign exchange earning activity today. Hotels alone earn about Rs. 1,300 crores worth of foreign exchange through services and not by the sale of any commodity.

Tourism, by its very nature, needs to protect the environment because direct contact with nature and different cultures is a significant aspect of the tourist industry.

It is relevant to note here that as against the current foreign tourist arrivals of about 1.25 million per annum in India, the target for 1990 is 2.5 million.

This region can make a positive contribution. It is estimated that 250,000 tourists visiting Mussoorie each year, spend Rs. 375 lakhs on board and lodge, Rs. 375 lakhs on shopping and travelling, and Rs. 75 lakhs under miscellaneous items of expenditure. The hotel workers' annual wage bill is estimated at Rs. 48 lakhs.

A guestimated budgeted expenditure on the development and marketing of Park Estate, Lakhamandal, Theytur and Surkunda Devi in and around Mussoorie is Rs. 4 crores. Should it increase the tourist inflow by even 10%, this would result in an additional annual tourist expenditure/contribution to the local economy of Rs. 90 lakhs.

Hotel occupancy in Dehra Dun is largely dependent on the patronage of institutes such as the ONGC, and litigents visiting the district courts.

9 Pitfalls of Tourism

Tourism necessitates the development of access roads, hotels, restaurants, shopping, recreation and entertainment facilities, and other civic amenities. These developments have taken place in a lopsided and haphazard manner in the Mussoorie region. Consequently, civic services such as the water supply to the town and communication (telephone) facilities have not kept pace with demand.

The peak tourist season population in Mussoorie of about 75,000 to 100,000 people in May and June requires water at the rate of thirty gallons of water per person per day. We therefore need to pump thirty lakh gallons per day, or 1.5 lakh gallons per hour per 20 hour-days. (Annex IV). As against this, our installed pumping capacity is 75,900 gallons per hour and, owing to poor maintenance of pumping stations, we do not pump more than 54,000 gallons per hour for a maximum of 18 hours per day.

We need to identify new spring water sources from which we can make up the present shortfall of 75,000 to 100,000 gallons of water per hour, within a reasonable time frame at a reasonable cost. Backup water storage needed for 2 days water supply is 60 lakh gallons. Out of Mussoorie's installed reservoir capacity of 45 lakh gallons, reservoirs with a total capacity of 23 lakh gallons are out of use because of poor maintenance.

The estimated requirement of 3,000,000 gallons of water per day for Mussoorie town does not take into consideration the needs of surrounding villages. It is also ironic that most of the mines temporarily closed by the Honorable supreme court, and awaiting a final decision, are situated very close to the existing water sources of Dehra Dun and Mussoorie.

In the 1980's, half a dozen highrise buildings were sanctioned for construction, including a 100 bed U.P. Government tourist complex costing Rs. 1 crore, when 100 hotels with a licensed capacity of over 10,000 beds already exist in Mussoorie. This also put a further strain on existing civic amenities.

10 The Right Emphasis for Development of the Economy

The emphasis should have been on developing recreation facilities, including off-season winter sports facilities, such as open-air ice skating rinks; theme parks, museums, and the preservation of historic landmarks such as Park Estate, the residence of Lt.Col. Sir George Everest, Surveyor General of India in the 1830's. This did not take place because town planners and the administration failed to appreciate that Mussoorie and Dehra Dun are:

1) Locations for leisure tourism, and
2) Transit towns, a base, a gateway to the Garhwal Himalayas and the hinterland with special tourist interests of photography, bird-watching, angling, trekking, hiking, mountaineering, river-rafting, folk festivals, mythology and social customs.

The Master Plan for this region, now being recast, should include in its zone of control the development of specific day-return excursions, trekking, river-rafting and folk-festival tour circuits. This valley forms a most convenient and logical base for them, irrespective of outdated, artificial municipal and district boundaries. In many cases this will mean going South to North along motor roads which follow the Yamuna and Bhagirathi/ Ganga river gorges, in search of day-return excursion circuits; and East to West along short cuts which run from one river to the other, with settlements along each river having separate and distinct cultures, dialects and religions, in search of trekking routes.

The tourist influx to Mussoorie, and the supporting floating population in search of seasonal jobs, outweighs the permanent population of about 25,000 residents. The infrastructural requirements of the permanent population would be largely and automatically taken care of under the umbrella of a tourist plan for Mussoorie. Town planning for Mussoorie is in fact, planning for tourism.

While tourism is a factor in national and international integration, it is necessary to keep in mind that it is particularly vulnerable to:

1) Political unrest and
2) Labour agitation.

Therefore, while emphasising the relevance of tourism to the economuy of the Dehra Dun-Mussoorie watershed, cognizance should be taken of the essentially rural character of this region. Any integrated plan for the economic uplift of this area should consider the favourable environmental impact of:

1) Introducing new handloom technology, and
2) Building minor irrigation field channels to bring more waste/grazing land under the plow.

The major source of funds for rural works would have to come from the many Government Schemes for poverty alleviation, such as The National Rural Employment Programme (NREP), Training Rural Youth for Self-Employment (TRYSEM), Rural Landless Employment Guarantee Programme (RLEGP), and so on.

11 Integrated Approach for the Economic Uplift of the Valley

It is necessary to learn a lesson from the attempts by vested industrial and political interests to discredit efforts to combat opencase limestone quarries in the Doon. In this context, one feels there is a strong case to be made for setting up a powerful, independent cell, with a "one-window" approach, in order to formulate, implement, monitor and evaluate the progress of poverty alleviation programmes at the grassroot level, by participation of the people through village panchayats/committees.

This body, reporting to the Doon Valley Board, should:

1. Receive Government funds and direct Government effort for intensive, integrated development of this watershed.
2. Mobilise financial resources.
3. Supplement Government effort.
4. Simplify procedural formalities.
5. Disseminate information.
6. Offer subsidies to break initial barriers.
7. Be the eyes and ears of the people at the village level.
8. Set an example and build confidence among the rural poor: happenings in this micro-watershed have a great influence on trends in the Garhwal hinterland.

This cell should concentrate on:

1. The development of tourism.
2. The development of the village economy by:
   a) Switching over from monsoon-based to irrigation-based agriculture, by the implementation of minor irrigation programmes (defined by Government as costing less than Rs. 10 lakhs each), which could increase the production of vegetables and oilseeds, such as mustard, by bringing wasteland into production.
   b) Consolidation of landholdings up to 2 hectares each, or more, as the need may be, of small and marginal farmers.

c) Rainwater management.

d) Afforestation and pasture development.

e) Social forestry, i.e., the setting up of rural fuelwood plantations of indigenous thermally efficient species acceptable to the people.

f) Manpower development by setting up of multipurpose community centers for the purpose of imparting training to workers to enable them to take up self sustaining, income-generating activities. One such occupation which may have good potential for generating resources needed for the uplift of the rural poor (defined by the Government as those with incomes up to Rs. 6,400 P.A. per family) and the lower middle class, is the introduction of the hand or electric driver AMPAR CHARKHA SPINNING UNIT.

g) Organisational support by setting up supply and marketing societies.

h) Infrastructural support by building village roads and by setting up nurseries.

i) Exploring the use of non-conventional sources of energy, such as wind energy. The minimum wind speed required to operate windmills is 7 km per hour and they can draw water, for irrigation, up to heights of 55 feet. The cost of the whole system is betweeen Rs. 11,000 to 20,000. While the mean daily surface wind speed for Dehra Dun falls within the 5 km per hour sector, more information is required to determine for what period of time wind speeds exceed the minimum necessary limit of 7 km per hour. Wind generators, developed in the Country, are also of relevance to the village economy.

12 Specific Proposals on Tourism

A) Park Estate.

Park Estate was the former residence of Lt. Col. Sir George Everest, Surveyor General of India, from 1833 to 1843. It is situated on Hathiapaon Hill, 7089 feet above sea level, on the main ridge about 3 miles west of Mussoorie; and within 2 miles of the hilghpoint, Begog. Between Hathipaon and Benog is the hill called Cloud End. To the south, the park overlooks the Doon Valley and to the north, the Nag Tibba Range can be seen; beyond that are the snow covered peaks of the Himalayas.

This estate has been divided and sold to many owners over the years. Originally, it covered some 570 acres. It is possible that the chain of ownership in the title deeds may not be very clear. However, Government acquisition proceedings can determine and overcome this problem.

The main building, Park House, the observatory, and the servants' quarters are partly in ruins. These with a surrounding 40 acres of land belong to Mr. Chowdhary Pooran Singh, a criminal lawyer of Dehra Dun.

The U.P.S.M.D.C. open-cast limestone mine is situated to the Southwest, on the next range of hills below Park Estate, known as Lambidhas. Some other caste limestone mines, temporarily closed by the Honorable Supreme Court of India, are situated nearby.

This area is accessible by two roads: the Cart Road and the road from the convent of Jesus and Mary. The Public Works Department has plans to improve these roads. This area, i.e., Hathipaon Cloud End and Benog hills, including parts of the Yamuna river, lends itself easily for development for tourism and can be declared a national park:

1) It is a satellite region 3 miles to the west of Mussoorie town and readily accessible by 2 existing roads which need only minor improvement.
2) Park House, with its historic background, is of international interest and The Survey of India can use it as a museum after restoration.
3) The Valley land mountain views are superb.
4) This is a traditional trekking area which can be improved at minor cost by: sign posts and foot bridges, building simple log cabins/alpine huts for shelter at convenient points along the trail, and by developing camp sites where supplies of kerosene and LPG can be stocked for use by trekkers.
5) The Yamuna river can be used for river rafting.
6) The meadows around Park House can be used for an annual 10 day summer festival of Himalayas Folk Dance and Music.
7) Some of the nearby abandoned limestone mines can be damned and flooded for use as an open air ice skating rink.
8) Park House can be flood-lit for a Son et Lumiere show.

B) Day-Return Excursions to Surkanda Devi, Lakhamandal and Theytur.

While accessible year round, these excursions would particularly help promote off-season, winter tourism.

A large variety of birds can be seen in the agricultural fields of Theytur in winter, when the birds come down to the Aglad River because of the extreme cold in the higher mountains. The naturalist, Dr. Fleming, lists 56 birds belonging to the Gangotri and Yamunotri Valleys, many of which can be seen near Theytur.

Theytur is the road head, 35 km from Mussoorie, and the starting point of the Nag Tibba trek. The development needed at Theytur are those of a campsite with drinking water and toilet facilities and storage for camping equipment (tents, sleeping bags, ground sheets, rucksacks and fuel). Simple provisions are already available in the village.

Lakhamandal is much lower and therefore warmer than Mussoorie in the winter. Lakhamandal Temple is 71 km and 3 1/2 hours drive from Mussoorie to Kuwa on the Yamundri route. From Kuwa one crosses the Yamuna river by a Forest Department trolley to Lakhamandal village on the meadowed banks of the river. This is a good place for picniking, camping, swimming, and horse riding. An iron suspension bridge is under construction. The temple itself is a 1 1/2 km hike up through the village along a 3 foot wide goat track. The temple has been classified by the Archeological Survey of India as dating back at least to the 8th Century A.D. There is a museum nearby and statues and Shive Lingams in the fields. This is the mythological site where the Kamaras tried to burn the Pardavas. Lakhamandal can also be an excellent half way halting site for Yatra (Pilgrim) tourism going to Yamundri Temple. Improvements needed here are a cable ropeway to the top of the hill and a camp site or tourist lodge at the bottom of the hill.

Surkunda Devi is 45 km and a one hour drive from Mussoorie to Kadukhal on the Tehri road, from where there is a 3 km/3000 feet hike up to the hill at 10,000 feet above sea level. This is the mythological site where the head of Lord Shiva's consort fell when it was cut off to stop the tantric dance. The 360 degree view is of Mussoorie and Dehradun on the one side, and of snow-capped peaks such as Swaragrohini, Banderpaonch, Srikanta, the Gangstri group Jaunli, Chankhamba, Nilkanth, Badrinlath, and Nanda Devi, on the other. There is a temple at the top of the hill. The Ganga Durshera impromptu folk festival is held here at the end of May/early June each year, depending on the Hindu Calendar. Improvements needed here are again development of a suitable tourist lodge or campsite and the installation of a 'ski lift' or cable ropeway from Kadhukhal to Surkanda Devi.

C) Trekking Routes.

The trekking routes of Harkidun and Dodital are fairly well known and easily accessible from Mussoorie. Harkidun is a green valley at the base of the Banderpoonch mountain. Dodital is known for its alpine lake with mahseer fish. The possibility of improving the track from the Yamundri side to Dodital needs to be explored, as this will make the Dodital trek, which starts from the village of Agoda on the Gangotri route, a circuitous trek.

If the disused army road from Dhanaulti to Son Danda is repaired, it will open up the Nagun trek and a new route to Nag Tibba along the ridge. Son Danda should then have a tourist lodge.

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SOME IDEAS ON THE DOON VALLEY ENVIRONMENT

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INTRODUCTION

The Doon Valley is a unique area, measuring 2080.25 sq.km. and lying between the Shiwalik ranges on the south and the Himalayas on the north. This is the only area along the Himalayas where the Shiwalik range separates from the Himalayas creating a wide valley in between. Because of its low altitude and tolerable climate, the Doon Valley has long been a favourite area for tourists and for retired Government and private persons to settle because of the peaceful and healthy environment. However, the high aspirations of those who settled in this area have been gradually shattered because the environment has deteriorated year after year. This reduction in environmental quality has been witnessed by the present generation. The environmentalists have collectively raised a voice against some of the causes for this deterioration and have been, to a certain extent, successful in making the government realize the gravity of the situation.

Through personal observations during the course of nearly 12 years, the important causes for environmental deterioration of the Doon Valley have been identified. These are briefly enumerated in this paper:

1 Deforestation

During the course of one decade, between 1972-1982, the forest area decreased from 1372.75 sq.km. to only 900.50 sq.km. The closed forest area decreased from 1046 sq.km. to 703 sq.km. and the open forest area from 257.50 sq.km. to 227.75 sq.km. As a result, the non-forest area increased from 806.5 sq.km. to 1119.75 sq.km. The Doon Valley has long been known for the quality of its mixed forest comprising Banj (Quercus incana), Chir (Pinus roxburghii), Saal (Shorea robusta) etc. luxuriantly growing on the lower Himalayas and Shiwaliks. Due to a lack of proper management policy and with utter disregard for the environmental effects of a loss of forest area, the Department of Forests of the State Government permitted reckless felling of trees. Afforestation is being undertaken but to a far lesser extent than deforestation. Some 25-30 years ago, the houses in the Valley had no provision for fans or other cooling devices during the summer season because the climate was moderated by the forests around. Wind storms and hot winds (Loo) during the summer season were unheard of in the Doon Valley. At present, the summer season is as hot in the Valley as in the plains; as a result, fans and room coolers have become a necessity. Wind storms of high velocity and hot winds from the plains cross through the Valley uninterrupted; the winds enter through the defile created by the Yamuna river near Paonta Sahib. In earlier times these winds were held back by the thick forest cover.

During the past few years, heavy deforestation of the Saal forest in eastern Doon Valley was authorized by the state Government to create residential complexes and agricultural fields for the Tehri Dam oustees. A huge dam on the Bhagirathi river near Tehri town is likely to be completed during the next few years and the submerged hill villages around Tehri behind the high dam will have to be evacuated. Doon Valley unfortunately has been selected for resettlement.

This has reduced the forest area still further.

Nearly 500,000 people reside in the Doon Valley. The population explosion for which the residents are themselves responsible, is another factor; people need increasing amounts of firewood. This also causes pressures on the forests, as well as on the trees along roads and in fields. New plantations of trees are far below the minimum number desirable and as a result, vast stretches of bare fields without trees on their periphery are a common sight. The young trees if planted, remain uncared for and are eaten by goats and sheep and uprooted by the cattle. Care of plantations is also extremely poor.

As a result of the reduction of forest cover, the number of small trees and bushes has decreased markedly and the carrying capacity of the remaining forest has tremendously reduced the population of wild life. The number of artiodactyles (deer and antelopes) and carnivores (small and big cats) has decreased greatly. Large herds of cheetal, a common sight at one time in the forests of the Valley, are no more seen. One hardly ever comes across a group of 2-3 cheetals or other antelopes even deep into the forests.

2 Mining

The Mussoorie and Sahastradhara hills are reknowed for their high quality of limestone, so badly needed for many industries in the country such as sugar, chemical, paper, glass, steel, cement and cosmetic. Other minerals in these hills are marble, phosphorite and gypsum. The miners have, however, proceeded in an utterly unscientific manner. Mining was, in fact, turned into plundering the mineral wealth of the hills. As a result, vast stretches of the wounded hills are visible along the Mussoorie and Sahastradhara hills. Due to reckless dynamiting of the area, these hills are now prone to serious geomorphological changes which could be disastrous for the human population in the Valley. In the mined area, the vegetation cover is completely removed and, therefore, the water retention power of the hills is greatly reduced. Many natural springs in these hills have gradually dried out, causing a serious local shortage of water and also in the city of Dehra Dun which depends solely on these springs. The aquifers below these hills are no longer charged properly and a permanent depletion of water is being felt by one and all. Thanks to the efforts of various organisations such as the Doon Science Forum (of which the present author is President), the Friends of Doon, the Villagers' movement, etc. who put this case to the highest judiciary level in the country, the Supreme Court of India has now restricted mining. But at this stage, rehabilitation remains a big problem needing scientific inputs and Government support. Huge quantities of stones, pebbles and rubble are washed down during the monsoon season, heavily silting up the beds of almost all streams. As an example, one can see a bridge on the way to Mussoorie where the bed of the stream, which was at one time nearly 20-25 feet below the bridge, almost touches the ceiling of the bridge.

The perenial streams of the Valley are gradually drying up and many of them run only during the rainy season. Due to this, aquatic fauna such as fish, crustaceans and amphibians have suffered tremendously. Those streams which still retain their perenial character do not have sufficient water to hold big fishes such as species of Mah Seer [Tor putitora (Hamilton) and Tor tor (Hamilton)], Labeos [Labeo dero (Hamilton) and Labeo dyocheilus (McClelland)]. This has imposed a great setback to the endemic fisheries of the area and has also been a great disappointment for eager anglers with their best fishing tackle who return home with empty fish bags. Serious thought and scientific study on the bioecology of these fishes is now needed for their rehabilitation by artificial means. The construction of dams along the Yamuna river has already inflicted great damage to the Mahseer by obstructing their upstream- downstream migrations, so necessary for spawning. The Mahseer does not breed in confined waters and must swim upstream in rivers for this purpose, ascending in altitude by an amount of 2000 ft.

3 Human Settlements and Overgrazing

All along the Shiwalik hills, there are hundreds of small villages, the predominant inhabitants being Gujjars who make a living from tending cattle. Each family has on an average 15-20 cattle which freely graze on these hills, preventing the natural forest seedlings from growing. In order to provide fresh and tender leaves for their cattle, the Gujjars intentionally put fire to the forest so that the dry leaves and bushes burn out and in the next rainy season, fresh grass shoots emerge. The Gujjars also burn out thorny bushes to make an easy passage through the forest for themselves as well as for their cattle. In such forest fires, hundreds of eggs of birds, including the Red Jungle Fowl, Khalij etc., are destroyed. The newly hatched fledglings and the new-born calves of deer and antelopes are roasted alive. As a result, the forest cover is reduced and wildlife is endangered.

4 Air Pollution

Air pollution in the Valley is increasing at a tremendous rate for several reasons:

(a) Thriving on the limestone, kilns burn limestone with coal and produce dehydrated lime. The chimneys of these kilns emit ash and carbon-based poisonous gases continuously. It is, in fact, difficult to breathe in the vicinity of these kilns. The ash and dust rain down on the houses nearby.

(b) Also based on limestone mining, factories crush limestone and marble into smaller grains and continuously throw tonnes of limestone dust into the atmosphere. The visible evidence is to be seen on the leaves of trees and bushes, houses etc. which turn almost white, as if they had been whitewashed. Due to this dust, the evapotranspiration of leaves is reduced, with other side effects.

(c) The cement and chemical factories installed in the Valley emit hundreds of tonnes of smoke and ash into the atmosphere and a black pall often covers the sky. The liquid effluents from the chemical factories near Rajpur and Harawala are discharged into the adjoining streams where aquatic life is endangered as well the human population which depends upon these streams for its water supply.

(d) The city roads in Dehra Dun are like rural roads, a situation that was tolerable when the number of automobiles and people was negligibly low. By rural roads, I mean that for a 20-30 ft. road width, only the central 12-15 ft. are covered with stones and tar whereas the 4-6 ft. flanges on either side remain unpaved. During the rainy season, the unpaved portion becomes muddy and slippery while during the dry season, huge amounts of dust fly into the atmosphere from passing automobiles. Unsanitary conditions prevail in many cases and the muddy parts of the flanges harbour millions of germs which fly into the atmosphere along with the dust particles. Respiratory diseases, such as the common cold and bronchial asthma are on the increase in the city and endanger the lives of many people. This problem could be eliminated by paving the roads with stone and tar.

II MODELLING AND STATISTICAL ANALYSIS

STATISTICAL ANALYSIS OF ANNUAL RAINFALL TIME SERIES

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The time series under analysis is presented in Figures 1a,b,c (Dehra-Dun, 1865-1984; India, 1875-1984). On the visual level there is no indication of the existence of any significant systematic variation in this time series despite common opinion that the average rainfall in Doon Valley decreased during the last 10-15 years. This discrepancy demanded a more thorough analysis.

Nonparametric tests

Translating the colloquial assumption that "nothing systematic happened during the observed interval" into probabilistic language, one can say that our observation $y_1,\ldots,y_n$ is a sample corresponding to random values $Y_1,\ldots,Y_n$, which are independent and identically distributed with an unknown distribution function. This assertion is usually called the "null hypothesis."

It is difficult to formulate well-structured alternatives in our case. Therefore the "run tests" oriented to the omnibus alternatives to randomness will be used. (See Hannan, Krishnaiah and Sen, 1985, page 107.)

Let $\tilde{y}$ be the sample median and write +(−) for any y_i so that $y_i \geq \tilde{y}\,(<\tilde{y})$. Then the run statistic R counts the number of runs above and below the median of the original sequence. When the null hypothesis is true for large n, R is approximately normal with mean equals $n/2$ and variance equals $n/4$ (in our case $n=120$). The simple calculation gives $\tilde{y} \cong 215$ and $R \cong 49$. So $R > n/2 - 1.96\sqrt{n}/2 = 48$ and for the significance level 0.95, there is no reason to reject the null hypothesis. Nevertheless we are quite close to a violation of inequality, so another test is necessary for certainty.

This test is based (Hannan, Krishnaiah and Sen, 1985, p. 109) on the statistic r = total number of runs up or down. A sequence of h consecutive inequalities $y_{i+1} - y_i > 0$ is called a "run up" of length h (a "run down" is similarly defined; if subsequent observations are equal, only one of them must be considered.) If the null hypothesis is true, then r is asymtotically normally distributed with mean $(2n-1)/3$ and variance $(16n-29)/90$. In our case $r=72$ which gives

$$r > (2n-1)/3 - 1.96\sqrt{(16n-29/90} \cong 70$$

Since this situation is similar to the previous one, more detailed analysis can probably clarify it. Of course we cannot create new data, but we can use more detailed models (or hypotheses) implicitly containing some prior information. In statistical analysis these could be regression models.

Regression analysis

To start this kind of analysis one has to formulate a regression model which accumulates prior information and assumptions, although some of them are still subject to verification. Here the assumptions will be (see also Table 1):

- There are long term fluctuations in average annual rainfall (e.g., in model I from Table 1, the fluction is described by the last term.)

- There is a permanent trend in average annual rainfall (parameter ϑ_2 describes this trend.)
- Deviations of annual rainfall from the average behavior are assumed to be random and independent and their variance does not depend on time.

The tested hypothesis is now $\vartheta_2<0$. It will be clear later that the first assumption is not crucial for the testing, but the last one can change the final result significantly. Unfortunately, if we start to verify this assumption, we would be led back to a situation similar to the one in the previous section. So one can only "believe" in it.

Table 1 Regression Models Fitting

Type of Model: Nonlinear with additive random noise

$$y_i = \eta(t_i, \vartheta) + \varepsilon_i, i = 1, n, t_i = real\ scale - 1985$$

Assumptions: ε_i are independent with variance σ^2 (unknown).

$$\eta(t,\vartheta) = \vartheta_1 + \vartheta_2 x + \vartheta_5 \sin \frac{2\pi(t-\vartheta_4)}{\vartheta_3} \quad (1)$$

$$\eta(t,\vartheta) = \vartheta_2 + \vartheta_2 x + \vartheta_5 \sin \frac{2\pi(t-\vartheta_4)}{\vartheta_3} + \vartheta_8 \sin \frac{w\pi(t-\vartheta_7)}{\vartheta_6} \quad (2)$$

For Doon Valley, y_i is the yearly rainfall in cm.

For India, $y_i = \frac{y_i^1 - \bar{y}}{\bar{y}}$, where y_i^1 is the average of the country's yearly rainfall, $\bar{y} = n^{-1} \sum_{i=1}^{n} y_i$.

The results of this analysis are summarized in Table 2 and are even more surprising than previous ones from the point of view of "common opinion." The regression analysis yields $\vartheta_2>0$, suggesting (insignificantly statistically, but nevertheless...) that during the last century an average increase (!) in rainfall occurred in Doon Valley. The reason for the existing common opinion may be the long-term periodicity (~60 years; see Table 2), which approaches its minimum in the late seventies. This periodicity is well-pronounced (see parameters ϑ_5); moreover, the same periodicity takes place for the whole Indian subcontinent (see the same Table). One can also see that there is a short-term periodicity (~6 years) which is statistically significant for Doon Valley.

In summarizing all currently available data, one must reject the hypothesis of a decrease in average annual rainfall in Doon Valley. The calculations were based on the algorithm from Fedorov, Vereskov, 1985.

Table 2 Parameter Estimates and their Estimated Standard Deviations

	Parameter number							
	1	2	3	4	5	6	7	8
DDI	205.2	0.109	63.0	3.4	11.4			
St.dev.	8.9	0.131	10.2	10.7	6.29			
India I	-0.58	0.131	61.1	-5.07	1.75			
St.dev.	2.64	0.0516	28.7	28.9	1.45			
DDII	205.9	0.099	60.85	4.59	11.78	6.06	-1.33	-14.4
St.dev.	8.75	0.129	8.95	8.67	6.08	0.7	0.727	7.04
IndiaII	-0.43	0.028	63.37	-7.58	1.95	6.26	-0.87	-0.83
St.dev.	2.28	0.043	20.1	19.9	1.47	0.329	2.8	1.64

Analysis of Monthly Data

The corresponding monthly data were available to us (see DATA BANK in Volume II) only for the last 14 years (Forestry Research Institute Station), and the length of the time series is therefore not sufficient for any serious statistical approach. Nevertheless, a comparison of data with long-term extremes seems to be useful (see Figure 2a,b,c) where the information for two dry months and one rainy month is presented. In order to illuminate the stability of traditional weather indicators, the temperature time series in Fig. 3a,b,c are presented for the same months. It is worthwhile to note that all extremes occurred earlier than expected in the time interval under consideration.

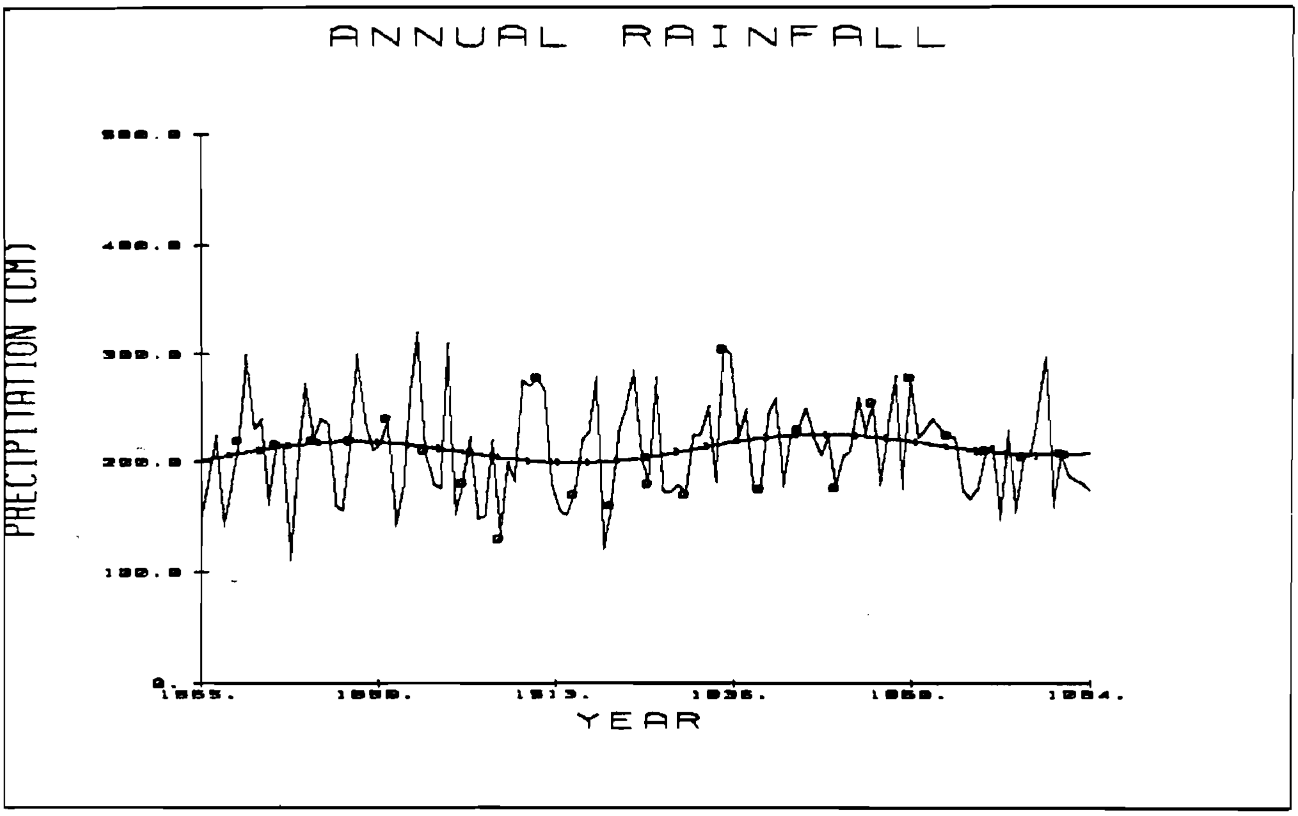

Figure 1a Rainfall in Dehra-Dun

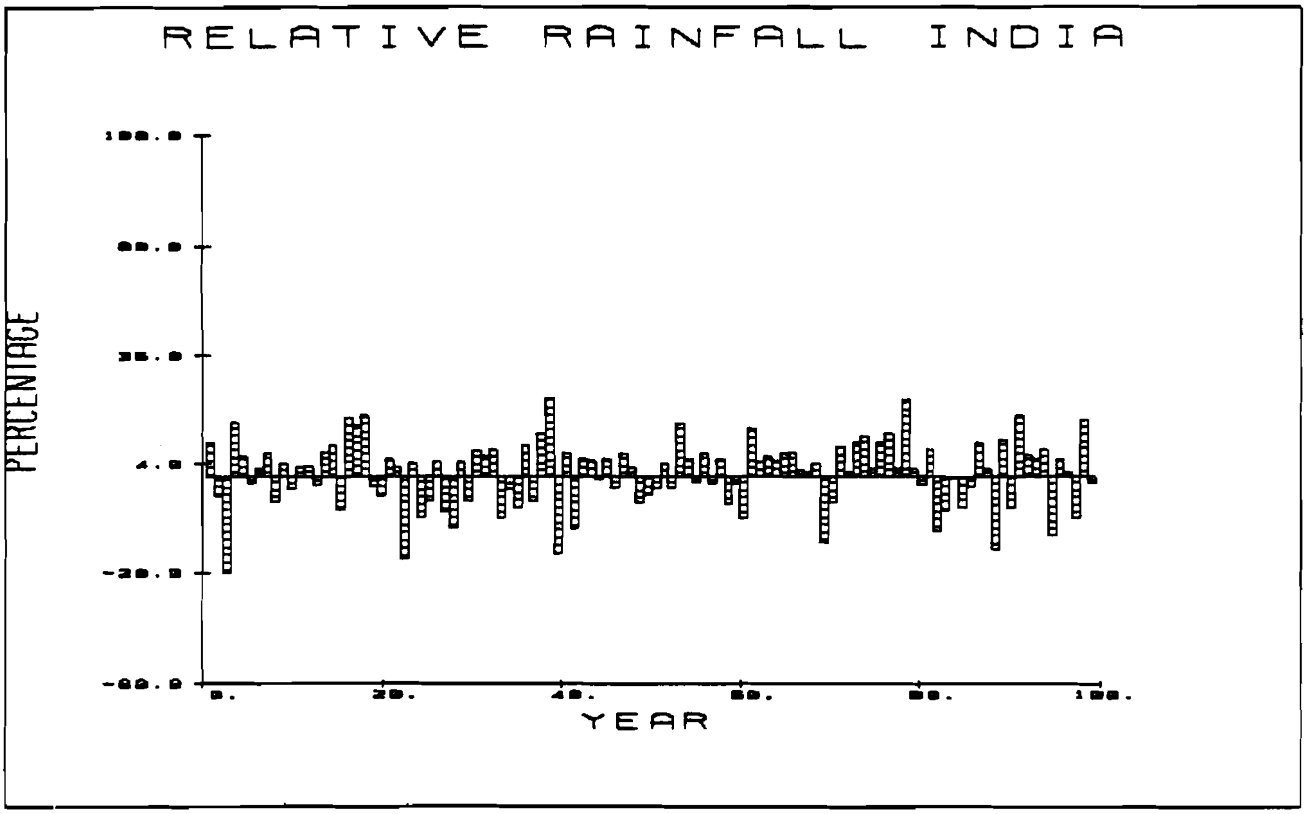

Figure 1b Rainfall in Dehra-Dun; percentage of the total average

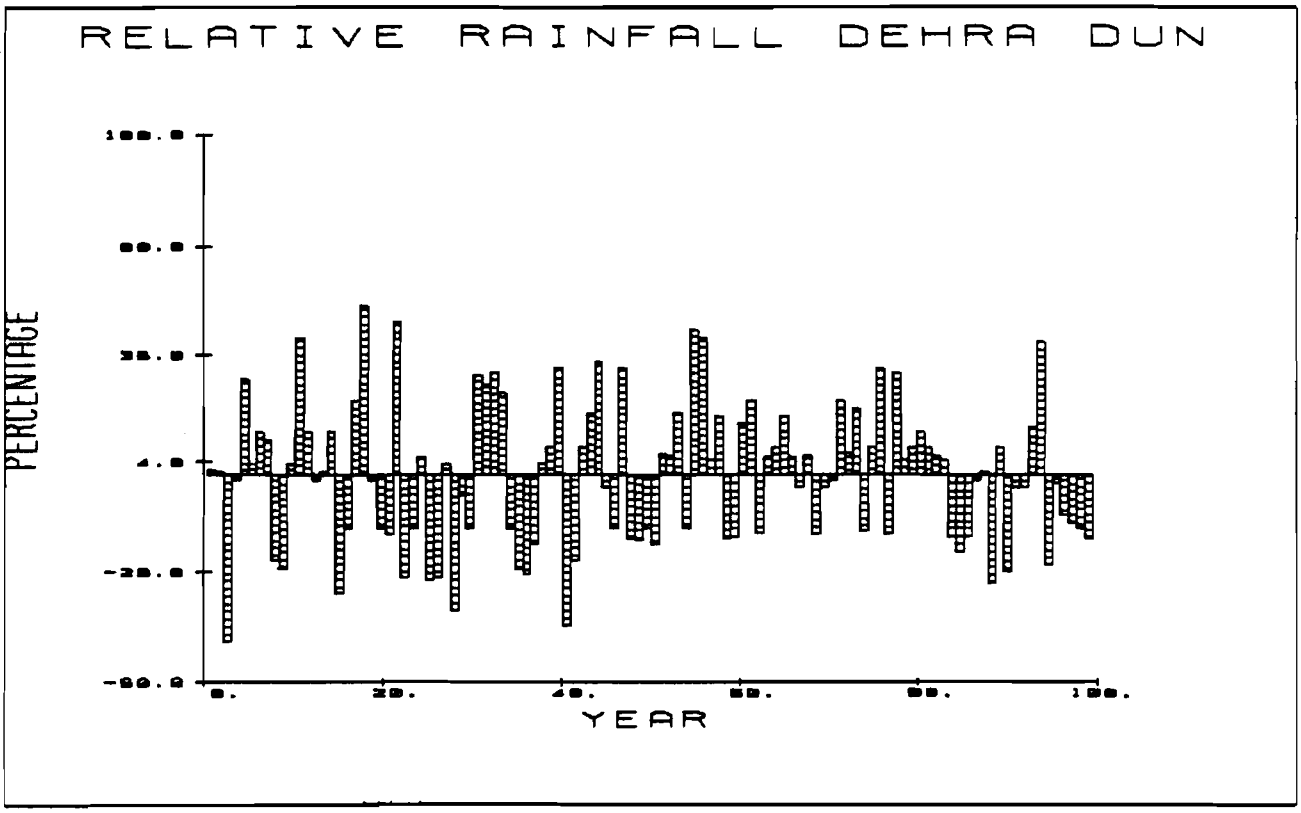

Figure 1c Average annual rainfall for India

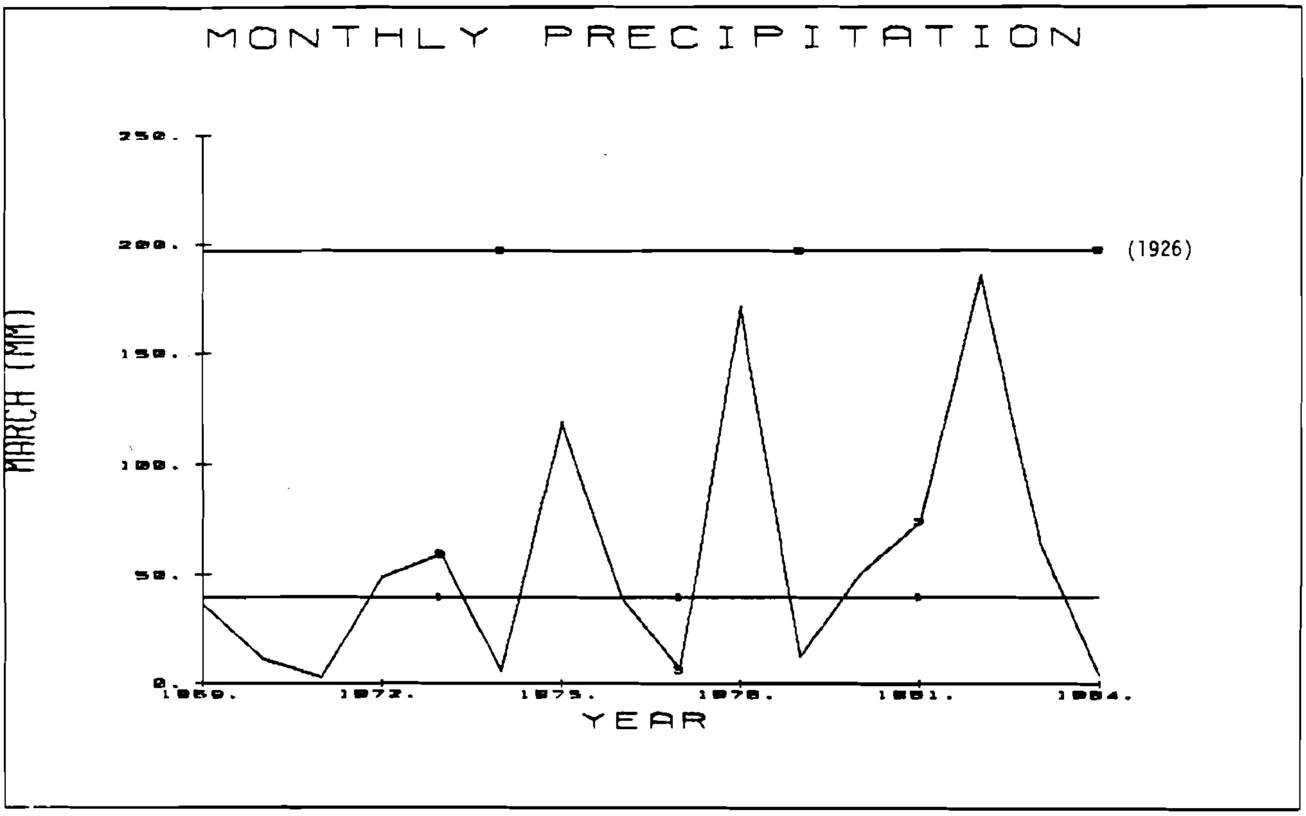
MONTHLY PRECIPITATION
250.
200.
150.
100.
50.
0.
MARCH (MM)
(1926)
1972.
1975.
YEAR

Figure 2a

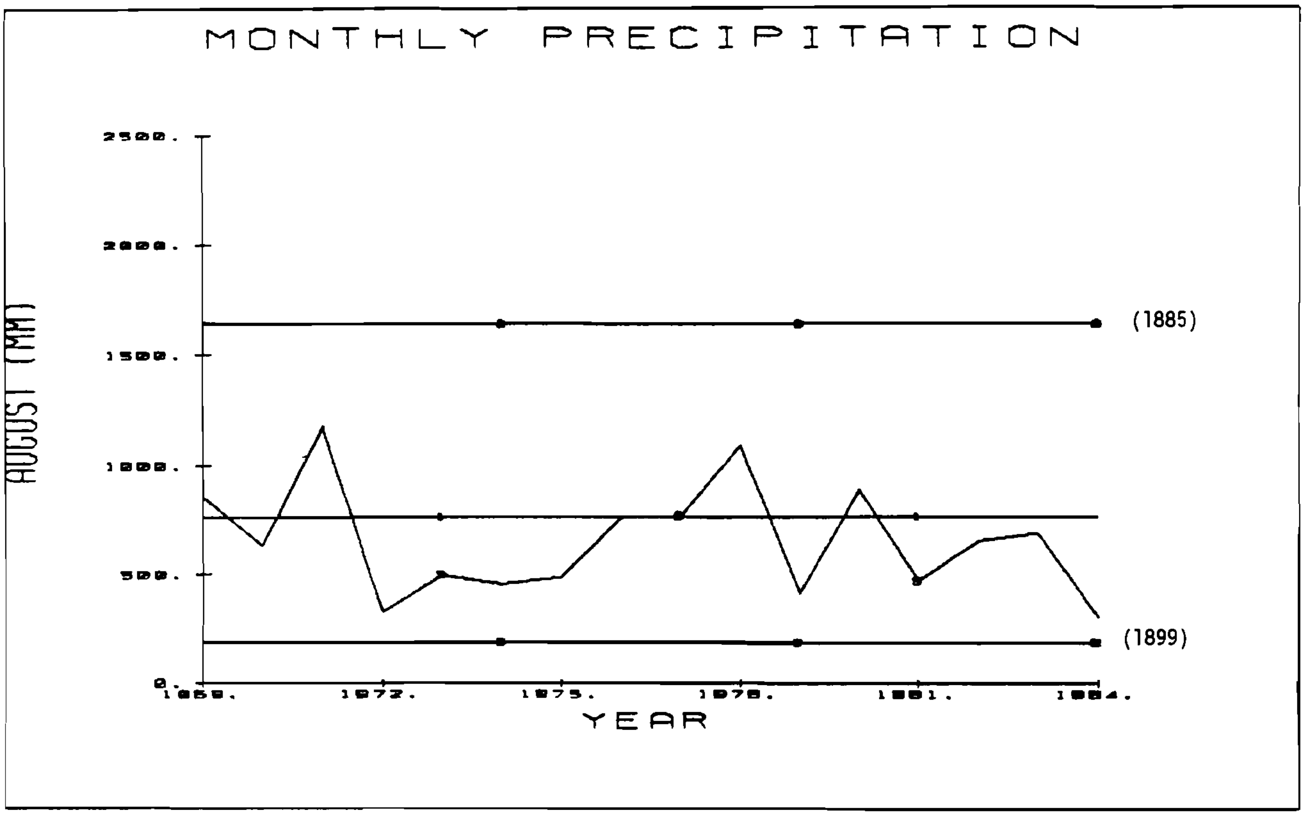
MONTHLY PRECIPITATION
2500.
2000.
1500.
1000.
500.
0.
AUGUST (MM)
(1885)
(1899)
1969.
1972.
1975.
1978.
1981.
1984.
YEAR

Figure 2b

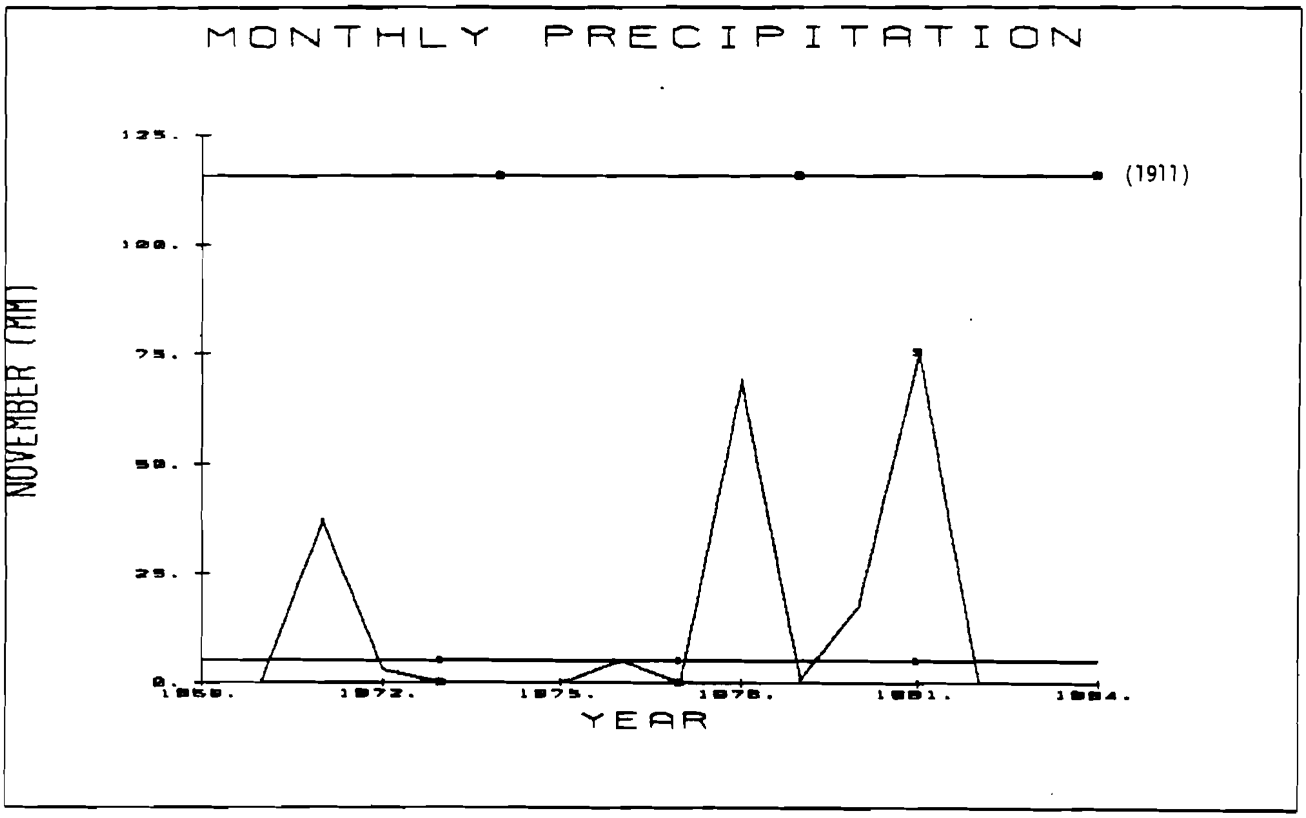
MONTHLY PRECIPITATION
NOVEMBER (MM)
125.
100.
75.
50.
25.
0.
(1911)
1972.
1975.
1978.
1981.
1984.
YEAR

Figure 2c

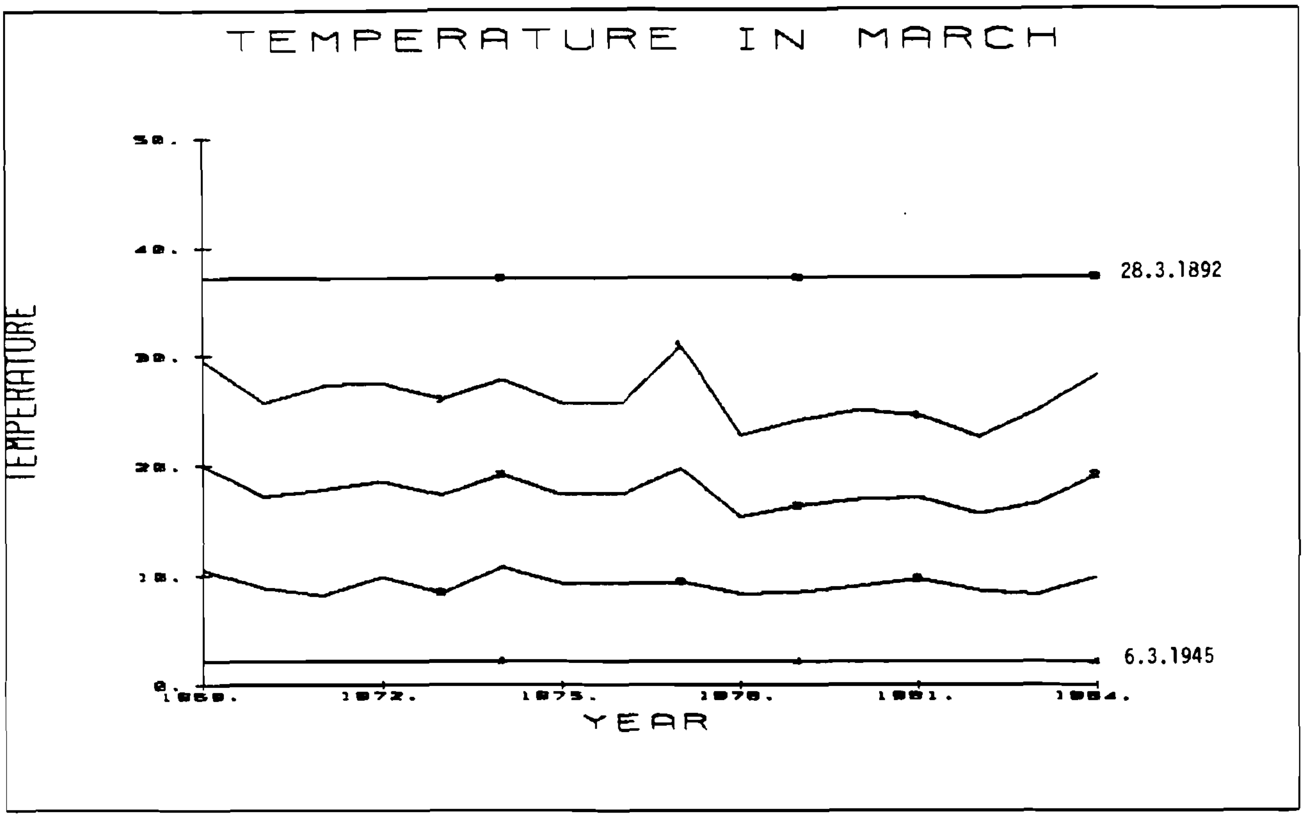

Figure 3a

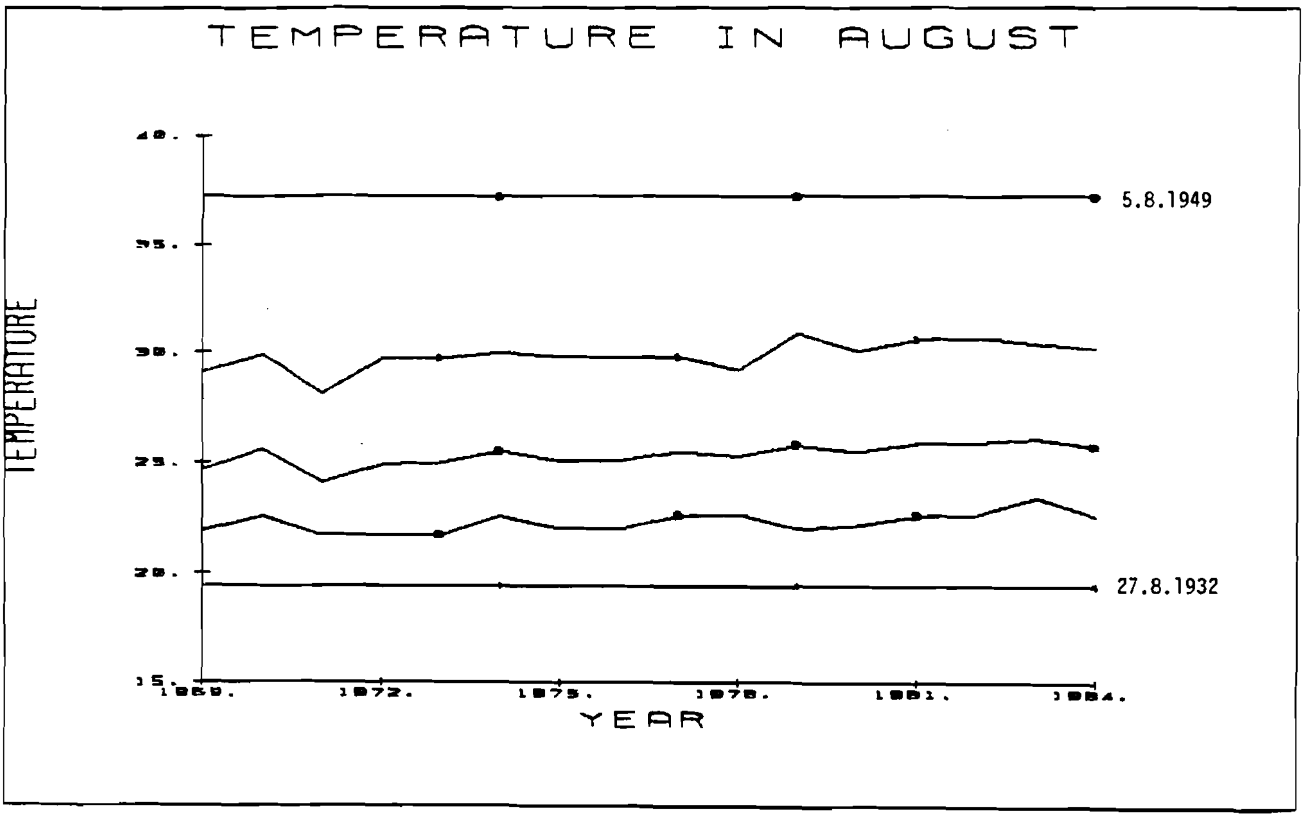

Figure 3b

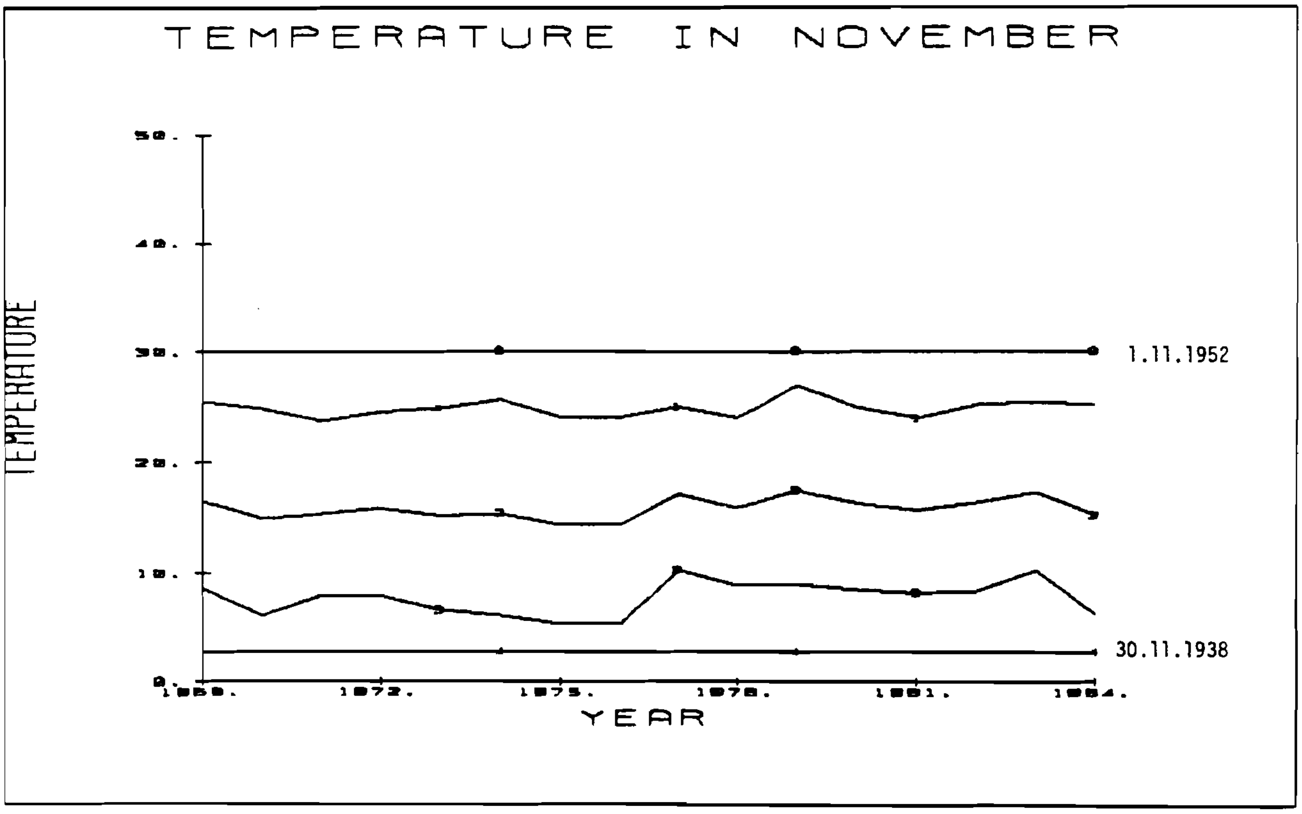
TEMPERATURE IN NOVEMBER
TEMPERATURE
1.11.1952
30.11.1938
YEAR

Figure 3c

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Hannan, E.J., P.R. Krishnaiah, M.M. Rao. 1985. Time Series in the Time Domain, North-Holland, p. 490.

POPULATION TRENDS IN THE DOON VALLEY

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The main data available on the population of Doon Valley is collected in Table 1; see also Figure 1 (Varun, 1979; Statistical Report, 1984). One can observe that the total population growth has had an exponential character of a sort usually observed when a region does not face saturation effects, for example, a significant shortage of major supplies.

Table 1 Main Demographic Characteristics

POPULATION DURING THE LAST 12 DECADES DEHRADUN DISTRICT					
YEAR	TOTAL	MALE	FEMALE	RURAL	URBAN
1872	117000				
1881	144000				
1891	168000				
1901	177500	102400	75100		
1911	204500	120500	84000		
1921	211900	128000	83400		
1931	229800	137300	92500		
1941	265789	161671	104115		
1951	361689	210860	150289		
1961	429014	242987	186027	231179	197835
1971	577306	326108	251798	305529	271777
1981	761668	420454	341203	389527	372141
PERCENTAGE OF DIFFERENT WORKERS IN MAJOR LABOR CLASSES					
Total major workers	247982	100%			
Farmers	69291	28%			
Agricultural workers	19682	8%			
Family industries	3168	1%			
Other	155841	63%			
POPULATION IN DEHRADUN TAHSIL					
1961	362300	205300	157000	167700	194600
1971	498200	278900	219300	232500	265700

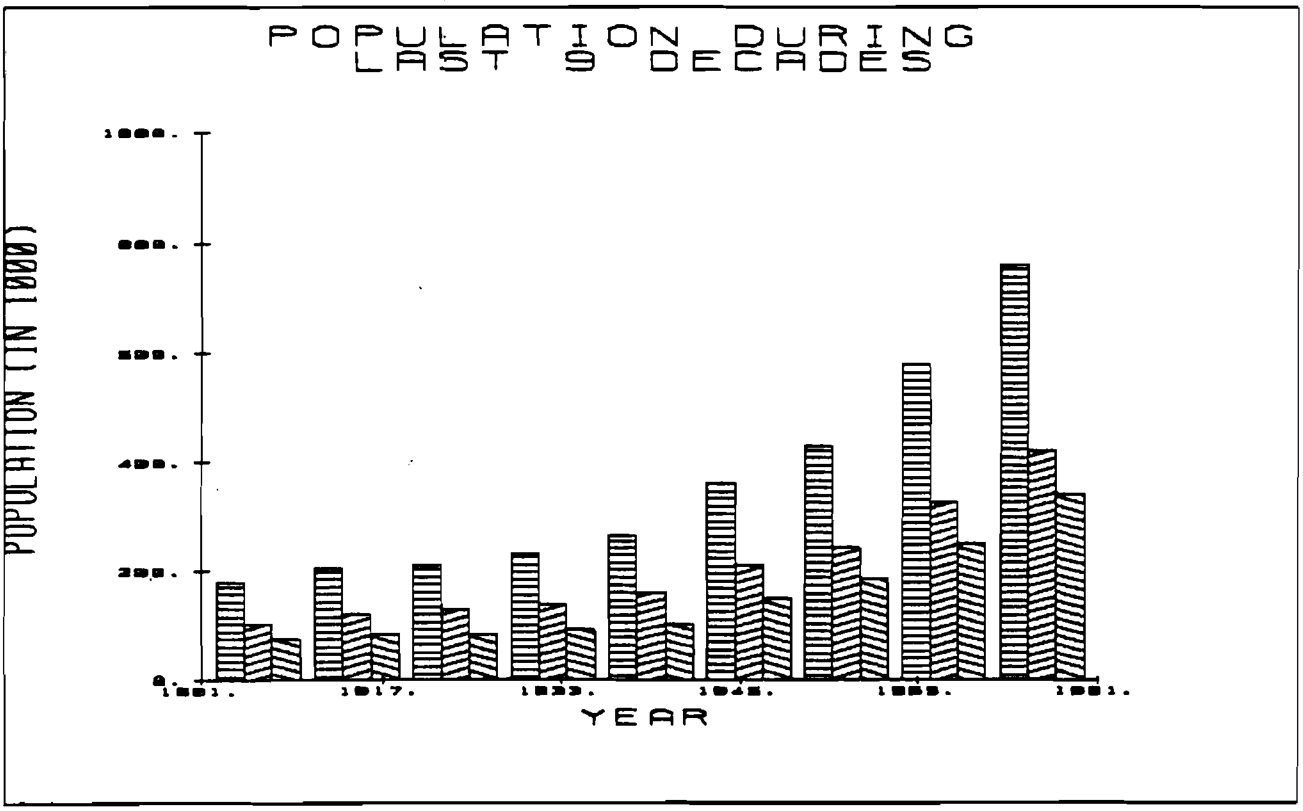
POPULATION DURING
LAST 9 DECADES
POPULATION (IN 1000)
1917.
YEAR

Figure 1

Three regression models were fitted to this available data. (See Figures 2a,b,c,d; the vertical lines indicate estimates of the standard deviation.) All three have approximately the same sum of square residuals, so they are statistically equally good; see Table 2. It is worthwhile to point out that the logistic model (which takes into account saturation effects) does not give any visible indication of a slowing down of the total population growth.

Table 2 Regression Models of Population Growth

$y_t = \eta(t_t, \vartheta) + \varepsilon_t, t_t = \tau_t - 1871,$
where ε_t are random values with constant variance σ^2,
τ_t are current years.

$$\eta(t,\vartheta) = \begin{cases} \vartheta_1 d^{\vartheta_2 t} & (1) \\ \vartheta_3 e^{\vartheta_1 + \vartheta_2 t} / (1 + e^{\vartheta_1 + \vartheta_2 t}) & (2) \\ \vartheta_1 e^{\vartheta_2 t} + \vartheta_3 e^{\vartheta_4 t} & (3) \end{cases}$$

$$s_j^2 = \Sigma[y_t - \eta(t_t, \hat{\vartheta})]^2 / (N - m_j),$$

where N is number of observations,
m_j is number of unknown parameters,
$\hat{\vartheta}$ are their estimates.

		Parameter numbers 1	2	3	4	s_j^2 / s_π^2
MODEL I	param. st.dev.	80.7 11.4	0.20 0.015			0.8162
II	param. st.dev.	-3.9 3.0	0.21 0.07	$4.0 \cdot 10^3$ $12.7 \cdot 10^3$		1.
III	param. st.dev.	3.4 4.3	0.45 0.09	139.7 8.2	0.065 0.039	0.766
IV*	param. st.dev.	3.5 1.7	0.43 0.05	109.6 12.4	0.104 0.012	0.454

*Case IV - Model III was used with the addition of information on the urban and rural population (1961, 1971, 1981)

The sum of two exponents gives the most interesting and "physically" reasonable result. It shows that there are two population groups with different growth rates. This can be explained by comparing the size of each group with the latest available data on rural and urban population (1961, 1971, 1981). The first group can be considered urban, the second, rural. One can see in Figure 2d that the urban population increases much faster than the rural one. Presumably this is a reflection of the fact that the forest-agricultural carrying capacity of the region has almost approached its upper limit; see contribution in this volume "A Preliminary Assessment of Some 'Carrying Capacity' Indicators for the Dehra-Dun District" by Fedorov, Lenko and Parikh.

In addition to the models presented in Table 2, models with the same response functions (average behavior) but with other assumptions on additive random deviations were fitted:

$$\sigma^2 = \delta^2 \eta(x, \vartheta) \text{ or } = \delta^2 \eta^2(x, \vartheta).$$

These models are popular in population growth studies and some probabilistic results confirm that they should be better than the models from Table 2. But in our case the final results (prognoses and parameter estimates) practically coincide for all modifications.

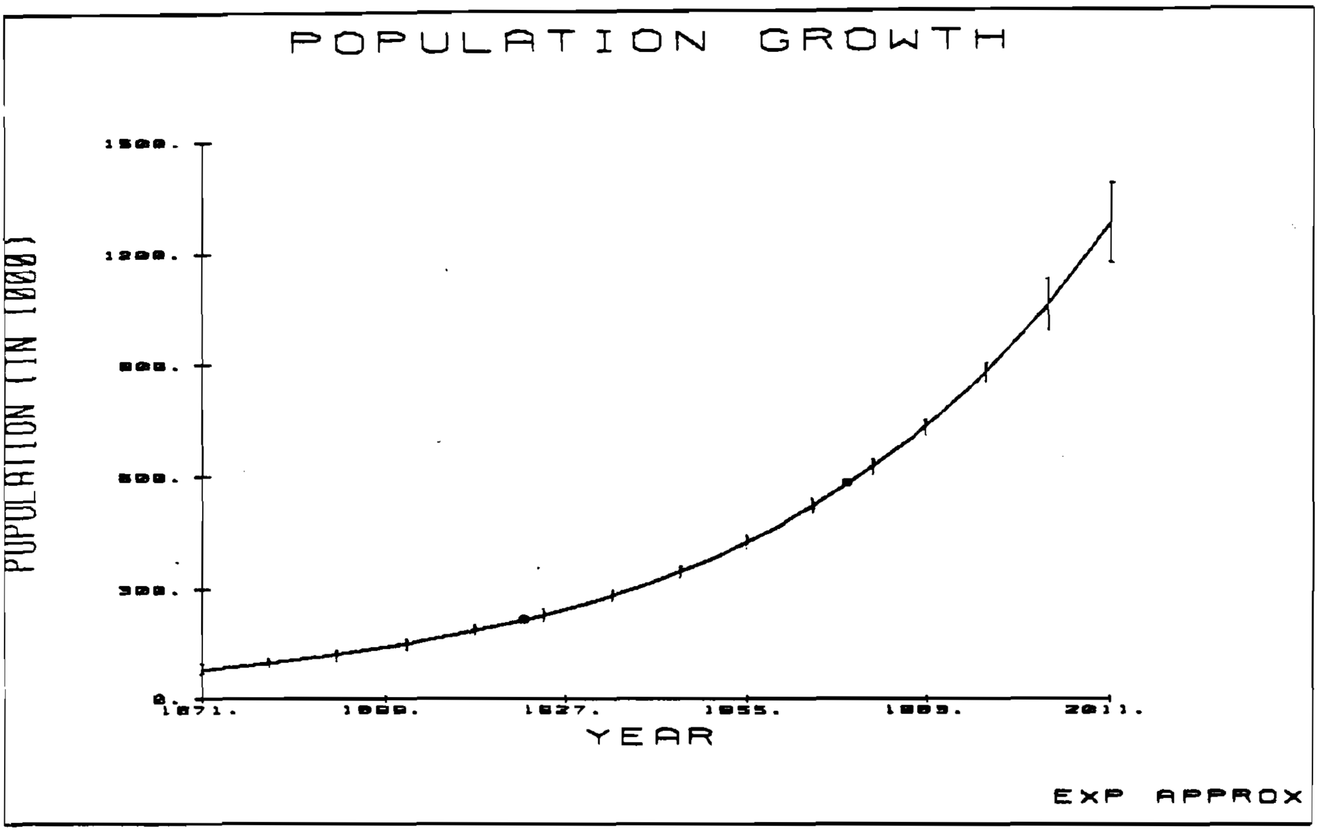

Figure 2a Model I

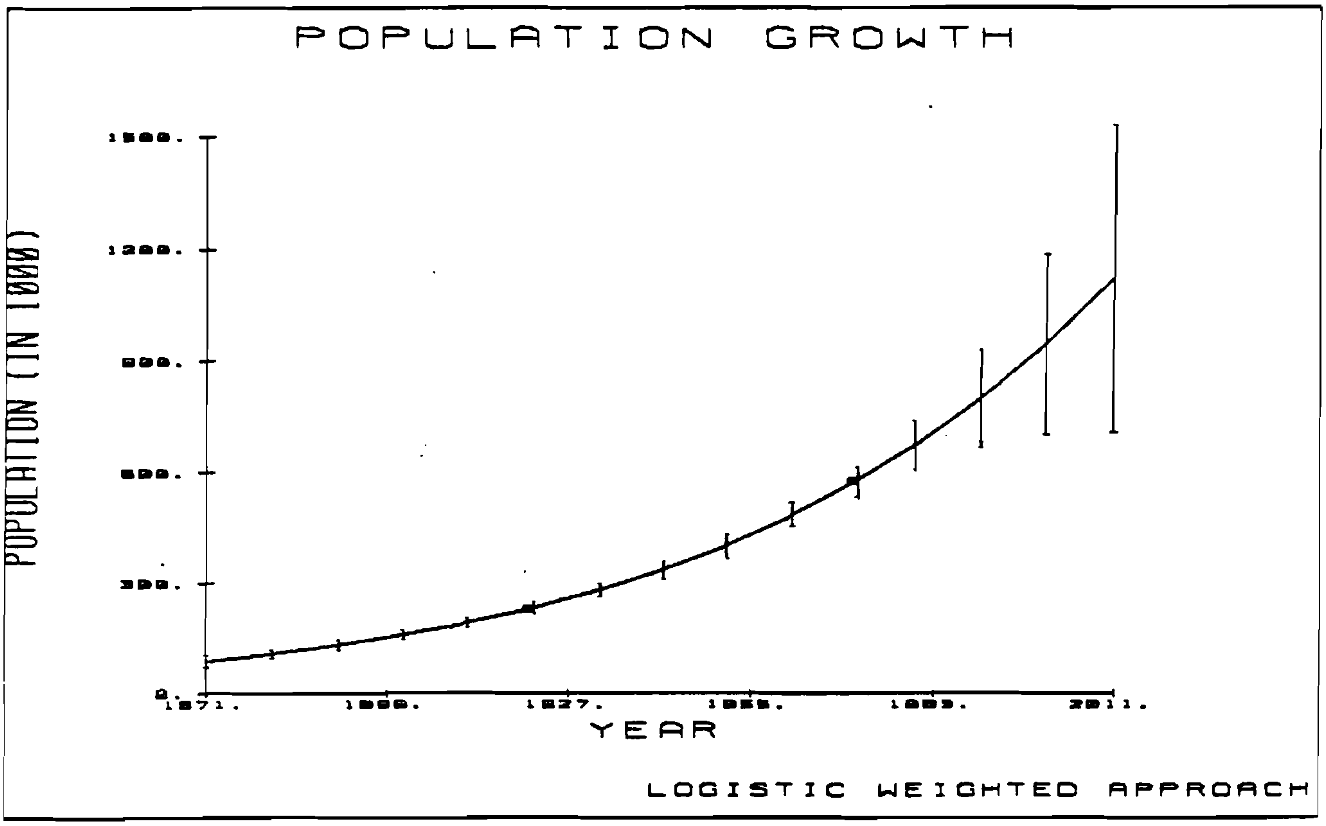

Figure 2b Model II

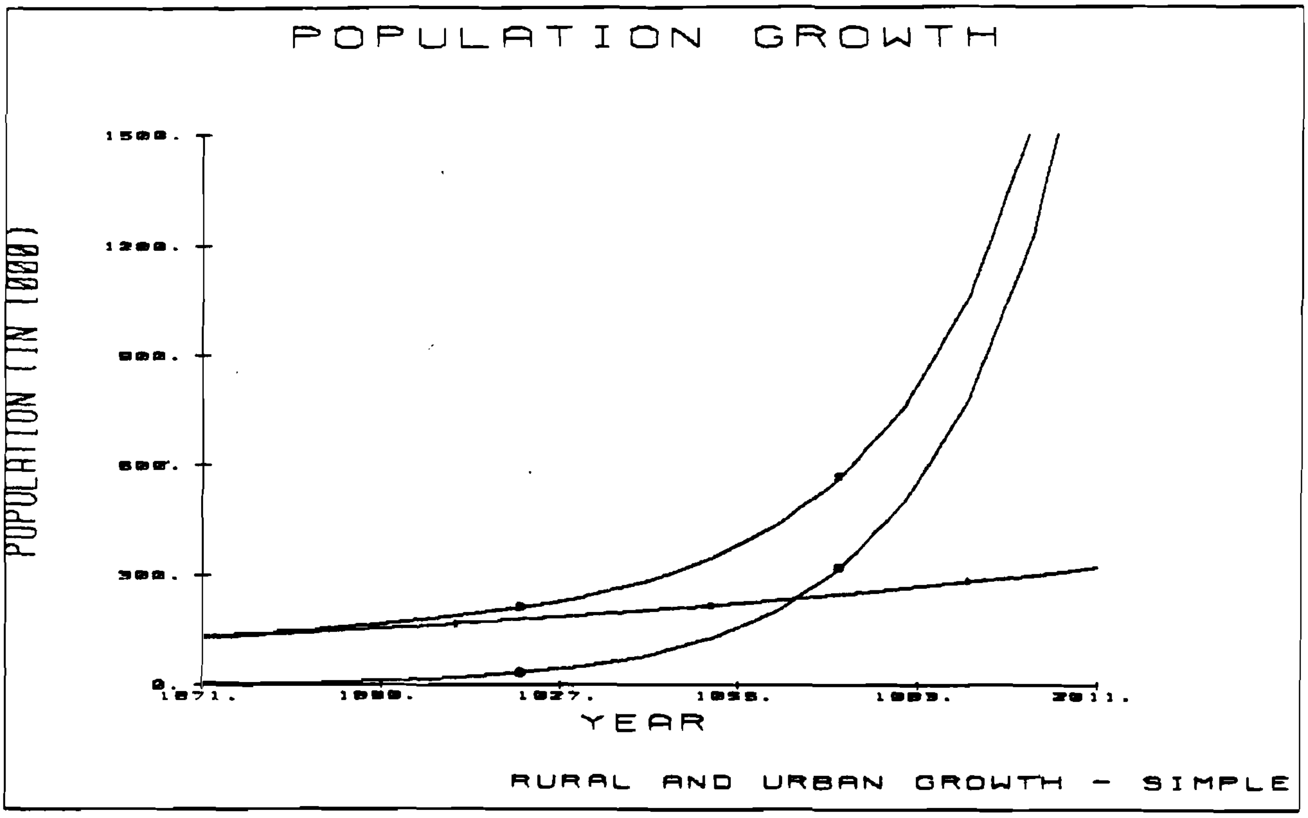

Figure 2c Model III

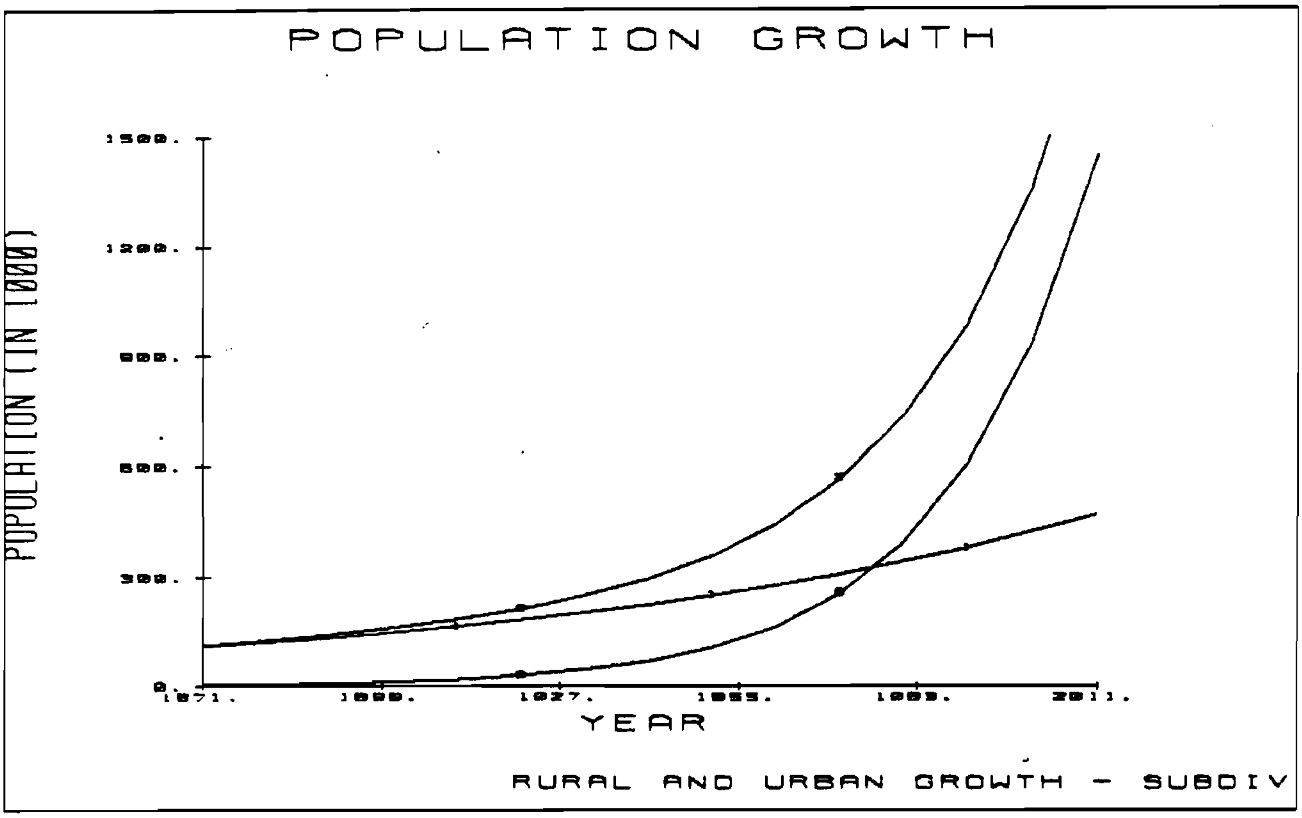

Figure 2d Model IV

A PRELIMINARY ASSESSMENT OF SOME "CARRYING CAPACITY" INDICATORS FOR THE DEHRA-DUN DISTRICT

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Introduction

An estimate of the "carrying capacity" of a region is often considered to be a necessary element of regional environmental assessments. It is clear that "carrying capacity" is a concept that can include many descriptive factors. (e.g., Slesser and Hounam, 1981). Because of data scarcity concerning the Dehra-Dun district, only a very models number of factors can be analyzed at present. In Phase II, the corresponding analysis may be done on a multi- factor base, and must comprise local industries and mineral resources.

At present only rural components will be considered, for the reason given in the contribution "Population Trends in the Doon Valley" by Fedorov and Lenko, where a brief statistical analysis of population dynamics was made. From this analysis it follows that the rural population has nearly approached its saturation level, while the urban is still growing intensively. (see "Population Trends in the Doon Valley", this volume, Fig.2d) One can also observe value-stabilization of arable lands and crops. (Compare Varun, 1979, and Statistical Reports, 1984.)

The basic information necessary and available for analysis is shown in Tables 1 and 2. All regional information corresponds to the Dehra-Dun district. Therefore, strictly speaking, the analysis was completed for this administrative unit.

Table 1 General Information

Cultivated area	580	sq.km.
Area yielding two annual crops	240	sq.km.
Foodgrain production	77,000	t
Forest area	1,500	sq.km.
Forest products		
Timber	40,000	cu.m.
Fuelwood	90,000	cu.m.
Cattle and buffalo	150,000	
Sheep	35,000	
Goats	35,000	

Table 2 Auxiliary Information*

Caloric Values on Fresh-weight Basis for Certain Agricultural Materials	
Category	KJ per kg $\cdot 10^3$
Grains	16.2
Pulses (various beans, etc.)	17.1
Leafy vegetables	2.8
Tubers (potato)	4.0
Vegetables	2.4
Green fodder	4.0
Tree and shrub leaves	4.2
Hay	14.6
Leguminous hay	15.0
Straw	14.0
Concentrates	13.9
Cakes, meals	18.2
Manure	7.3
Fertilizer	30.3
Fuel	16.8
Milk	4.2
	KJ per day $\cdot 10^3$
One man-day	16.7
One bullock-day	72.7
Fuelwood consumption	1.5 KJ/day · capita
*Pandey, Singh, 1984	

Fuelwood Consumption

From Tables 1 and 2, it follows that in this district the volume of the extracted fuelwood is sufficient to support 130,000 people. The coefficient 0.8 was used for transformation of cu.m. of fuelwood to tonnes. A rather high coefficient was taken and it corresponds to the best species. Usually the value 0.6 is more realistic.

Our estimate is based on current fuelwood extraction. If we assume an annual increment of forest biomass (in this area it is 160 t/sq.km.) used as fuelwood, then the district can support about 440,000 people. Of course this figure is purely theoretical and even grazing was not taken into account here. At best, one can hope for 50% use of the annual increment and this reduces the upper limit to 220,000.

It should be pointed out that demand for fuelwood per capita is decreasing steadily due to the use of more efficient energy sources. For instance, about 60% of villages are now electrified (See Volume II, DATA BANK), but the corresponding energy is mainly imported.

Food Consumption

From Tables 1,2 and Figure 1, it follows that the current level of foodgrain production the district can support is about 190,000 people. If one takes into account the production of fruits, vegetables and domestic animal products, this figure can increase up to 400,000. So the rural population, which is now about

390,000, can support itself but contributes very few products to towns.

This fact is reflected explicitly in "Population of India", 1984, which states that in 1971-1973, when the total population was 580,000 and rural was 300,000, the district produced around 58,000 t of foodgrain (compared with 77,000 t in 1984), and about 30,000 t was imported.

Conclusion

In summarizing the results one can assert that the Dehra-Dun district has approached saturation at least for two essential factors: fuelwood and available food consumption. There is evidence that water resources (at least under existing water-management policies) have become insufficient in the district. This fact has been pointed out by different authors (Singh, 1973; Saxena, Verma, 1981). In addition, the increase of arable lands seems to be very problematic because it will almost certainly result in deforestation with subsequent deterioration of environmental conditions.

Therefore, considering previous tendencies and currently available data, extensive development of this area looks inadmissible. Of course, this conclusion should be considered very cautiously because it is based on a very preliminary, single-factor, type of analysis.

This preliminary assessment does not include several important factors. These relate to:

- Improvements in a static picture of 1980
- Dynamic variations in future
- Effects of different policies

1. Improvements in base year

- Demographic composition of population, i.e., different calorie requirements of men, women, and children
- Livestock composition in terms of cows, bullocks, goats, sheep, pigs and their different feed requirements
- Fuel composition and rural energy survey

2. Dynamic variations in future

In addition to these improvements for the base year, carrying capacity in future needs to be a *dynamic concept*. This would mean that in the future, one could have many *trade-offs between alternatives*. Some of them are indicated below:

- What amount of population growth and livestock growth could be sustained in the future and with what measures?
- How do increased industrial activities and imports of oil products affect fuelwood situation and employment questions?

3. Effects of alternative policies

In addition, there are policy alternatives:

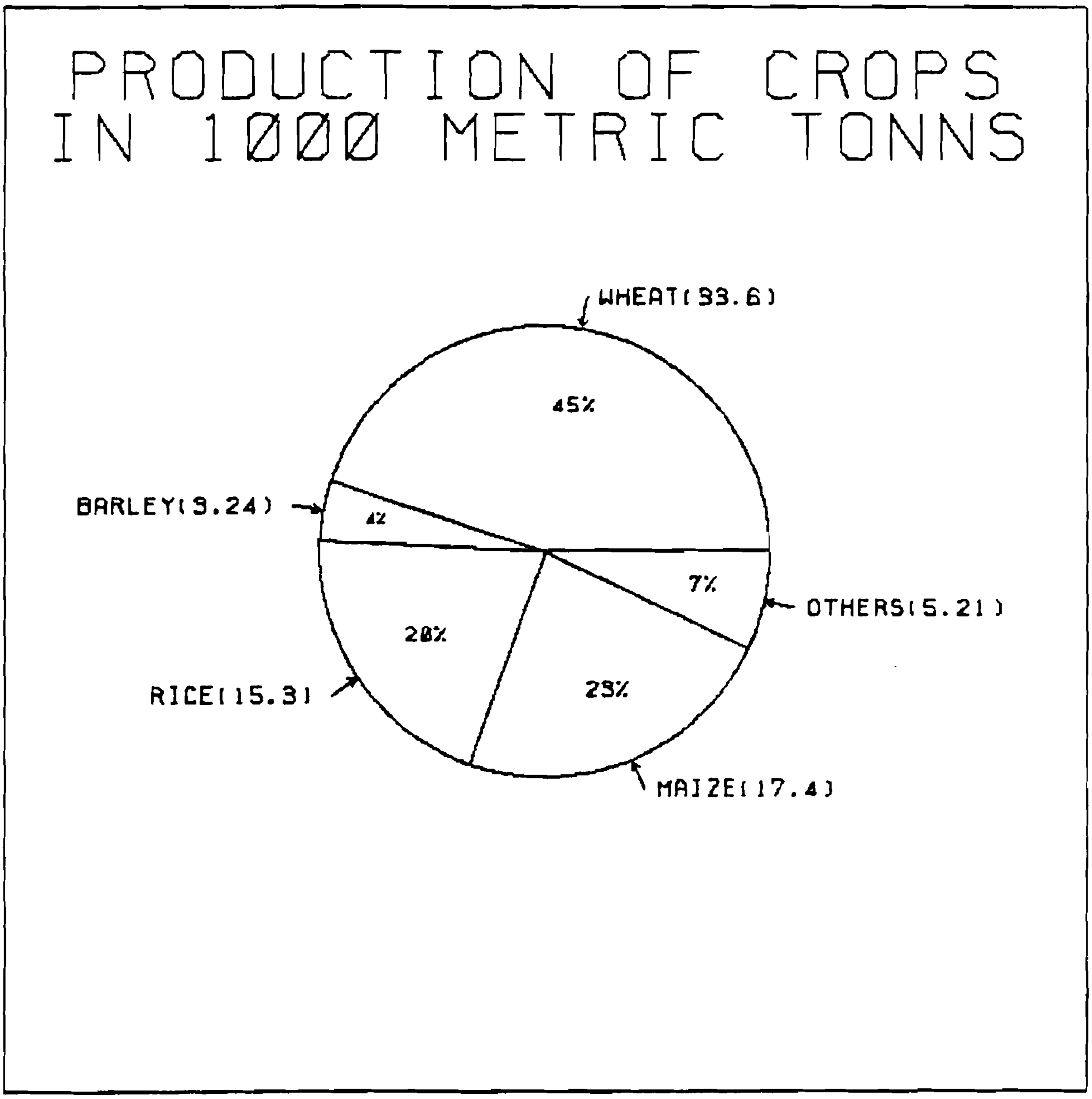
PRODUCTION OF CROPS
IN 1000 METRIC TONNS
WHEAT(33.6)
45%
BARLEY(3.24)
4%
7%
OTHERS(5.21)
20%
RICE(15.3)
23%
MAIZE(17.4)

Figure 1

- Improved efficiencies of fuel-use
- High-yielding varieties and additional chemical fertilizers
- More investment in the region

How do such policy measures alter the life in the Doon Valley? These and other aspects will be looked into in Phase 2.

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Integrated Software for Environmental Assessment of Industrial Development in the Doon Valley

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SUMMARY:

This proposal describes an **integrated set of software tools** that could form the core of a computer-based Environmental Assessment of Industrial Development for the Doon Valley.

It is based on the integration of established techniques of environmental impact assessment, simulation modeling, data base management, operations research methodology, and modern computer technology including interactive color graphics and techniques of Artificial Intelligence (AI).

The basic idea is to draw together, into one integrated software environment, the components of a comprehensive assessment, such as the background data, descriptive and normative models for the analysis of what-if questions and the design of management alternatives, and decision-support methods. Linking them into a coherent, easy-to-use system provides a coordinating framework and project structure that interactively and dynamically supplements any static, i.e., printed impact assessment or report.

The basic functions of the system include:

- providing background information on the ***status quo*** and likely ***development options***;
- ***design and analysis*** of feasible development policies (optimization of individual activities, designing/optimizing sets of coordinated activities) and their environmental implications and consequences;
- and finally, the ***comparative evaluation*** of development alternatives and decision support (policy analysis).

The system would be implemented on a super-microcomputer graphics workstation. Numerous component models relevant to the Doon Valley and similar situations of industrial development-environment interactions (e.g., a number of models developed at the US/EPA) are available at IIASA or have been developed at IIASA (see Appendix). Basic software techniques for user interface design and systems integration, and an operational prototype of such an interactive software system, developed by ACA, are available for demonstration (see attached bibliography).

RESEARCH APPROACH AND CONTENTS

The central method of the proposed approach, which is to be understood as complementary to other methods proposed, is ***knowledge engineering*** together with and around well established techniques of Applied Systems Analysis, Artificial Intelligence, and modern computer technology. The project will design and develop an *integrated set of software tools*, building largely on existing models and computer-assisted procedures. This set of tools is designed for a broad group of users with diverse, including non-technical, backgrounds. Its primary purpose is to provide easy access and allow efficient use of methods of analysis and information management which are normally restricted to a small group of technical experts. The use of advanced information and data processing technology should allow a more comprehensive and interdisciplinary approach to development policy design and analysis.

To facilitate the access to complex computer models for the more casual user, and for more experimental and explorative use, it also appears necessary to build much of the accumulated knowledge of the subject areas into the user interface for the models. Thus, the interface will have to incorporate software that is capable of assisting any non-expert user to select, set up, run, and interpret specialized software. By providing a coherent user interface, that makes interactions between different models, their data bases, and auxiliary software for display and analysis transparent for the user, a more experimental and educational style of computer usage can be supported, allowing for an easy exploration of alternative development policies and strategies in actual planning situations or for training purposes.

Conceptually, the main elements of the system are:

- an **Intelligent User Interface,** which provides access to the systems' workings for the user. This interface must be attractive, easy to understand and use, and to a certain extent provide the translation between natural language and human style of thinking to the machine level and back. This interface must also provide a largely menu-driven conversational guide to the system's usage (dialog - menu system), and a number of display and report generation styles, including color graphics and linguistic interpretation of numerical data (symbolic/graphical display system);
- **Information System,** which includes the system's Knowledge and Data Bases as well as the Inference and Data Base Management Systems, which not only summarize application- and implementation-specific information, but also contain the most important and useful domain-specific knowledge;
- **the Model System,** which consists of a set of models (Simulation, Optimization), which describe individual processes that are elements of a problem situation, perform risk and sensitivity analyses on the relationship between control and management options and criteria for evaluation, or optimize plans and policies in terms of their control variables given information about the user's goals and preferences according to some specified model of the system's workings and rules for evaluation.
- **the Decision Support System,** which assists in the interpretation and multi-objective evaluation of modeling results, and provides tools for the selection of optimal alternatives with interactively defined preferences and aspirations.

Recognizing the potentially enormous development effort required and the open-ended nature of such a project, we propose a well-structured cooperative effort that takes advantage of the large volume of scientific software already available. A modular design philosophy enables us to develop individual building blocks, which are valuable products in their own right, in the various phases of the project, and interface and integrate them in a framework which, above all, has to be flexible and easily modifiable with growing experience of use.

Using an open architecture concept with a functional and problem-oriented, rather than a structural and methodological design for this framework, the demonstration prototype can be constructed at relatively low cost and with only incremental effort.

The decision support system proposed here is based on ***information management*** and ***model-based decision support.*** It envisions experts as its users, as well as decision and policy makers, and in fact, the computer is seen as a mediator and translator between expert and decision maker, between science and policy. The computer is thus not only a vehicle for analysis, but even more importantly, a vehicle for communication, learning, and experimentation.

The three basic, interwoven elements, are

- to supply *factual information, based on existing data*, statistics, and scientific evidence,
- to assist in *designing alternatives* and to assess the likely consequences of such new plans or policy options, and
- to assist in a systematic *multi-criteria evaluation and comparison* of the alternatives generated and studied.

The framework foresees the selection of criteria for assessment by the user, and the assessment of scenarios or alternative plans in terms of these criteria.

An example of these concepts in a practical application, namely a structurally similar study on industrial risk, carried out by IIASA/ACA under contract to the Commission of the European Communities, Joint Research Centre (EURATOM), Ispra Establishment, Ispra, Italy, is described by Fedra (1985, 1986). The material and approach described in these reports could serve as a starting point for the Doon Valley case study software development and integration.

Also, a similar case study developing *Experts Systems for Integrated Development: A case study of Shanxi Province, the People's Republic of China*, developing and implementing model-based decision support software for industrial development under environmental constraints, is in progress in the ACA project.

A short list of references is given in the attached bibliography.

Structure and Contents

The highly modular system will be structured around a major **regional development model** based on concepts of systems dynamics and rule-based simulation similar in scope to the models used in **AEAM** workshops (Adaptive Environmental Assessment and Management), but based on substantial background data and with a higher degree of resolution in time and space.

This model will be augmented by a **decision-support** module for discrete optimization, i.e., the selection of preferred alternatives from a set of feasible options, generated through scenario analysis.

This decision-oriented top-level will be connected to selected **sectoral simulation and optimization models** (e.g., individual industries, mining, forestry, agriculture, urban development, air quality, water resources, etc.). These models can either be used directly or they can provide input (aggregated parameters) to the top level.

Both levels of models are connected to a set of **data bases**, which again can be used directly as an interactive information system. All elements of the system are tightly integrated and driven by an interactive, graphics-oriented **intelligent user-interface** and display system.

Basic software systems components:

Data Bases should include, e.g.:

- industrial activities and establishments (including emission data)

- industrial technologies (including pollution abatement methods)
- water resources and climatic data
- land use and agriculture
- population.

Access to the Data Bases is either transparent through the component simulation models or through an interactive query format, i.e., menu-driven and symbol-oriented interface to the heterarchical*) information structure, combining static as well as dynamic data elements with geographical display and simple statistical analysis features (e.g., regression, time-series analysis).

Tentative topics for component models:

Selected models (covering the topics addressed e.g., in the Dehradun Master Plan) will be integrated into the system in a hierarchical, top-down approach, starting from an overall regional development planning level:

- dynamic, qualitative (symbolic) simulation of regional development, based on principles of system dynamics and rule-based symbolic simulation, linked, in a hierarchical structure, to the sectoral models below;
- process-oriented detailed simulation models for specific activities (e.g., mining, forestry) for the estimation of economic descriptors, resource consumption, and pollutant emission, in scenario analysis or possibly optimization mode;
- water resources planning, including water allocation, with specific emphasis on the effects of land use changes (deforestation);
- environmental quality (air, water) in relation to industrial activities;
- urban development and demography.

This list is certainly neither complete nor definite; is should only serve as an outline of the possible scope of such a system. However, it is important to understand that due to the modular structure, the individual components can be of various degrees of detail; initially, they may be very simple modules, that can be easily replaced by more detailed ones as the study progresses. The models integrated can include any computerized assessment method deemed relevant; integration will provide an appropriate user interface and the coupling with other models in the system and the data bases.

Systems integration and user interface:

Data bases and component models will be supplemented by a decision-support level, based on multi-objective multi-criteria methods.

The decision support level is based on:

- at the top level of aggregation, the use of a development planning module, consisting of a dynamic, rule-based simulation/gaming model which summarizes and aggregates the results of the sectoral simulation models;
- scenario analysis with the component sectoral models (e.g., water resources, mining, forestry, agriculture). Individual models are supplied with rule-based problem- and input-generators and directly coupled to the data bases to facilitate interactive use;

*) The term heterarchy refers to a multi-dimensional hierarchy with arbitrary linkages.

- and finally background information from the heterarchical information system, providing geographically organized data as well as statistical analyses in an interactive, display-oriented format.

The user interface is based on menu-driven, largely symbolic input and a mixture of symbolic, graphical, and alphanumerical tabular or textual output with the emphasis on (geo)graphical color display. On-line explain functions and input error correction and automatic feasibility checking are basic elements of the user interface.

The development of the system will start from a **minimal set of functional components**, so that an early prototype is available for extensive testing; progress towards increasing refinement and more components would be dependent on the time and resources available. The inclusion of additional elements also depends on the availability of the appropriate data bases.

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APPENDIX: available simulation models.

The following list compiles selected models that could be relevant for the Doon Valley study, that are available and already partly implemented at ACA, and that could be integrated into the software system outlined above:

IRDM: a spatially distributed Interactive Regional Development simulator, including industrial production and waste generation (production based waste coefficients, estimating water as well as airborne pollution), wastewater treatment, and agricultural production;

MITSIM: a river basin simulator developed at MIT and widely applied in developing countries, that optimizes water allocations among agricultural, industrial and domestic use; includes irrigation and hydropower generation;

RRM: a water budget and rain-runoff simulator, describing effects of land use changes (e.g., deforestation, urbanization) on runoff (peak and low-flow) and groundwater recharge;

FEFLOW: a 2D finite elements groundwater quantity and quality simulator;

HSPF: a comprehensive hydrological simulation package developed at US-EPA;

QUAL-II, RIVER, WODA, TOX-SCREEN, EXAMS, TOXIWASP: a set of water quality simulators with various degrees of resolution, ranging from DO-BOD to multiple pollutants and toxics;

ARM: Agricultural Runoff Management, describing runoff and nonpoint source pollution (including erosion and pesticides) from agricultural watersheds;

DISCRETE: a scenario analysis post-processor for discrete multi-criteria optimization.

In addition, various data base management and graphical display programs, as well as statistical data analysis programs have been developed and implemented at ACA.

POSSIBLE WATER MANAGEMENT MODELS FOR THE DOON VALLEY

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Preliminary Remark

The following contribution is based on a review of the literature. There has been no possibility to visit the Doon Valley and to talk to Indian specialists on water management and hydrogeology in the region. Some of the assumptions contained in this Appendix may therefore be incorrect and the proposed modeling schemes may need to be revised.

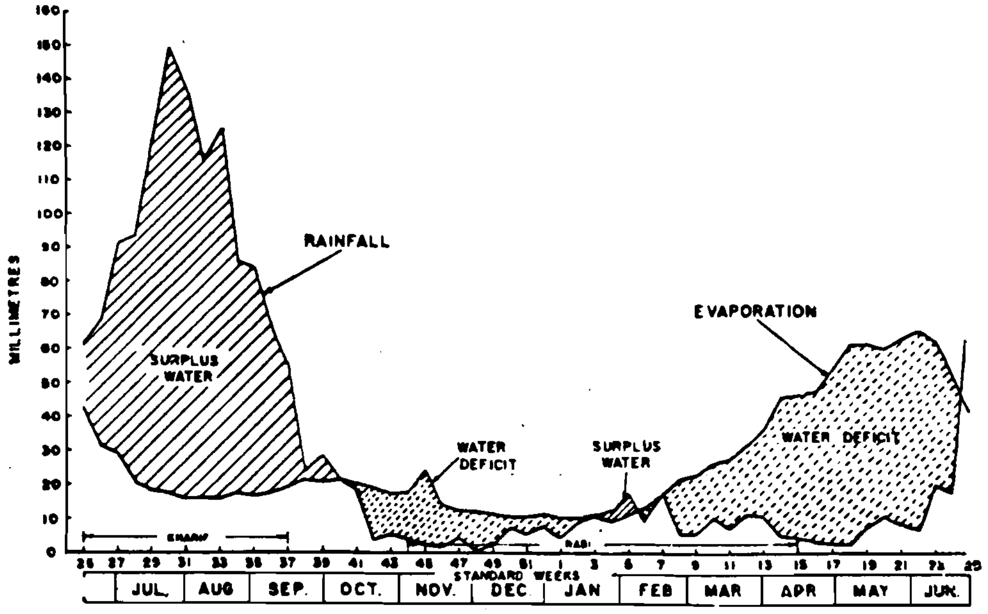
The Water Resources System in the Doon Valley

The Doon Valley is located between the Lesser Himalayas to the NE and the Shivalik range to the SW. The Ganga River to the East and the Jumna River to the West divide the valley into two major watersheds. The total length of the valley is about 70 km, the width of the floor between 10 and 20 km, the width of the watersheds 30 km at maximum. The total area of both watersheds amounts to approx. 2000 km2.

The Doon Valley is characterized by extremely heavy summer precipitation. Along the south-facing slope of the Mussoorie hills, the monsoon rainfall averages 2000 mm per year. About 80% of total annual precipitation is received from June to September. At an observation point near Dehra Dun, the following figures have been given (Singh, 1973):

- 24 yr. average 1688.1 mm
- maximum 2613.5 mm
- minimum 1265.4 mm

For the Doon Valley, the yearly average precipitation amounts to about 3.4 billion m3. In order to evaluate the available water resources, the real evapotranspiration would have to be estimated. After Sastry and Narayama (1984), the evaporation in the Doon Valley amounts to about 1350 mm/year (2.7 billion m3). This is the value for evaporation from a free water surface; Singh et al. (1981) give the same value therefore. Using this value, the total runoff of the valley (precipitation minus evaporation) would be 340 mm or 680 million m3. This is only a very rough estimate, because the real evapotranspiration from the valley (mostly agricultural area and forestry) differs from that of a free water surface. A rough estimate of the real evapotranspiration based on Korsun et al. (1984) is 700 mm. From that, a total runoff of about 1000 mm/year (2 billion m3) results. As expected, the runoff is characterized by a strong annual cycle as Fig. 1 indicates.



STANDARD WEEKWISE CLIMATIC WATER BALANCE AT SELAKUI FARM – DEHRADUN.
(1956 – 1979)

Figure 1 Annual water balance of the Doon valley, comparing precipitation and evaporation

It is clear that intermediate storage of runoff during the dry season is important for the natural ecosystem in the Valley as well as for the socio-economic systems. In the valley itself, there are practically no natural or artificial surface water storages (neglecting short-term storage effects of rivers, especially during floods). The only relevant storages are natural subsurface ones:

- the limestone deposits of the Lesser Himalayas (Mussoorie hill)
- the river beds
- the Doon gravel.

Karstic aquifer of the limestone deposits

The fissured limestone deposits contain cavities of several sizes. The connected cavities form a karstic aquifer which is able to store and to release large amounts of water. The aquifer is recharged by the monsoon rainfall. After the monsoon, the stored water is discharged through springs at the lower parts of the deposits.

Bandyopadhyay et al., (1984) state that: "The aquifer function of the fissured limestone belt of the Mussoorie hills is the most critical factor of transforming a temporally uneven distribution of incident water from rainfall into a perennial and temporally uniform distribution of spring and stream discharges. Through its dynamic role in the hydrological cycle of the Valley, the limestone deposit acts as a mechanism for avoiding the twin hazards of floods and droughts."

An open question is whether the karstic aquifer is connected subteraneously with the Doon gravel aquifer and contributes to its recharge. See below.

Subsurface water courses of river beds

Only the main rivers, the Jumna and the Ganga, and a few of their tributaries have perennial flow. All other rivers in the valley are seasonally dry (Nossin, 1971). The river beds are formed by erosion processes from boulder and gravel sediments, undergoing continuous modification. These sediments have high storage capacity and permeability. Obviously a part of the river flow especially in the dry season occurs below the surface in the river bed. The river beds are hydrogeologically connected with the Doon gravel. The runoff (surface and subsurface) in the river bed, including flood areas, recharges the Doon gravel. In the lower parts of the valley, baseflow occurs from the Doon gravel into the rivers.

Doon gravel aquifer

The topsoil of major parts of the floor of the Doon Valley is a silty clay loam of low permeability. Below the topsoil, a thick gravel formation of medium permeability exists - the Doon gravel. Its depth amounts to 200 m at maximum (Roy, this volume). The Doon gravel is the main aquifer being used for water supply purposes in the valley. It is recharged by infiltration from the surface, above all from alluvial fans and terraces and from the rivers. Because the subsurface catchment area is not known, it is not clear whether there are further sources of recharge, e.g. from the limestone deposit.

Another open question is the hydrogeological nature of the deeper geological formations. Probably these are also permeable and water bearing.

In dry periods, the Doon gravel aquifer may recharge rivers, especially in lower parts of the valley. More details on the hydrogeological setting can be found in Roy (this volume).

Figure 2 gives an overview of the relevant elements of the water resources system in the Doon Valley.

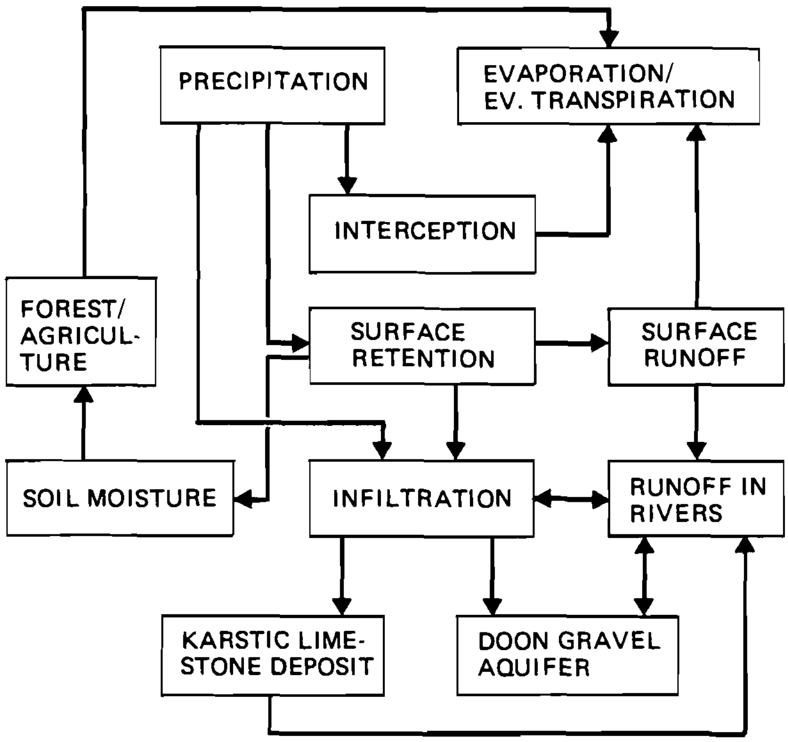


Figure 2 Water resources system in the Doon Valley

Impacts on the Water Resources System

The major water user in the Doon Valley is the population. The water consumption in Dehra Dun City amounts to 68 - 128 liter/day (1984) per person. Assuming a population in the urban agglomeration of 293,000 (1984), we get an annual water consumption of 7.3 - 13.7 million m3. This is only 0.3 - 0.7% of the average yearly runoff.

The water consumption figure above contradicts that in Bandyopadhyay (1984), who assumed a daily consumption of 25 liter/day per person. In this case the annual water consumption would amount to 2.7 million m3, i.e. only 0.1% of the total runoff.

The 1982 water consumption of various industries in Dehra Dun City was estimated to about 407 m3 per day, i.e., only 0.15 million m3 per year. This figure is less than 10% of the water consumption of the population.

Figures on water consumption in agriculture are not known. In total, water consumption may be estimated to be in the range of 10 million m3 per year. This means that in the annual mean, there should not be any problems for water supply and the impact of water consumption on water resources should be negligible.

The situation looks quite different if one considers the annual cycle of runoff (see Figure 1). If the monsoon rainfall cannot be stored sufficiently, in the dry period water deficits may occur. According to Roy (this volume), the water table near Dehra Dun City is already lowered by about 7 to 15 m. The significance of this information is not clear (Is it a mean value? How far is the observation point from the extraction wells etc.?) Nevertheless, the observed depletion indicates that a depletion of groundwater resources may have already started in this region (the pumpage is larger than the natural recharge). And this may effect other parts of the water resources system, e.g. the river flow in lower parts of the valley during dry periods.

In addition to the direct impact on the water resources system described above, there are a number of indirect human impacts. These impacts are probably more relevant than those listed above. According to the available publications, the major impacts are caused by:

- changes in land-use practice including deforestation, resulting in an increased surface runoff and reduced groundwater recharge,
- limestone mining, changing the recharge condition for the karstic aquifer of the limestone deposits, increasing surface runoff,
- flood protection measurements and removal of sediments from river beds, increasing the amount of unused discharge during monsoons (the reduced size of flooded area reduces groundwater recharge!),
- siltation caused by increased runoff and erosion due to land degradation, resulting in surface clogging of river beds and groundwater recharge areas (alluvial fans), consequently reducing groundwater recharge.

In Volume I, Chapters 6 and 7, several practical measures for a rational water management strategy are listed. Here we would like to emphasize the possibility of artificial groundwater recharge.

Artificial Groundwater Recharge

Artificial recharge of groundwater basins is becoming increasingly important in groundwater management, particularly in the joint use of surface water and groundwater resources (Asano, 1985). Major objectives for artificial recharge are:

- augmentation of the amount of available groundwater for water supply,
- conservation and disposal of runoff and floodwaters,
- improved water quality by removing suspended solids by filtration through the ground.

These objectives are applicable to the Doon Valley. Due to the good permeability of the Doon Valley during the monsoon, large volumes of runoff could be stored in the aquifer.

The engineering techniques needed for artificial recharge are well-known, e.g.:

- direct surface techniques such as flooding, ditch and furrow systems, basins,
- direct subsurface techniques such as wells, reverse drainage, pits and shafts,
- combinations of these techniques for subsurface drainage (collectors with wells).

Details can be found for instance in Asano, (1985). (This comprehensive text also gives a voluminous list of references.)

The storage method does not require high capital investment. One important benefit is that evaporation losses are negligible in comparison with those from surface water reservoirs. A properly designed system for artificial recharge in the Doon Valley could help meet the water supply needs of the residents as well as being environmentally beneficial (e.g. increasing the baseflow in the lower part of the valley).

Tasks for Water Management Modeling

The common tasks of water management for regional systems in many countries include the following:

- to elaborate development policies (long-term) for the water resources and management system in the region,
- to design water management systems (such as reservoirs, groundwater extraction wells etc.),
- to derive rational medium- and long-term management strategies for existing and/or planned water management systems,
- to consider the needs of short-term (real-time) operational control of such systems.

In principle these tasks are relevant for the Doon Valley. But, at present a comprehensive water management plan does not exist. There are practically no runoff controls (reservoirs, weirs, etc.). Groundwater extraction is done by the help of tube wells, obviously more or less uncontrolled. So the first two tasks are of major interest for the Doon Valley - elaboration of development policies and design of water management systems, above all the controlled groundwater extraction for water supply. In solving these problems, future aspects of rational management strategies and operational control would have to be taken into account.

In the Doon Valley, one has to consider the strong inter-relationships between the water resources system, the environmental system in general, and the impacts of socio-economic development. The deterioration of the environment affects the water resources system and thus also the different water users. At the same time, there is a strong reverse impact of the water resources system on the environment.

In principle there is a requirement for the development of a complex model including all aspects of environmental and socio-economic development. It is certain that such a model would be absolutely unrealistic under the conditions in the Doon Valley, above all because of the lack of knowledge on subprocesses and the lack of data. Nevertheless, any water management modeling for the Doon Valley has to consider these complex interrelationships. The models should be designed in such a way that results of modelling other environmental subsystems (e.g. soil erosion) can be easily included, and results of the water management model can be used for modeling of other subsystems.

The accuracy and relevance of water management modeling depends on knowledge of the basic processes and on the available relevant data on the system and systems impacts. In the Doon Valley, one has to work with both missing knowledge and missing data. As a result, another task for modeling arises - process modeling in order to understand the water resources processes (hydrological cycle) and as a basis for the design of effective exploration and monitoring programs.

Water Resources Process Modeling

Water resources modeling for the Doon Valley can only be based on deterministic model concepts, at least for the near future. Due to the lack of long-term observations (frequently a lack of any observations at all) any statistical or black-box approach as is common in hydrology would fail.

The starting point should be a general water balance model of the Doon Valley, covering all relevant subprocesses depicted in Figure 2. The time step should be if possible one month at maximum.

Precipitation patterns are well-known. For evapotranspiration, semi-empiric models may be applied based on available geographical and climatological information. To describe the distribution of total runoff into surface runoff, infiltration, baseflow etc., simple conceptual models (with lumped parameters) can be used, e.g. based on the model of a linear reservoir. The principal parts of such a water balance model are depicted in Figure 3.

Within the Regional Water Policies project at IIASA in collaboration with the Institute for Water Management, GDR, a methodology for developing simplified models for regional studies has been elaborated with special regard to surface water - groundwater interactions, (Kaden et al., 1985b). The concepts and models could be useful for the Doon Valley too. The choice of approach depends finally on the available information. Detailed model concepts have to be selected later.

Such a conceptual balance model could be used for a first impact assessment of environmental deterioration. Furthermore it provides a framework for the development of more comprehensive process models.

The elaboration of more comprehensive models for surface and river runoff does not seem to be necessary or realistic. But a comprehensive groundwater flow model for the Doon gravel should be developed in a second step. This model should consider distributed parameters, the interrelationship between surface water and groundwater, and the time-dependent recharge. Because of the lack of data, a simple finite-difference flow model can be used.

Calculations with this model would increase our knowledge of the water resources processes and could be used for designing monitoring and exploration programs.

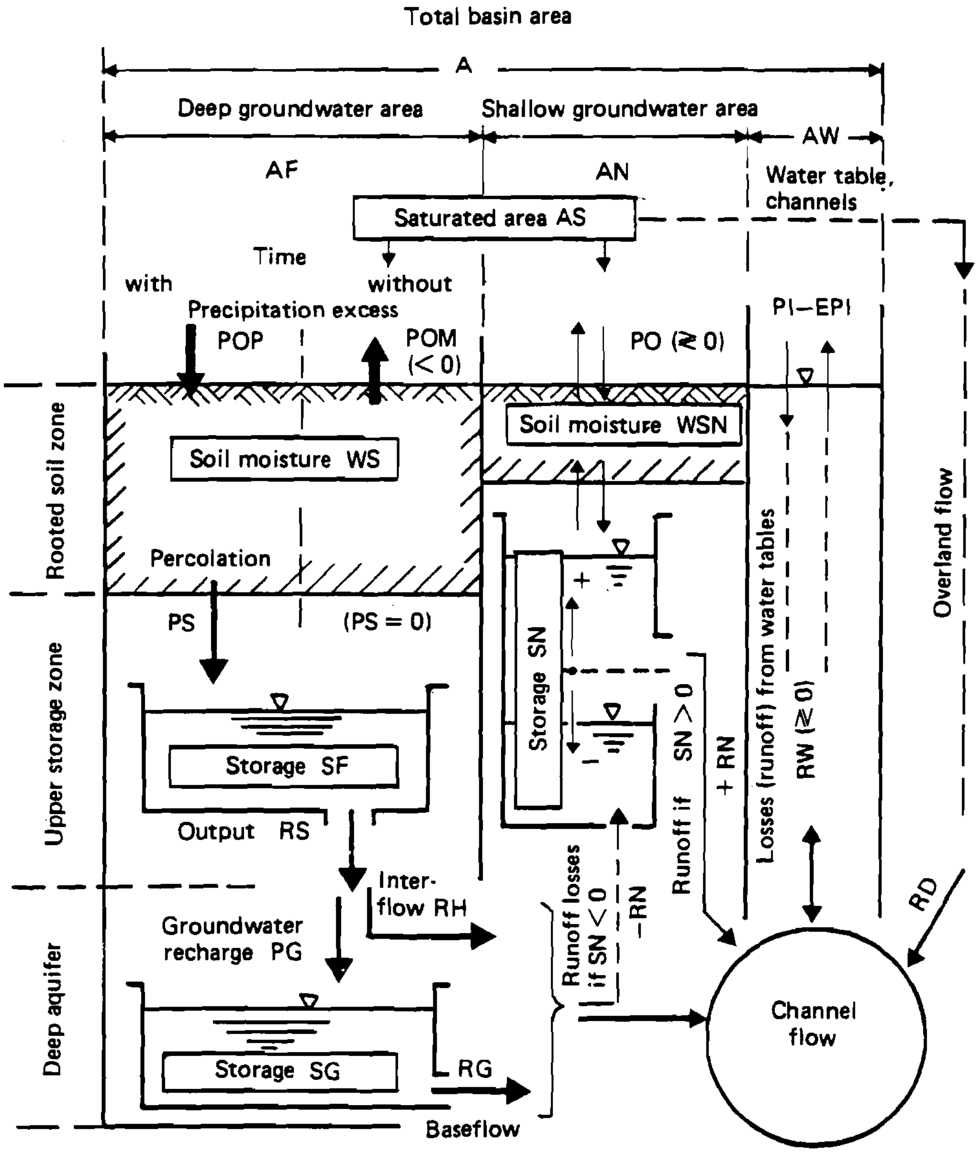


Figure 3 Structure of a catchment model, from Kaden et. al. (1985b)

Water Management Modeling

Depending on the success of the process modeling, more management-oriented models should then be developed.

An improved groundwater flow model should be applied for the design of a controlled system of groundwater extractions. This model should be used continuously for controlling the groundwater extraction and the design of new installations. As new measurement data are obtained, the model could be further improved. This would be the so-called concept of a continuously working model (Kaden et al., 1985b).

Based on the balance model above, a planning model should be developed as a tool to find rational strategies of long-term development. Such a model should be capable of dealing with the following complexities:

- controversy among different water users, socio-economic development and environment,
- multiple criteria of evaluation of strategies (it may not be possible to evaluate some of the criteria quantitatively),
- uncertainties and stochastic character of systems input (e.g. precipitation).

An appropriate Decision Support Model System for the analysis of regional water policies in lignite mining areas has been developed at IIASA. It combines a multi-criteria analysis for planning periods greater than one year with a stochastic simulation of monthly systems behaviour (Kaden et al., 1985a). The system is highly interactive and user friendly. Computer color graphics are used for the visual display of results. An example (monochrom) is shown in Figure 4. In principle, this concept could be applied to water management in the Doon Valley as soon as submodels of the relevant processes have been developed. Perhaps even other environmental subprocesses could be included into this model concept.

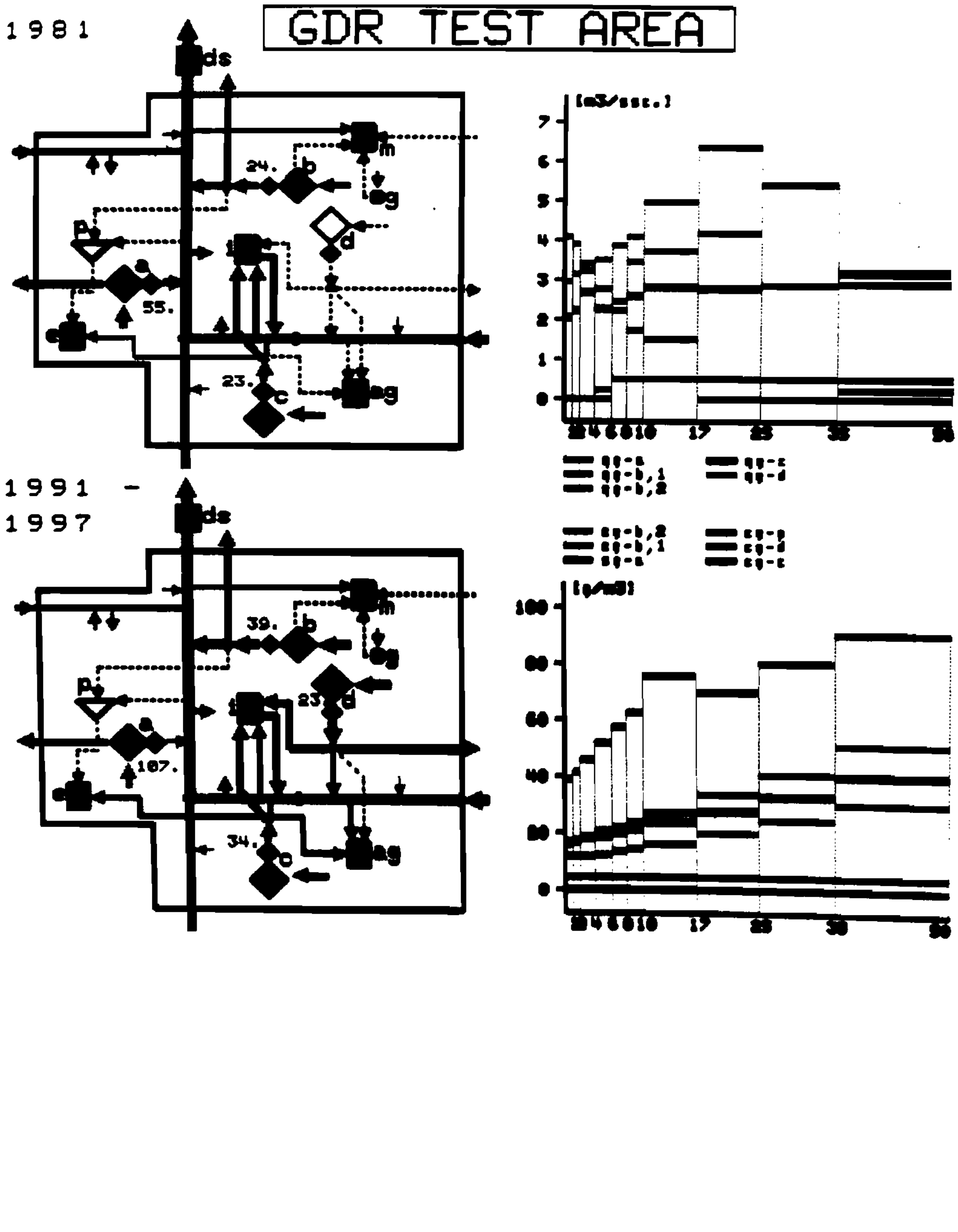


Figure 4 Example of a computer graphic of a regional water management study

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DEFORESTATION AND CLIMATIC CHANGE

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Abstract

The effect of deforestation on rainfall was examined at 32 stations distributed over the breadth and width of India. More than 50 years of rainfall observations available from a non-parametric rank test applied to the above series of rainfall data showed that except for an isolated case (Shimoga in Karnataka), there was no significant decrease in rainfall at any station.

Introduction

Industrial projects and other development activities may cause some adverse ecological effects like deforestation. Often the damage caused is irreversible. Despite industrial and other development activities in India, possible irreversible and adverse effects have not yet caused alarm although relevant studies are very limited.

In particular, the effect of deforestation on rainfall is still controversial. There are many examples where rainfall has decreased due to deforestation, and a few where no change has been noticed (Johnson et al., 1975). Denudation of vegetation causes disastrous floods, soil erosion and loss of fertile soil resulting in waste lands. Such examples are in Little Andaman, Middle Island and in Great Nicobar. Loss of yield has been noticed due to loss of fertility. A study on the effect of forest cover on rainfall distribution at Andaman and Nicobar Islands indicates that rainfall increases with increasing forest cover (Biswas, 1980).

Large trees besides providing shelter and comfort to human beings increase the rainfall. It has been concluded in the USSR that precipitation increased by 10-12% over the forests (Fedorov et al., 1967). The idea that deforestation leads to a decline in rainfall is based on the fact that the presence of a forest has a favourable influence on the water economy of an area. Deforestation increases maximum air and soil temperatures and decreases slightly the minimum air and soil temperatures. Deforestation also decreases the net incoming radiation and increases radiative cooling of the air. Deforestation changes the reflectivity of the surface of the earth and increases dust particles in the air due to increased wind speed and dry soils. This changes the regional radiation exchange between the earth and the atmosphere. The relative humidity also is lowered. Deforestation increases surface wind.

Rajasthan desert is presumed to be man-made - a result of ecological mismanagement. Archaeological and pollen studies indicate that the desert was indeed relatively fertile several thousand years ago and that it contained a freshwater lake that supported the Indus civilization. Suggestions are that deforestation led to increased tropospheric dust loading which in turn enhanced air subsidence, thus inhibiting precipitation. It should be mentioned here that destruction of forests is almost an irreversible process as reforestation is successful only with the greatest of difficulty.

The luxuriant forest growth and unusual climate of early America invited conjecture on the climatic effects of the forests and the consequences of their removal (Thompson, 1980). Pioneer settlers in America thought that clearing of the forests was producing a warming trend and affecting the climate in other ways. By the nineteenth century there was wide, but not entirely unanimous belief that deforestation had caused significant climatic changes, especially higher temperatures and lower precipitation. It was also believed that tree planting might increase precipitation in the semi-arid west. Modern scientists now attribute an important microscale climatic influence to forests and are considering the macroscale effects, especially as related to atmospheric carbon dioxide and albedo changes.

The effect of forests upon the total amount of rainfall is a question upon which writers are not agreed, some denying their influence altogether. In the present paper, the author has attempted to study the impact of forest clearing on rainfall at several stations spread across India (Fig. 1).

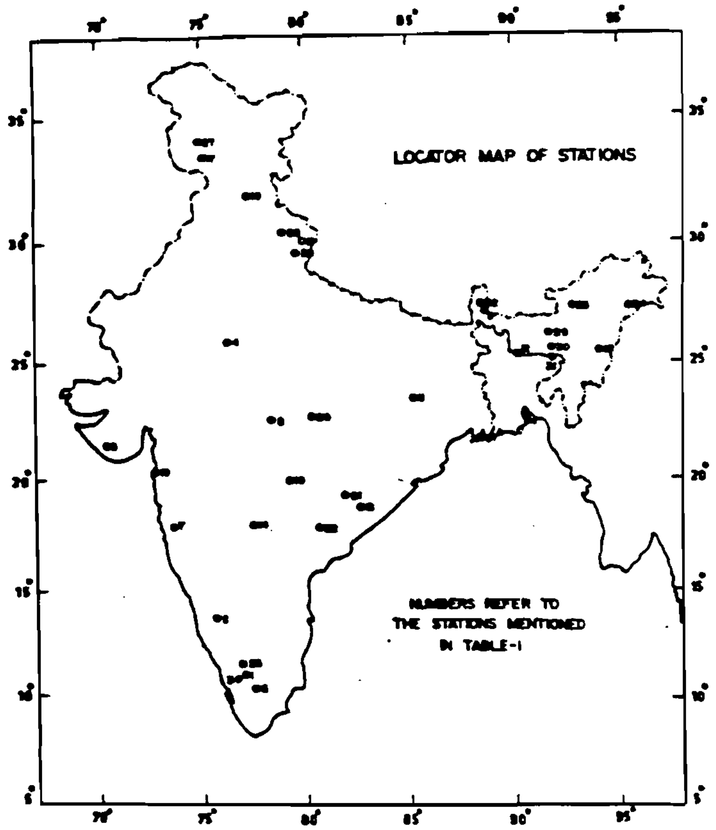

Figure 1

Methodology

A non-parametric Rank Test has been applied to the series of rainfall data. Let x1 , x2 .....xn be the amounts of rainfall in the successive years of the series. Let n1 , n2 .....nN be the frequency occurrence of each amount of rainfall. Then Test Score P is defines as P = n1 + n2 ......nN. For example,

Rainfall (MM)	250	500	180	750	390
Frequency of Occurrence	3	1	2	0	0

Then P = 3 + 1 + 2 + 0 + 0 = 6

A Test statistic S is defined as $S=2P-\frac{N(N-1)}{2}$, where N is the number of of observations. According to the above example

$$S=12-\frac{5x4}{2}$$

$$=12-10=2$$

$$Standard\ error\ of\ S=SE(S)=\sqrt{\frac{N(N+1)(2N+5)}{18}}$$

$$=\sqrt{\frac{5x6x15}{18}}=\sqrt{25}=5$$

$$Z\text{-}Score\,(Standard\ Normal\ Variation)=\frac{S}{SE(S)}=\frac{2}{5}=0.4$$

Z follows a normal distribution with mean 0 and variance 1. If $z > 2.58$ the test score is significant at the 1% level. If $z > 1.96$, the test score is significant at the 5% level. The inference could then be that a significant trend exist.

Results:

The trend in rainfall analysis as per the non-parameteric rank test is given in Table 1 which shows the stations, the number of years of rainfall data used, the Test Statistic (S), Standard Error of S and the z Score.

TABLE 1

Trend in rainfall series by Non-parametric Rank Test

S.No.	Name of Station	No. of Years	Test Statistic S	SE(S)	z Score S/E(S)
1.	Coimbatore (Tamil Nadu)	56	-90	144	0.63
2.	Shimoga (Karnataka)	49	-248	118	2.10*
3.	Phalghat (Kerala)	62	-37	167	0.22
4.	Sawai Madhopur (Jajasthan)	70	217	200	1.08
5.	Keshod (Gujarat)	9	-18	19	0.96
6.	Kodaikanal (Tamil Nadu)	53	166	133	1.25
7.	Mahabaleshwar (Maharashtra)	38	-69	82	0.84
8.	Panchmarhi (M.P.)	70	-11	200	0.05
9.	Kalimpong (West Bengal)	61	318	163	1.95
10.	Bulsar (Gujarat)	52	64	129	0.49
11.	Ranchi (Bihar)	53	-86	133	0.65
12.	Tora (Maghalaya)	67	-91	188	0.49
13.	Koraput (Orissa)	52	144	129	1.11
14.	Bidar (Karnataka)	60	240	159	1.51
15.	Mukeshwar (U.P.)	49	-116	118	0.98
16.	Kohima (Nagaland)	57	66	148	0.45
17.	Udhampur (J & K)	59	123	156	0.79
18.	Kulu (H.P.)	66	145	183	0.79
19.	Chanderpur (Maharashtra)	70	157	200	0.78
20.	Mandla (M.P.)	20	-54	32	1.67
21.	Jagdalpur (M.P.)	61	-122	163	0.75
22.	Shadrachalam (A.P.)	64	188	175	1.07
23.	Nilgiri (Tamil Nadu)	54	-187	136	1.37
24.	Digboi (Assam)	5			
25.	Bomdila (Arunachal Pradesh)	4	Time series too short		
26.	Pauri Garwal	74	-333	217	1.58
27.	Srinagar (Garhwal)	67	-17	187	0.91
28.	Almora	75	-267	221	1.21
29.	Gauhati	65	12	179	0.07
30.	Shillong	67	125	167	0.67
31.	Cherrapunji	61	68	163	0.42
32.	Gangtok	15	-9	21.6	0.42

*Significant at 5% level (slightly decreasing trend).

Conclusion

Rainfall data from 32 stations have been tested for trend using a non-parametric rank test. Except for Shimoga (Karnataka) none of the series exhibits any significant trend in long-term rainfall. Shimoga has a slightly decreasing trend which is significant at 5% level but not at 1%.

The data for Digboi and Bomdila were not sufficient to apply the test.

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A BRIEF SURVEY OF AIR POLLUTION MODELS ROUTINELY EMPLOYED AT THE CENTRAL INSTITUTE OF METEOROLOGY AND GEODYNAMICS IN VIENNA INCLUDING DATA REQUIREMENTS AND OUTPUT EXAMPLES

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1 Introduction

The general scope of the Doon Valley project from the air pollution modeler's point of view includes the selection or development of proper air pollution models, the application to the specific sites and the gathering of appropriate data. Together with the aid of Indian authorities (Pollution Control Research Institute, Indian Meteorological Department), the procedure will therefore probably be as follows:

1 Creation of an emission inventory:
   - classification of industrialized and built-up areas as well as traffic conditions
   - determination of emissions

2 analysis of meteorological and air pollution data at hand (including landsat data)

3 choice of the locations of monitoring stations (air pollution, meteorology) with special emphasis on temperature inversion characteristics in the valley

4 data analysis after e.g. two years of monitoring

5 simulation of different air pollution scenarios

6 discussion of results; interdisciplinary recommendations for future developments

In the following, a brief survey of air pollution models, which are run on a routine basis at the Central Institute of Meteorology and Geodynamics, is given, with special emphasis on input requirements and output facilities.

2 Survey of Air Pollution Models

The survey starts with very simple models not requiring meteorological input and ends with the description of a multiple point- and area-source model. All the models are Gaussian. Concerning the India project and the difficulty in obtaining data, it seems desirable to use models which need little input.

2.1 Point Source Models Not Requiring Meteorological Input

2.1.1 Predicting Maximum Concentrations in Flat Terrain

The model predicts location and amount of maximum concentrations of a single pollutant depending on stability class and wind velocity. The model uses Turner stability classes, i.e., classes 1 to 3 are unstable, class 4 is neutral and classes 5 to 7 are stable.

Input requirements:

1) stack height (m)
2) effluent temperature at the stack (° C)
3) air temperature (° C)
4) effluent volume (m^3/h)
5) source strength (mg/s)
6) stack diameter (m)
7) vertical velocity of effluent (m/s)
8) height of anemometer (m)

If the temperature of the effluent is greater than 50 ° C, inputs 6) and 7) are not used.

The output is given as a table and a plot (Fig. 1,2).

A model run is very fast, so e.g. different stack heights can be tested easily.

TABELLE
EFFEKTIVE SCHORNSTEINHOEHE HE(M), MAXIMALIMMISSION SMAX(10** 0 MG/M**3) UND DEREN ENTFERNUNG X(M) VON DER QUELLE IN ABHAENGIGKEIT VON DER WINDGESCHWINDIGKEIT U(M/S) UND DER AUSBREITUNGSKLASSE

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KLASSE	2			3 LABIL			4 NEUTRAL			5			6			7 STABIL		
U	SMAX	X(M)	HE	SMAX	X(M)	HE	SMAX	X(M)	HE	SMAX	X(M)	HE	SMAX	X(M)	HE	SMAX	X(M)	HE
1.0	.712	319	251	.431	742	246	.336	1553	205				.137	17535	170	.032	>20KM	167
1.5	.562	442	229	.353	981	224	.274	2034	188				.113	>20KM	158	.027	>20KM	155
2.0	.519	534	203	.373	1062	191	.236	2472	177	.186	6258	152	.098	>20KM	150			
2.5	.532	594	177	.401	1109	167	.248	2577	158	.164	7306	146	.090	>20KM	142			
3.0	.535	652	159	.417	1164	151	.260	2655	143	.162	7744	136	.096	>20KM	130			
3.5	.531	710	146	.425	1222	139	.266	2753	133	.166	7975	127						
4.0	.524	766	137	.428	1283	130	.269	2961	125	.167	8249	120						
4.5	.514	823	129	.427	1345	124	.269	2976	119	.167	8551	114						
5.0				.423	1409	118	.267	3097	114	.165	8873	110						
5.5				.417	1474	114	.264	3222	110									
6.0				.411	1540	110	.260	3353	107									
6.5				.404	1607	107	.255	3481	104									
7.0				.396	1674	105	.251	3613	101									
7.5				.388	1741	102	.246	3747	99									
8.0				.380	1809	100	.241	3882	97									
8.5				.371	1877	98	.235	4019	96									
9.0				.363	1945	97	.230	4156	94									
9.5				.355	2014	95	.225	4294	93									
10.0				.348	2082	94	.220	4433	92									
12.5				.312	2427	89	.193	5133	86									

SCHADSTOFF SO2

FESTE SCHORNSTEINHOEHE H(M) = 70
GESAMTABGASMENGE Q(BETRIEBS-M**3/H) = .511E+06 QUELLSTAERKE QS(MG/S) = .236E+06
GESAMTABGASMENGE Q(NORM-M**3/H) = .309E+06 QUELLSTAERKE QS(KG/H) = .851E+03
ABGASTEMPERATUR TG(GRAD CEL) = 180 UMGEBUNGSTEMPERATUR TL(GRAD CEL) = 10
OBERE LICHTEWEITE D(M) = AUSTRITTSGESCHWINDIGKEIT VE(M/S) =

ANEMOMETERHOEHE (M)=10

Figure 1 Effective stack height HE(m), maximum concentration SMAX (mg/m^3) and its distance X(m) from the source depending on wind velocity (U(m/s)) and stability class
pollutant: SO_2
stack height H(m): 70
effluent volume (m^3/h): 511000
source strength (mg/s): 236000
effluent temperature at the stack (°C): 180
air temperature (°C): 10
height of anemometer (m): 10

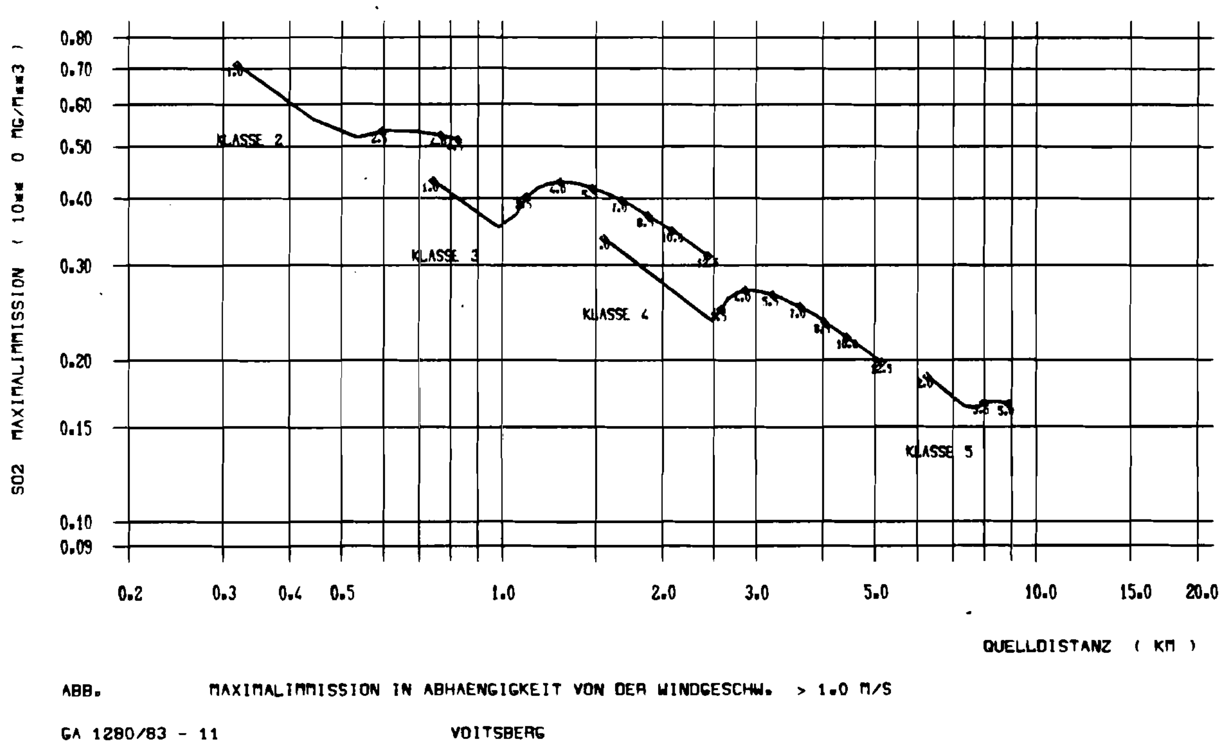

Figure 2 Maximum concentration depending on wind velocity $\geq 1 m/s$ and stability class

2.1.2 Predicting Concentration Fields in Flat Terrain

Using the same input as above, concentration fields for a given combination of wind velocity and stability class for a single stack in flat terrain can be plotted. An example is given in Figure 3.

2.1.3 Predicting Concentrations in Flat Terrain or Along Slopes for Multiple Sources

The computer calculates a concentration field in the $x-z$-plane under the assumption that any grid point is influenced by topography except on the line $z=0$. For low windspeeds, streamlines go over obstacles; for higher windspeeds they go around them. The user can choose up to 19 receptor points along the x-axis and up to 10 "layers" (recommended vertical distance: 50 m). Data are required in a similar manner as in Section 2.1.1 for up to 15 stacks, but additional information is required concerning field width (number of steps in the x-and z-directions and distance of steps). The program also includes different mixing heights.

An example of output in the form of a table is given in Figure 4; an interpretation of this output is given in Figure 5.

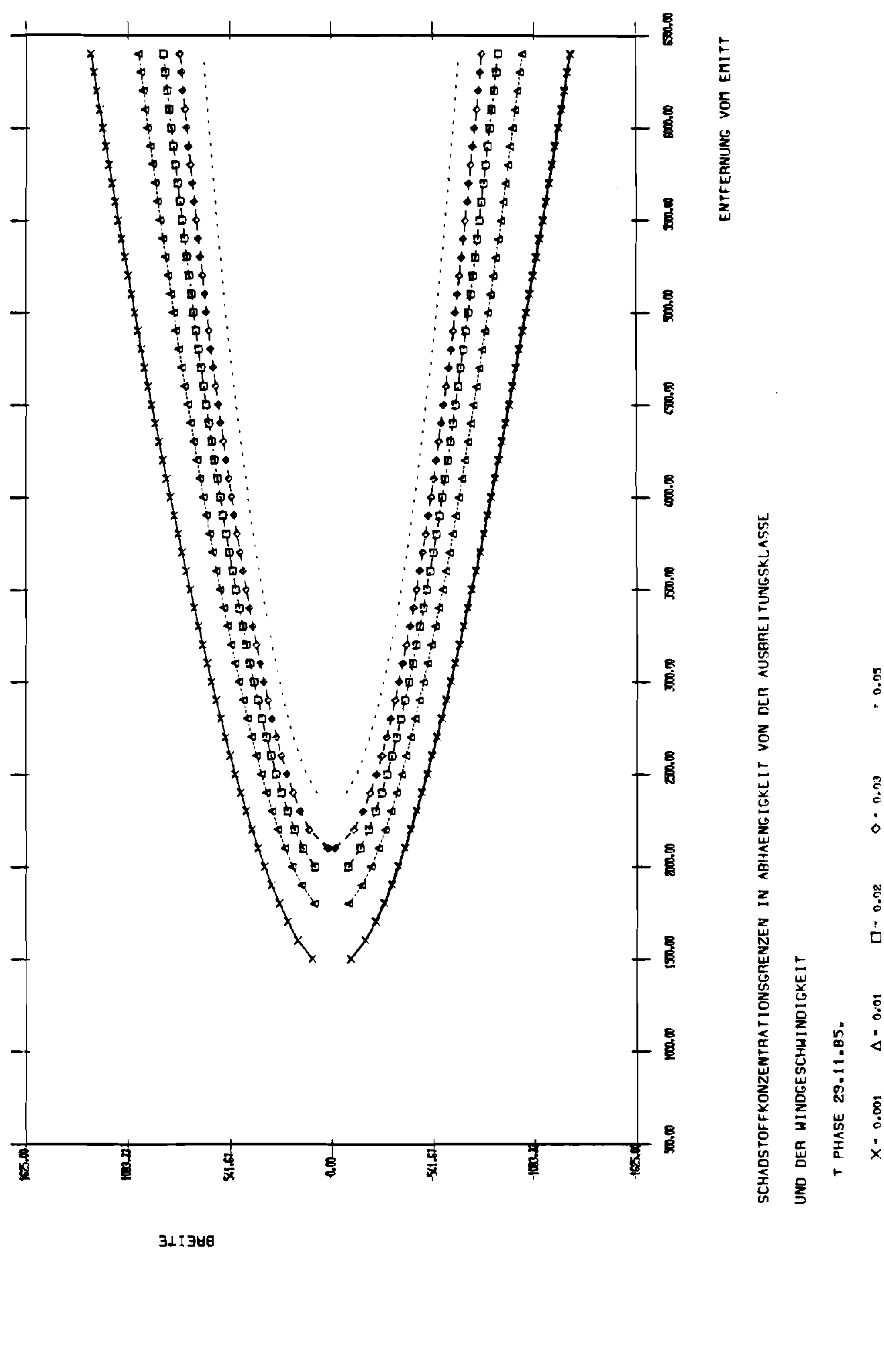

Figure 3 Limits of pollutant concentrations depending on stability class and wind velocity

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NR.  SCHORNSTEINHOEHE(M)  ABGAS-  LUFTTEMP(C)  ABGASMENGE(M3/H)  QUELLSTAERKE(MG/S)  STANDORT(M)  ZA(M) EMITTENTENBEZEICHNUNG

 1          70              180          10          .5108E+06          .1291E+05          0     0   100       DV2  KALK
          SCHORNSTEINDURCHM.(M)= 0.00  AUSTRITTSGESCHW.(M/S)= 0.00     0.                  0 ?  VD(M/S)=0.00 VG(M/S)=0.00

 2         180               80          10          .1614E+07          .8035E+05          0     0   100       DV3  NASS1
          SCHORNSTEINDURCHM.(M)= 0.00  AUSTRITTSGESCHW.(M/S)= 0.00     0.                  0 ?  VD(M/S)=0.00 VG(M/S)=0.00

MAXIMALE EFFEKTIVE QUELLHOEHE  470.29  M

 WINDRICHTUNG :   270.0

 300.0 KLASSE     0     5     5     5     5     5     5     5     5     5     5     5     5     5     5     5
 300.0 GESCHW   0.0   1.5   1.5   1.5   1.5   1.5   1.5   1.5   1.5   1.5   1.5   1.5   1.5   1.5   1.5   1.5
 250.0 KLASSE     0     5     5     5     5     5     5     5     5     5     5     5     5     5     5     5
 250.0 GESCHW   0.0   1.5   5.0   5.0   5.0   5.0   5.0   5.0   5.0   5.0   5.0   2.0   2.0   2.5   2.5   2.5
 200.0 KLASSE     0     5     5     5     5     5     5     5     5     5     5     5     5     5     5     5
 200.0 GESCHW   0.0   1.5   1.5   1.5   1.5   2.0   2.0   2.0   2.0   2.5   2.5   2.5   3.0   3.0   3.0   3.5
 150.0 KLASSE     0     5     5     5     5     5     5     5     5     5     5     5     5     5     5     5
 150.0 GESCHW   0.0   4.5   5.0   5.0   5.0   5.0   5.0   5.0   5.0   5.0   5.0   5.0   5.0   5.0   5.0   5.0
 100.0 KLASSE     0     4     4     4     4     4     4     4     4     4     4     4     5     5     5     5
 100.0 GESCHW   0.0  12.5  12.5  12.5  12.5  12.5  12.5  12.5  12.5  12.5  12.5  12.5   5.0   5.0   5.0   5.0
  50.0 KLASSE     0     2     2     3     3     3     3     3     4     4     4     4     4     4     4     4
  50.0 GESCHW   0.0   1.0   1.5   1.0  12.5  12.5  12.5  12.5  12.5  12.5  12.5  12.5  12.5  12.5  12.5  12.5
   0.0 KLASSE     0     2     2     3     3     3     4     4     4     4     4     4     4     3     3     3
   0.0 GESCHW   0.0   1.0   1.5   1.0   1.0   1.0   1.0   1.0   1.0   1.0   1.0   1.0   1.0  10.0  12.5  12.5

XI         0.0      0.0   7777.0   7777.0   7777.0   7777.0   7777.0   7777.0   7777.0   7777.0
ETA        0.0      0.0   7777.0   7777.0   7777.0   7777.0   7777.0   7777.0   7777.0   7777.0
MISCHUNGSHOEHE (M) :    KEINE

MAXIMALKONZENTRATION IN 10** -2 MG/M**3
                      0.   200.  400.  600.  800. 1000. 1200. 1400. 1600. 1800. 2000. 2200. 2400. 2600. 2800. 3000.
        300.000.0000 .2203 .0470 .0489 .0321 .0232 .0177 .0141 .0116 .0097 .0083 .0072 .0063 .0055 .0051 .0046
        250.000.0000 .1250 .0588 .0350 .0236 .0173 .0133 .0107 .0092 .0076 .0067 .0060 .0055 .0050 .0046 .0043
        200.000.0000 .1260 .0493 .0276 .0183 .0138 .0114 .0098 .0095 .0075 .0068 .0062 .0057 .0052 .0049 .0045
        150.000.0000 .2448 .0885 .0490 .0321 .0231 .0176 .0140 .0115 .0097 .0013 .0073 .0064 .0058 .0052 .0049
        100.000.0000 .1797 .0599 .0314 .0179 .0139 .0104 .0081 .0056 .0055 .0047 .0040 .0039 .0035 .0033 .0031
         50.000.0000 .0044 .0042 .0033 .0037 .0035 .0032 .0028 .0026 .0025 .0024 .0023 .0021 .0020 .0019 .0018
          0.000.0000 .0040 .0041 .0032 .0030 .0025 .0025 .0025 .0024 .0023 .0021 .0020 .0018 .0017 .0016 .0016
 300.0 KLASSE     0     5     5     5     5     5     5     5     5     5     5     5     5     5     5     5
 300.0 GESCHW   0.0   4.0   5.0   5.0   5.0   5.0   5.0   5.0   5.0   5.0   5.0   5.0   5.0   5.0   5.0   5.0
 250.0 KLASSE     0     5     5     5     5     5     5     5     5     5     5     5     5     5     5     5
 250.0 GESCHW   0.0   5.0   5.0   5.0   5.0   5.0   5.0   5.0   5.0   5.0   5.0   5.0   5.0   5.0   5.0   5.0
 200.0 KLASSE     0     5     5     5     5     5     5     5     5     5     5     5     5     5     5     5
 200.0 GESCHW   0.0   4.5   5.0   5.0   5.0   5.0   5.0   5.0   5.0   5.0   5.0   5.0   5.0   5.0   5.0   5.0
 150.0 KLASSE     0     5     5     5     5     5     5     5     5     5     5     5     5     5     5     5
 150.0 GESCHW   0.0   4.5   5.0   5.0   5.0   5.0   5.0   5.0   5.0   5.0   5.0   5.0   5.0   5.0   5.0   5.0
 100.0 KLASSE     0     4     4     4     4     4     4     4     4     4     4     4     4     4     5     5
 100.0 GESCHW   0.0  12.5  12.5  12.5  12.5  12.5  12.5  12.5  12.5  12.5  12.5  12.5  12.5  12.5   5.0   5.0
  50.0 KLASSE     0     2     2     2     3     3     3     3     4     4     4     4     4     4     4     4
  50.0 GESCHW   0.0   1.0   1.0   1.0  12.5  12.5  12.5  12.5  12.5  12.5  12.5  12.5  12.5  12.5  12.5  12.5
   0.0 KLASSE     0     2     2     2     3     3     3     3     4     4     4     4     4     4     4     4
   0.0 GESCHW   0.0   1.0   1.0   1.0   1.0   1.0   1.0   1.0   1.0   1.0   1.0   1.0   1.0   1.0   1.0   1.0

XI         0.0      0.0   7777.0   7777.0   7777.0   7777.0   7777.0   7777.0   7777.0   7777.0
ETA        0.0      0.0   7777.0   7777.0   7777.0   7777.0   7777.0   7777.0   7777.0   7777.0
MISCHUNGSHOEHE (M) :     500

MAXIMALKONZENTRATION IN 10** -2 MG/M**3
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Figure 4 Maximum concentrations depending on stability class and wind velocity in complex terrain

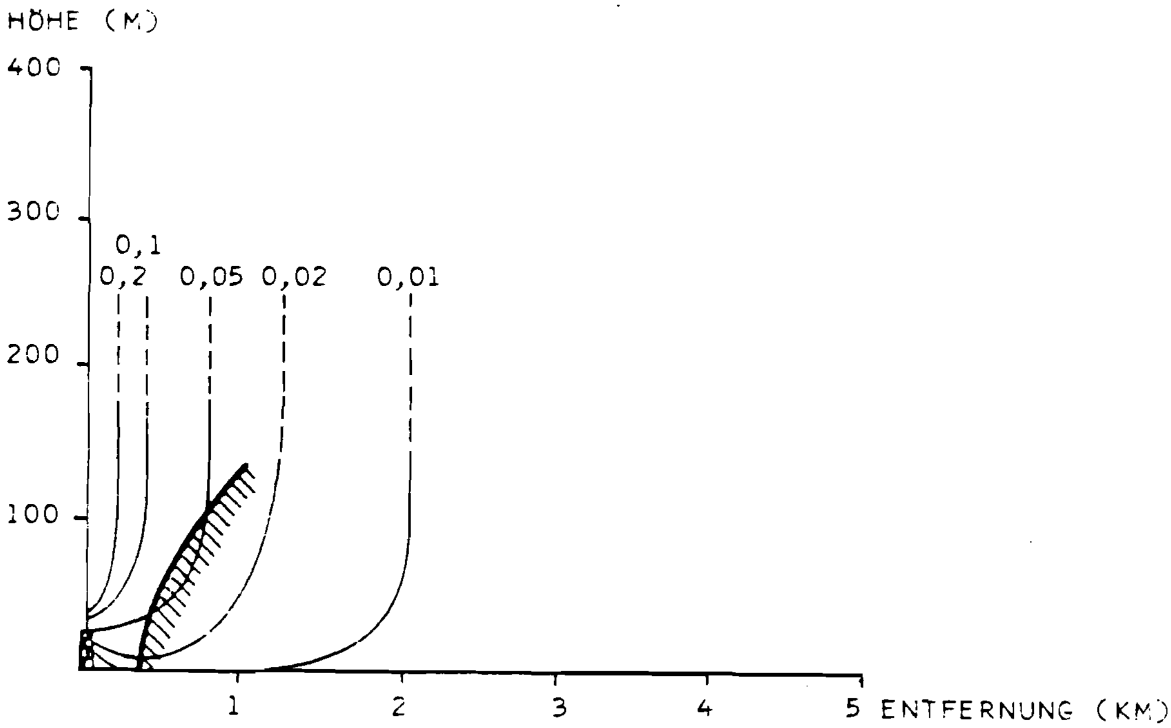


ABB.7: MAXIMALE NOX - IMMISSIONSKONZENTRATION (MG/M3, DÜNNE LINIEN) IN ABHÄNGIGKEIT VON DER ENTFERNUNG VOM EMITTENTEN (KM) UND DER HÖHE ÜBER GRUND (M)
DICK AUSGEZOGENE LINIE: HANGPROFIL
MISCHBETRIEB

Figure 5 Maximum NO_x - concentrations (thin lines, mg/m^3), depending on distance from the source (km) and height above ground (m); thick line: profile of the slope

2.2 Analysis of Meteorological and Air Pollution Data

Programs for analyzing meteorological and air pollution data (half-hour mean values) are available under the assumption that the data are correct and have been placed on working file with certain format specifications.

2.2.1 Mean Values

The program calculates daily, monthly, half-year or yearly means of meteorological parameters or air pollution concentrations. Name and unit of the parameter, desired data period and desired mean values are requested. An example of an output is shown in Figure 6.

LFILE PROGRAM : MITTUD 85/03/05. VDITBG

MITTELWERTE FUER: SISO2 (E -3 MG/M**3) GA - ZAHL: 1280/83

MONATSMITTELWERT	1/80:	93(31)
~~MONATSMITTELWERT~~	~~2/80:~~	~~51(29)~~
MONATSMITTELWERT	3/80:	36(31)
HALBJAHRESMITTELWERT	1/80- 3/80:	50(3)
MONATSMITTELWERT	4/80:	30(30)
MONATSMITTELWERT	5/80:	19(31)
MONATSMITTELWERT	6/80:	13(30)
MONATSMITTELWERT	7/80:	21(30)
MONATSMITTELWERT	8/80:	15(31)
MONATSMITTELWERT	9/80:	13(30)
MONATSMITTELWERT	10/80:	16(31)
HALBJAHRESMITTELWERT	4/80-10/80:	18(7)
JAHRESMITTELWERT	1/80-10/80:	39(2)
MONATSMITTELWERT	11/80:	19(30)
MONATSMITTELWERT	12/80:	31(31)
MONATSMITTELWERT	1/81:	44(29)
MONATSMITTELWERT	2/81:	23(28)
MONATSMITTELWERT	3/81:	18(31)
HALBJAHRESMITTELWERT	11/80- 3/81:	27(5)
MONATSMITTELWERT	4/81:	12(29)
MONATSMITTELWERT	5/81:	14(31)
MONATSMITTELWERT	6/81:	10(30)
MONATSMITTELWERT	7/81:	12(31)
MONATSMITTELWERT	8/81:	14(31)
MONATSMITTELWERT	9/81:	13(30)
MONATSMITTELWERT	10/81:	17(28)
HALBJAHRESMITTELWERT	4/81-10/81:	13(7)
JAHRESMITTELWERT	11/80-10/81:	20(2)
MONATSMITTELWERT	11/81:	27(29)
MONATSMITTELWERT	12/81:	52(31)
MONATSMITTELWERT	1/82:	108(31)
MONATSMITTELWERT	2/82:	55(27)
MONATSMITTELWERT	3/82:	29(31)
HALBJAHRESMITTELWERT	11/81- 3/82:	56(5)
MONATSMITTELWERT	4/82:	24(27)
MONATSMITTELWERT	5/82:	12(26)
MONATSMITTELWERT	6/82:	11(30)
MONATSMITTELWERT	7/82:	22(31)
MONATSMITTELWERT	8/82:	14(31)
MONATSMITTELWERT	9/82:	19(30)

Figure 6 Monthly, half-year, and yearly measured mean concentrations of SO_2; in brackets: number of days of mean

2.2.2 Mean Daily Variation of Elements

A quick glance at a graph depicting the daily mean pattern of a meteorological or air pollution element can often be informative. As an example, Figure 7 shows the daily mean pattern of SO_2, together with the standard deviation. Given the working file, only a small amount of information is required, mainly the parameter to be printed and the time period to be selected.

2.2.3 Matrix Representation

Matrix representation offers the possibility of comparing two meteorological elements (or pollutants, or pollutant versus time, etc.) using the system of frequency distributions. The idea is to construct intervals for each element and to count frequencies (absolute or relative) for all intervals of the matrix (see Figures 8,9). Figure 8 gives the frequencies of air temperature at two different locations at the same time; Figure 9 shows a time-dependent frequency distribution. The matrix framework is still more flexible: it allows for almost all combinations of elements, for cumulative frequencies, and for different kinds of relative frequency distributions.

Input requirements are again very simple: elements and times have to be chosen, and the lettering of the matrix can be chosen by the user.

In summary, data analysis is possible in an efficient manner with a great amount of detail. Thus, it allows meteorologists to draw preliminary conclusions on the meteorological situation or concentration pattern in the region of interest.

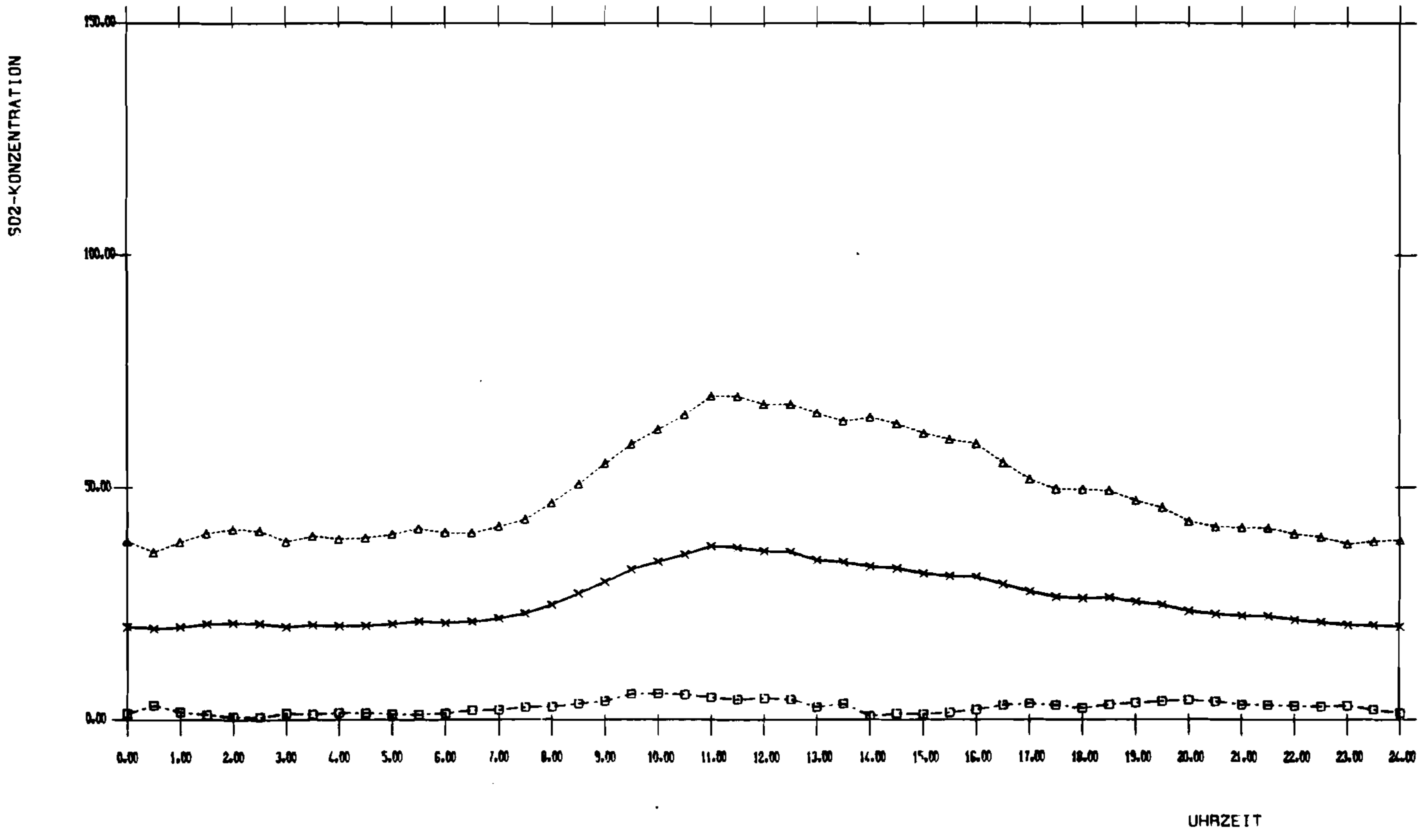


ABB MITTLERER TAGESGANG DER SO2-KONZENTRATION IN E-3 MG/M3

IN TRAISMAUER

X = MITTELWERT △ = STREUUNG □ = STREUUNG

Figure 7 Daily mean pattern of SO_2 in 10^{-3} mg / m^3

GLEICHZEITIGKEITSMATRIX = ABSOLUT
ZWENTENDORF (TEMP, 1/10 C) - TRASDORF (TEMP, 1/10 C)
ZL.: 3540/83

WINTER - GESAMT

ZWENTENDORF

TRASDORF	SUMME	-150	-100	-50	-30	-10	10	30	50	100	150	200	250	300
-150	207	112	83	12	0	0	0	0	0	0	0	0	0	0
-100	321	0	107	205	8	1	0	0	0	0	0	0	0	0
-50	818	0	0	291	320	173	31	2	1	0	0	0	0	0
-30	332	0	0	0	27	156	128	19	1	1	0	0	0	0
-10	338	0	0	0	1	25	229	67	16	1	0	0	0	0
10	777	0	0	0	0	20	171	248	281	57	0	0	0	0
30	953	0	0	0	0	[illegible]	95	277	244	342	0	0	0	0
50	674	0	0	0	0	0	12	177	239	235	11	0	0	0
100	1117	0	0	0	0	0	0	17	237	812	51	0	0	0
150	668	0	0	0	0	0	0	0	7	357	294	10	0	0
200	246	0	0	0	0	0	0	2	6	13	143	82	0	0
250	7	0	0	0	0	0	0	0	0	0	0	7	0	0
300	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 8 Air temperature measured at the same time at two different locations over a winter period

WINTER - TAGESGANG

UHRZEIT	SUMME	10	20	30	40	50	75	100	200	500
0:30	134	50	30	11	10	7	21	5	0	0
1:00	134	54	29	7	8	13	19	4	0	0
1:30	134	57	23	13	9	6	23	2	1	0
2:00	133	57	20	13	11	8	19	4	1	0
2:30	133	51	22	15	15	6	20	4	0	0
3:00	133	51	27	15	10	6	19	4	1	0
3:30	133	48	29	18	3	13	18	4	0	0
4:00	133	50	25	13	14	7	19	4	1	0
4:30	133	53	21	16	8	9	22	3	1	0
5:00	133	53	23	14	11	10	17	4	1	0
5:30	133	56	21	12	8	12	19	5	0	0
6:00	132	54	26	9	9	13	17	4	0	0
6:30	132	54	24	10	12	12	14	6	0	0
7:00	132	51	26	12	9	12	17	4	1	0
7:30	132	52	26	11	5	13	20	4	1	0
8:00	132	53	21	13	11	5	23	5	1	0
8:30	131	49	20	10	13	8	23	8	0	0
9:00	132	46	16	19	8	14	18	9	2	0
9:30	132	44	18	12	17	6	25	7	3	0
10:00	131	41	19	9	15	9	27	8	3	0
10:30	133	33	21	16	11	9	29	10	4	0
11:00	133	35	18	13	13	12	28	11	3	0
11:30	132	37	19	9	16	11	26	13	1	0
12:00	134	33	26	12	13	11	25	13	1	0
12:30	134	34	21	11	17	11	23	16	1	0
13:00	134	35	19	9	15	12	24	18	1	0
13:30	134	30	24	13	12	14	24	17	0	0
14:00	132	31	16	15	13	11	27	19	0	0
14:30	132	36	13	12	14	17	26	13	1	0
15:00	131	35	13	15	13	15	29	11	0	0
15:30	131	37	18	11	11	14	31	9	0	0
16:00	133	40	13	17	15	11	26	11	0	0
16:30	131	39	18	15	15	10	25	8	1	0
17:00	133	37	28	9	14	20	18	7	0	0
17:30	132	40	23	14	18	11	22	4	0	0
18:00	132	41	25	16	12	13	21	4	0	0
18:30	133	43	21	21	18	9	15	6	0	0
19:00	133	43	24	18	19	6	15	8	0	0
19:30	133	44	27	11	12	14	20	5	0	0
20:00	133	51	24	8	16	11	19	4	0	0
20:30	133	59	16	13	12	9	20	4	0	0
21:00	133	56	19	12	12	6	23	5	0	0
21:30	133	56	17	15	9	12	22	2	0	0
22:00	133	59	15	17	9	12	20	1	0	0
22:30	133	51	26	13	9	11	19	4	0	0
23:00	133	50	29	12	9	8	22	3	0	0
23:30	133	52	23	11	15	7	20	5	0	0
24:00	133	56	17	18	11	6	21	4	0	0
SUMME	6369	2218	1039	528	579	502	1040	333	30	0

Figure 9 Time-dependent frequency distribution of wind velocity

2.3 Multiple Point Source Models Requiring Meteorological Observations

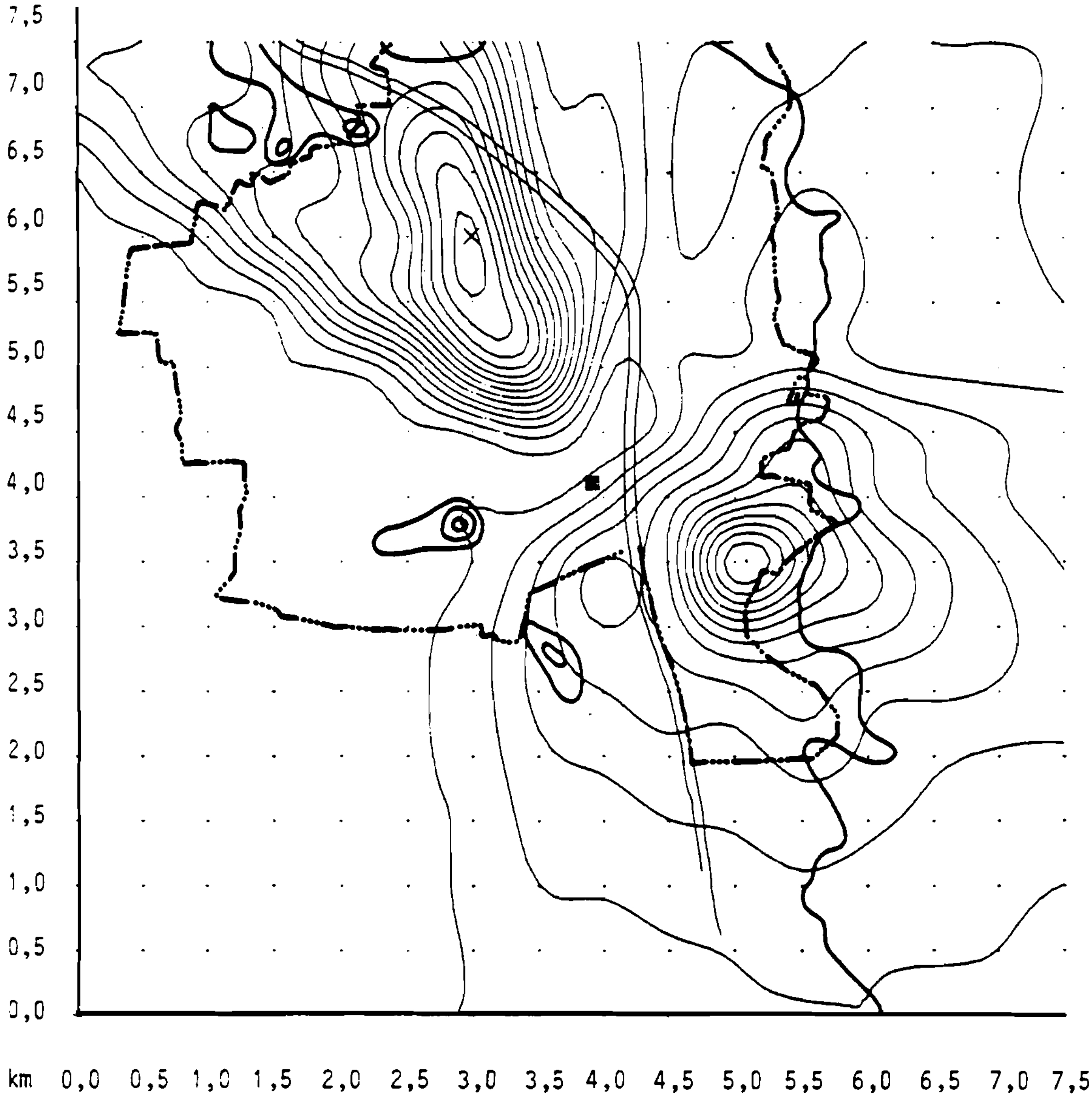
Subdivided by wind direction and wind velocity categories, a frequency distribution of each stability class (obtained from a combination of temperature gradient and wind velocity or radiation balance and wind velocity) with respect to the season of the year is used as input to the following two models.

2.3.1 Seasonal Mean Concentration Fields

The model calculates a field of half-year (winter or summer) or yearly mean concentrations of up to 15 stacks with the aid of the above mentioned statistics of stability classes. There are several options: inclusion of topography, of intermittently emitting stacks, of chemical reactions and of deposition. An example of a graphical output is given in Figure 10.

2.3.2 Determination of the Number of Cases Above or Below Prescribed Concentration Levels

The user is allowed to choose two concentration levels of interest, and the computer program calculates at each gridpoint the relative frequencies of concentrations below the lower level, between the lower and the upper level, and above the upper level. The relative frequencies are again calculated on the basis of seasonal means with the aid of the statistics of stability classes. Again, emission data from up to 15 stacks can be used; the same information as in Section 2.1.1 is required. An example of an output in tabular form is given in Figure 11.



Scale: 1:50,000
Period: Average concentrations of emissions
for the winter half-year (Oct-March)
Units: 10^{-4} mg/m^3
Maximum concentration: 0,00144 mg/m^3 (indicated X on map)
Intervals of isolines: 0,0001 mg/m^3

Computation: Central Meteorological Office, Vienna
Graphics: Austrian Institute for Regional Planning, March 1983

Figure 10 Calculated mean concentrations (SO_2, winter) for a single power plant

```
UEBERSCHREITUNGSHAEUFIGKEITEN IN 0/00 GEGEBENER SCHWELLENWERTE SW
J=1 FUER SW< .10 , J=2 FUER .10<SW< .20 , J=3 FUER SW> .20
GA 1290/83 - 1

VOITSBERG
UNTERER SCHWELLENWERT .10   OBERER SCHWELLENWERT  .20 MG/M**3
```

JAHR	J	GESAMT															
7.50	1	458	630	811	811	850	928	975	914	833	756	770	830	842	842	901	956
	2	285	183	2	6	46	52	4	12	45	1	22	3	1	47	54	45
	3	256	187	187	183	102	20	20	74	122	231	[illegible]	167	157	110	45	0
7.00	1	174	290	532	858	832	902	952	912	832	768	800	934	842	877	948	933
	2	287	372	278	39	23	46	27	14	54	0	15	9	1	53	40	39
	3	539	338	188	103	144	51	20	74	112	232	184	158	157	59	12	22
6.50	1	64	394	357	514	883	910	911	960	832	768	821	842	854	931	936	925
	2	128	71	236	313	34	8	46	20	43	0	8	0	32	41	31	17
	3	808	535	407	173	82	82	43	20	124	231	170	158	114	27	32	58
6.00	1	115	83	436	395	518	864	897	953	830	756	830	849	867	912	913	913
	2	69	31	4	55	202	53	21	20	46	11	8	34	61	25	12	2
	3	816	886	560	550	280	82	81	26	124	231	162	115	72	62	74	85
5.50	1	-16	58	10	413	394	510	858	904	914	775	815	917	895	909	889	940
	2	487	412	118	23	42	160	60	53	14	20	73	14	28	4	24	24
	3	529	529	872	563	563	320	82	42	72	199	111	68	76	87	87	95
5.00	1	247	159	-25	-114	-79	302	418	788	904	778	845	827	876	841	840	795
	2	40	112	307	158	151	135	202	116	10	32	55	34	23	40	33	48
	3	712	728	722	956	929	563	379	96	85	189	87	38	101	119	127	156
4.50	1	252	250	242	217	67	13	378	672	892	856	855	875	895	736	736	735
	2	10	4	10	31	152	104	42	56	18	24	50	37	17	37	48	39
	3	738	745	748	752	780	883	778	272	92	120	94	77	86	225	214	225
4.00	1	155	71	163	222	99	59	42	657	1000	750	593	601	664	654	390	721
	2	407	268	162	20	134	53	34	14	0	17	109	150	87	112	117	153
	3	438	660	674	758	766	888	922	329	0	232	298	249	247	202	290	120
3.50	1	488	469	536	630	563	473	525	856	879	578	436	576	652	532	675	763
	2	112	127	165	55	122	175	72	16	25	30	52	110	42	21	41	14
	3	399	403	297	314	314	352	402	118	96	392	411	312	295	240	283	277
3.00	1	596	617	631	661	583	745	867	900	853	736	575	600	640	654	683	695
	2	48	25	34	38	86	166	66	41	13	9	55	90	31	34	21	14
	3	355	357	335	300	331	87	66	58	134	256	359	309	325	311	295	287
2.50	1	699	731	768	862	925	937	926	900	866	806	674	654	690	673	659	666
	2	141	129	135	87	24	11	42	41	18	41	157	28	22	28	53	58
	3	160	139	97	51	51	51	31	58	118	152	159	307	287	298	288	275
2.00	1	846	926	948	946	949	960	940	830	657	845	848	732	674	704	700	589
	2	109	22	0	0	0	15	17	34	205	50	30	95	20	13	13	31
	3	42	51	51	51	42	24	42	96	138	103	112	173	296	282	286	279
1.50	1	949	948	948	949	967	967	948	959	587	403	372	297	433	485	713	709
	2	1	3	3	19	12	10	13	8	177	28	42	30	204	115	25	15
	3	50	48	48	32	20	22	36	33	135	568	585	672	362	395	250	275
1.00	1	949	949	953	970	979	957	929	952	916	910	871	841	314	752	652	698
	2	9	16	22	10	0	21	19	16	9	5	28	54	148	154	216	110
	3	42	34	24	20	20	22	51	31	74	84	100	105	538	93	130	191
.50	1	951	961	973	979	977	947	915	931	777	424	480	780	851	872	767	709
	2	20	14	4	0	2	35	22	14	107	134	98	125	45	29	152	163
	3	28	24	20	20	20	17	62	55	115	441	522	95	103	99	70	127
0.00	1	969	979	979	979	972	940	915	903	864	424	441	667	806	893	872	522
	2	10	0	0	0	14	35	12	12	32	135	19	99	63	12	45	87
	3	20	20	20	20	12	24	72	85	103	440	539	234	131	94	82	391
KM		0.00	.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50

```
SCHADSTOFF SO2
ANZAHL DER EMITTENTEN  2  E-POTENZ =
 1.EMITTENT: DV2 SULFUR    STANDORTKOORDINATEN XX(M)=  3900.0 YY(M)=  3900.0     BETRIEBSDAUER =  100 %
FESTE SCHORNSTEINHOEHE   H(M)        =        70
GESAMTABGASMENGE          Q(M**3/H)  =  .511E+05  QUELLSTAERKE              QS(MG/S)     =  .236E+06
ABGASTEMPERATUR           TG(GRAD CEL)=      180  UMGEBUNGSTEMPERATUR       TL(GRAD CEL)=        10
OBERE LICHTEWEITE         D(M)       =      0.00  AUSTRITTSGESCHWINDIGKEIT  VE(M/S)      =      0.00
QUELLSTAERKE DES PRIMAERSCHADSTOFFES QSP(MG/S) = 0.          UMWANDLUNGSRATE (%/H) =   0    GEWICHTSFAKTOR = 0.0000

 2.EMITTENT: DV3 SULFUR    STANDORTKOORDINATEN XX(M)=  3900.0 YY(M)=  3900.0     BETRIEBSDAUER =  100 %
FESTE SCHORNSTEINHOEHE   H(M)        =       150
GESAMTABGASMENGE          Q(M**3/H)  =  .129E+07  QUELLSTAERKE              QS(MG/S)     =  .102E+07
ABGASTEMPERATUR           TG(GRAD CEL)=      150  UMGEBUNGSTEMPERATUR       TL(GRAD CEL)=        10
OBERE LICHTEWEITE         D(M)       =      0.00  AUSTRITTSGESCHWINDIGKEIT  VE(M/S)      =      0.00
QUELLSTAERKE DES PRIMAERSCHADSTOFFES QSP(MG/S) = 0.          UMWANDLUNGSRATE (%/H) =   0    GEWICHTSFAKTOR = 0.0000
```

Figure 11 Calculation of the number of cases below 0.1 mg SO_2/m^3, between 0.1 and 0.2 mg SO_2/m^3 and above 0.2 mg SO_2/m^3

2.4 Line-Source Model

The Central Institute of Meteorology and Geodynamics runs an EPA-version of a line-source model called HIWAY, where the space-dependent diffusion parameters σ_y and σ_z, which determine the angle of spread of the pollutant, are replaced by time-dependent ones. The model calculates concentrations at chosen downwind receptor locations of a highway of variable size. The user can choose between an at-grade highway or a cut section. The following input is required:

1) dimension of the highway (length, number of lanes, width of each lane)
2) meteorological input (wind direction, wind velocity, stability class)
3) line-source strength of each lane, depending on traffic volume and mean emission rate of vehicles.

The output is given in tables, as shown, for example in Figure 12.

SEMMERINGSCHNELLSTRASSE GLOGGNITZ - SPITAL/S.

ENDPOINTS OF THE LINE SOURCE

0.000, .425 AND 2.155, 2.980

EMISSION HEIGHT IS 0.000 METERS

EMISSION RATE (GRAMS/SECOND*METER) OF 4 LANE(S)

.132E-02 .132E-02 .132E-02 .132E-02

WIDTH OF AT-GRADE HIGHWAY IS 15.000 METERS

WIDTH OF CENTER STRIP IS 3.000 METERS

THE SCALE FACTOR IS 1.0000 KM/USER UNIT.

WIND DIRECTION IS 315. DEGREES

WIND SPEED IS 1.0 METERS/SEC

STABILITY CLASS IS 2

HEIGHT OF LIMITING LID IS 5000.0 METERS

RECEPTOR LOCATION		HEIGHT	CONCENTRATION	
X	Y	Z (M)	UGM/M**3	PPM*
1.9750	2.6750	0.0000	201.	.175
1.9000	2.5450	0.0000	97.	.085
1.8000	2.2500	0.0000	24.	.021

WIND DIRECTION IS 315. DEGREES

WIND SPEED IS 1.0 METERS/SEC

STABILITY CLASS IS 4

HEIGHT OF LIMITING LID IS 5000.0 METERS

RECEPTOR LOCATION		HEIGHT	CONCENTRATION	
X	Y	Z (M)	UGM/M**3	PPM*
1.9750	2.6750	0.0000	210.	.183
1.9000	2.5450	0.0000	156.	.136
1.8000	2.2500	0.0000	82.	.071

WIND DIRECTION IS 315. DEGREES

WIND SPEED IS 1.0 METERS/SEC

STABILITY CLASS IS 6

HEIGHT OF LIMITING LID IS 5000.0 METERS

RECEPTOR LOCATION		HEIGHT	CONCENTRATION	
X	Y	Z (M)	UGM/M**3	PPM*
1.9750	2.6750	0.0000	447.	.388
1.9000	2.5450	0.0000	383.	.333
1.8000	2.2500	0.0000	260.	.226

WIND DIRECTION IS 315. DEGREES

WIND SPEED IS 5.0 METERS/SEC

STABILITY CLASS IS 2

HEIGHT OF LIMITING LID IS 5000.0 METERS

Figure 12 Highway line source concentrations (CO, ppm)

SAISON (S(OMMER), W(INTER)): W
TURNERKL.: 2 GESCHW.: 1.0 M/S RICHTUNG: 16 HMISCH: 9999 M
UMGEBUNGSTEMP.: 10 C

REZEPTORPUNKT			HAUSBRAND	GROSZEMITT.	GESAMTIMISS.
NR.	X-KOOR.	Y-KOOR.		MG/ M** 3	
1	5500	2700	.002179	.155169	.157348
2	6600	4600	.008086	.000673	.008759
3	8400	1800	.015530	0.000000	.015530
4	9200	800	.009859	0.000000	.009859
5	1500	3500	.003374	.007401	.010775
6	3200	3300	.007585	.017565	.025150
7	6400	2600	.003785	.952512	.956297
8	6700	3500	.002361	.016677	.019038
9	7300	2500	.010374	0.000000	.010374
10	7700	2000	.019359	0.000000	.019359
11	8200	1400	.012284	0.000000	.012284
12	10400	300	.000431	0.000000	.000431

Figure 13 Urban model SO_2 concentrations (mg/m^3); area sources; point sources; concentration at receptor location

2.5 Gaussian Multiple Point and Area Source Model (Urban Model)

The area of interest (in general a big town and its immediate surroundings) is divided into equal area sources of about 1 km^2 size. For each of these squares, mean emission rates are required (e.g., from an emission inventory), where up to 9 different emission heights can be assigned for each area source. Furthermore, emission rates of big point sources of almost any amount at known locations can be accepted by the model. The model then calculates concentrations for chosen receptor locations (max.99) and chosen weather conditions (any number); point source and area source concentrations are printed separately, and also the sum of concentrations at each recepter location is given (Figure 13).

Input requirements are as follows:

1) Input file for grid and weather specifications
   - number of area sources in the x- and y-directions; grid distances (m)
   - number of chosen emission heights; value (in m) for each height
   - mean plume rise for area sources for each stability class
   - number of wind velocity classes; calculated value for each class (m/s)
   - mixing height (m) for each wind velocity class
   - coordinate pairs for max.99 receptor locations (m)
   - meteorological conditions (any number)
     - wind velocity class
     - wind direction
     - air temperature
     - stability class
2) File containing emission heights and area-source emission rates
3) File containing the point-source emission rates

The input is the same as in Section 2.1.1, but the locations of the point sources are also required.

III RECOMMENDATIONS AND SUGGESTIONS MADE AT THE ADVISORY COMMITTEE MEETING

RECOMMENDATIONS ON WATER MANAGEMENT STUDIES FOR THE DOON VALLEY

S. Kaden

International Institute for Applied Systems Analysis
Laxenburg, Austria

Objectives and Work Plan

The water resources system is an important component of the environment and the socio-economic development in the Doon Valley. The valley though located in a high rainfall area, faces acute shortage of water during the dry season. The situation is becoming more serious in recent years because of increased surface runoff during the monsoon and reduced storage of water to the dry seasons. The availability of water may become one of the most restricting factors of industrial development, agriculture, and human welfare.

In order to study the role of the water resources in the environmental system, the endangering to be depleted and polluted by industrial and other human activities, and their availability for industrial, agricultural and municipal water supply, the following tasks should be realized:

1. Basis analysis and data collection for water resources problems.

As a first step, an analysis of the water resources problems has to be undertaken. All relevant and available data on geography, hydrology, and hydrogeology have to be collected. During a field trip to the Doon Valley, the problems related to both water quantity and water quality have to be studied. Based on that, necessary monitoring activities have to be designed.

2. Water balance - conceptual hydrological model.

A general water balance model of the Doon Valley, covering all relevant subprocesses of the hydrological cycle has to be developed for monthly time steps at maximum.

Precipitation patterns are well know. For evapo-transpiration, semi-empirical models may be applied based on available geographical and climatological information. To describe the distribution of total runoff into surface runoff, infiltration, baseflow, etc., simple conceptual models (with lumped parameters) has to be used.

The conceptual hydrological model is a basis for the assessment of industrial and other human ilmpacts on the water resources system, direct impacts as well as indirect impacts due to environmental deterioration.

3. Groundwater flow model

A groundwater flow model for the Doon gravel has to be developed. This model should consider distriburted parameters, the interrelationahip between surface water and groundwater, and time-dependent recharge. In view of the lack of data, a simple finite-difference flow model is recommended.

Calculations with this model increases our knowledge of water resources processes and is a basis for the design of monitoring and exploration programs. Such programs should be started as soon as possible in order to gain a better understanding of the functioning of the system. Based on that an improved groundwater flow model has to be implemented to help in the design of a controlled system of groundwater extractions, including scheduling and design of artificial groundwater recharge. This model has to be used further operationally for control of groundwater extraction rates and the design of new installations.

4. Water management modeling

Depending on the success of the process modeling mentioned above based on th conceptual hydrological model a management model has to be developed as a tool to find rational strategies for long-term development with special regard to industrial, agricultural, and human requirements. This model has to be capable of dealing with the following complexities:

- controversy among different water user, socio-economic development and environment,
- multiple criteria of evaluation of strategies, some of the criteria may not be evaluated quantitatively,
- uncertainties and stochastic character of systems input (e.g., precipitation).

The final product should be a Decision Support Model System designed hilghly interactively and user-friendly including the use of computer color graphics.

Organizational Aspects

We propose to subcontract for the water management studies, the Institute for Water Management (IFW), GDR, 1190 Berlin, Schnellerstr. 140.

The IFW is experienced in developing water management models as the collaboration with IIASA during the last years demonstrates, i.e., developing a Decision Support Model System for the analysis of regional water policies in lignite mining areas. For the above defined tasks the basic methodologies and models are available. They have to be adapted to the Doon Valley conditions and implemented.

In order to realize this subcontract, adequate funds have to be allocated. The following possibilities may be considered:

- direct payment in US dollars from UNIDO;
- use of national currency of the GDR assigned to UNIDO.

SOME PRACTICAL APPROACHES FOR MAINTAINING FOREST SUSTAINABILITY IN THE DOON VALLEY

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1. INTRODUCTION

The basic aim of forest management is to keep forest carrying capacity at a high level. The idea of maintaining forest productivity distinguishes forestry as a profession from forest devastation. Sustained productivity may be envisaged in two senses: as a continuity of forest growth and a continuity in harvest yield. Sustained yield management means, as a rule, both of these.

The introduction of the sustained yield management principle into practical forestry is necessary in order to ensure that the needs for timber and environmental protection are met steadily. Under the conditions of intensive, multi-objective forest use (of wood and its protective functions) in the Doon Valley Phase II, the following approaches and means to solve the problems are suggested.*

1. To calculate the long-term harvest capacity of the existing forest.

   This can be done using the forst reproduction model. Such a model is considered to be an effective tool with which to ***optimize the allowable cut*** and to normalize the age structure of a forest, ensuring the rational use of mature stands' resources.
2. To adopt an optimal forest thinning system in the Doon Valley forest with conditional high density. This can enable one to maintain forest sustainability and to cover wood demand for fuel.
3. To implement the management system, particularly for reserve forests of high density that enable one to form, in the forest, stands of maximum productivity. To establish local standards of stands of maximum productivity, the module of the most productive forest stands should be used.
4. Finally, the forest sector should be integrated into the Doon Valley's regional economy. To achieve this, the dynamic optimum correlation among the regional economy branches (land users) and correlations between the main territories (agricultural, forest, urban-industrial, recreational, con-servational, etc.) must be established. The optimization and specialization of forest growth must be based on a purposeful function of each large landscape unit.

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*For application of methods and software discussed in this paper, detailed information can be obtained from the Lithuanian Research Institute of Forestry, Girionys, Kaunas, Lithuanian SSR (Prof. A. Juodvalkis, Dr. S. Mizaras, Dr. R. Deltuvas or Dr. J. Grigaliunas).

A description of the practical tools and measures for implementation above in forestry practice in the Doon Valley follows below.

2. CALCULATIONS OF THE LONG-TERM HARVEST CAPACITY OF THE FOREST

The history of European forest resources depletion during the last centuries has shown that forest depletion is simultaneously a precondition and a consequence of the sustainability and continuity of the use of forest resources. Lessons learned in Europe (for example, introducing strong regulating forces and laws, programs of afforestation, the monitoring of forest resources dynamics, can be used in the case of the Doon Valley. Most important among theses is the final yield regulation.

In the author's opinion, an area method named "OPTINA*" can be used for the final yield regulation in the Doon Valley (Deltuvas, 1982; Kairiukstis et al, 1985). This method is based on the rotation and age class contribution into management classes.

When constructing the model, the following was presumed:

a) applicability to any management unit (forest enterprise, rural community, region, country, etc.);

b) examination of the complete age structure of a mangement class;

c) improvement (normalization) of the age class structure; and

d) monotonous (if necessary) transition of the allowable cut to an uniform annual cut from rotation-aged timber.

The volume yield can be determined by multiplying the estimated cut area by the average volume of mature stands in a given management class for one ha. The yield for the forest enterprise (rural community) would equal the sum of yields estimated for all management classes.

2.1 Module of Forest Reproduction

The module is made to obtain the data of the forest state, forest utilization volume and economic indexes of forestry at different variants of the forest reproduction:

Preconditions of the model formation:

a) the state of the forest is described by the tables of age-classes differentiated on the basis of the main purposeful destination of the forest;

b) the dynamics of the forests are determined by the movements of the age-classes; and

c) the OPTINA model is used to determine the amount of main forest cutting.

*OPTINA: "OPTimalus NAudojimas" (in Lithuanian) which means optimal amount of forest cutting.

The module imitates the following means of forest reproduction:

- the increase or decrease of the areas covered with forests;
- change in the structure of the forest; and
- increase or decrease in forest productivity.

The following input data are needed:

a. The area distribution into age classes according to prevailing tree species:

	Age Class							
Tree Species	I	II	III	...	...	n-1	n	Total
Sal	$\frac{ha}{m^3}$	$\frac{ha}{m^3}$	$\frac{ha}{m^3}$			$\frac{ha}{m^3}$	$\frac{ha}{m^3}$	$\frac{ha}{m^3}$
Pine, etc.								

b. Rotation age for every tree specie.

c. Number of age classes in the rotation age for every tree specie.

d. Average volume for 1 ha of mature stands in a given management class.

The dynamics of the forests are conditioned by the stands growth, silvicultural activities and random factors (natural calamities, fire, etc.). Every ten years each element of the area matrix is moved to the next age-class.

$$c\ (i,j,k) \rightarrow c\ (i,j+l,k)\ .$$

The model of forest dynamics and forest use (forest reproduction) imitates 12 variants:

1) the basic variant when other factors influencing forest dynamics are not considered in transferring age-classes;
2) the increase in forest areas;
3) the decrease in forest areas;

4) an ideal state of forests (the purposeful species composition, a normal age-class structure, purposeful timber resources);
5) the fertilization of forests;
6) forest land reclamation;
7) forest growth from elite seeds;
8) forest growth from fast growing species and hybrids;
9) the impact of hunting fauna on the forests;
10) unclear cutting;
11) the formation of standard stands; and
12) the variant in which climatic fluctuations are taken into consideration.

Table 1. Forest age classes (area, ha).

Tree specie	Age class, 10 years													
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	Total
Pine	25028	80092	75585	61029	58440	58084	45953	33887	16303	10620	5111	4752	4987	479873
Spruce	9698	13527	11167	20398	33842	40887	26659	17844	9681	5697	1378	786	236	192000
Oak	230	1450	1466	1289	658	633	501	456	473	644	384	868	1129	10189
Ash	2109	2593	2835	2599	1892	1876	1235	705	470	270	179	212	67	17042
Birch	13318	37133	56861	56485	40952	30480	13898	3323	414	76	3	32		252975
Black alder	5415	6597	9257	14939	12039	8281	5276	2437	772	217	29	34	10	64403
Asp	2950	6330	12172	13244	13309	11531	4723	757	156	18	3	3	-	65196
White alder	3586	12128	10082	6004	1383	41	28	-	-	-	-	-	-	33242
Total	61434	159858	179425	175987	162515	151813	98269	59409	28269	17542	7287	6687	6429	1114920

Based on the results of the forest dynamics analysis variant, the influence of the whole complex of forests is estimated.

When estimating the allowable cut for a management class which is characterized by the dominant tree specie, its rotation and areas of age classes in ten-year intervals, we seek a normal age-class distribution to ensure a sustained yield. The area yield for a ten-year period can be calculated by the following formula:

$$L_r^k = \frac{1}{r}\left(\sum_{i=0}^{r-1} f_i^k + \alpha f_r^k\right) \quad ; \qquad \alpha = 0{,}9 \div 0{,}1 \quad ; \qquad r = 1 \div T_k - 1 \quad ; \qquad (1)$$

$$L_k = \min_{r=1 \div T_k - 1} \{L_r^k\} \quad . \qquad (2)$$

In order to secure the increasing allowable cut from one ten-year period to the next, the following limitations are favored:

1. *If* $N_k \geq f^k_{T_k}$, $N_k = \dfrac{F_k}{T_k}$; (3)

then:

a) if $L_k \leq N_k$, then area yield is L_k ;

b) if $L_k > N_k$, then area yield is N_k ;

2. *If* $N_k < f^k_{T_k}$, *then area yield is* N_k ,

3. *If* $f^k_{T_k} \geq \beta L_k$, $\beta = 0{,}1$, *then area yield is* L_k,

$$f^{k'}_{T_k} = f^k_{T_k} - L_k + f_{t_k - 1} \, .$$

Indices:

L_k - calculated minimal area yield;
F_k - total area of k management class per ha;
T_k - rotation deceniums;
f^k_i - area of i age class per ha;
f_1 - area of the stands at felling age, ha;
N_k - normal allowable cut for k management class, ha.

The volume yield can be determined by multiplying the estimated area by the average volume of actual stands at the felling age in a given management class for one hectar. The yield for the whole region would equal the sum of yields estimated for all management classes.

The results of the calculations, based on the average 1 ha volumes of the mature stands should they stay at today's level are presented in Table 2). In Figure 1, the calculations of final forest cutting up till the year 2050 are suggested in the case that stands are formed according to standard of the most productive stands as described above.

Besides, the scenario is distinguished considering the influence of eco-climatic backgrounds fluctuations. Possible changes of eco-climatic conditions in the Doon Valley have been discussed in the Final Report of the Doon Valley Study - Phase I. Such changes are favorable to a different degree for production processes of the forest. In predicting forest dynamics these changes can be evaluated and considered by a dendro-climatic-chronological method. Taking into consideration the climatic fluctuations ($y(t)$), the timber resources are determined according to the formula:

$$V_t = M \left(I \div \frac{K_y(t)}{100}\right) ,$$

where:

M – average resources for many years;

Ky(t) – percent of changes in resources depending upon climatic fluctuations;

K – coefficient of proportionality;

$$y(t) = \sum_{j=I}^{n} A_j \cos\ (\frac{2\Pi t}{T_j}\ \varphi_j)\ ,$$

where:

y(t) – dendroclimatic index (relative deviation of forest productivity from perennial) per year t;
j – number of a climatic cycle;
n – number of cycles;
A_j – fluctuation amplitude of j cycle;
φ_j – fluctuation phase of j cycle;
T_j – j cycle duration.

The computer determines the values of final felling for each variant of forest resources reproduction for 10 to 15 years ahead and for the longer term.

2.2 An Example of Calculations of Forest Resource Capacity in the Lithuanian SSR

The Lithuanian SSR is one of the Republics of the USSR situated on a area of 6.5 million ha with an average population density of 52 inhabitants per km^2. The high level of landscape cultivation, intensively developed and highly-productive silviculture which meets the requirements for wood by approximately 75%, are characteristic for the Republic. Of the total area, woods cover 27,6%; the average forest district covers 3000 ha, and forest management covers 30000 ha. There is a well-organized nature protection system, intensively developed tourism and recreational facilities, game management and sport hunting.

The characteristics of a Lithuanian forest according to age classes is given in Table 1. Such a table can be described as a three-dimensional matrix c (i,j,k), where i is the index of a tree specie, j is that of an age-class, k is that of the specialized use of the forest sector. Any element c (i,j,k) of the matrix will show the forst area of i tree specie, j age class, and k specialised use of the forest sector. The analogous matrix describes the standing volume.

Using the model described above (see Section 2.1), the amount of available wood for cutting was calculated for the long-term future. The results of the calculations, based on the average 1 ha volumes of the mature stands, should they remain at the present level, are given in Table 2. In Figure 1, the calculations of final forest cutting up till the year 2050 are suggested in the case that stands are formed according to the standards of the most productive stands (as described in Section 3 of this article).

Table 2. Long range volume yield for the Lithuanian SSR (100 m^3).

Tree Species	Years						
	1990	2000	2010	2020	2030	2040	2050
Pine	1577	2285	3586	652	8791	9614	9614
Spruce	2927	3398	4009	4397	4397	4397	4397
Oak	99	109	115	125	122	122	122
Ash	69	84	106	167	283	319	336
Birch	3615	5535	6712	6712	6712	6712	6712
Black alder	1549	1926	1974	1974	1974	1974	1974
Asp	2903	2903	2903	2903	2903	2903	2903
White alder	1377	1377	1377	1377	1377	1377	1377
Total	14115	17618	20781	24206	26559	27419	274436

3. CALCULATIONS OF THE OPTIMAL INTERMEDIATE FOREST USE

Taking into consideration that the forest in the Doon Valley is fulfilling multiobjective purposes, intermediate cuttings may play a important role in both maintaining the forest system's sustainability and covering wood demand for fuel.

The model of optimal thinning can be used to plan intermediate use of a forest on a sustainable basis. A simplified scheme of the model is presented in Figure 2.

Using input data such as tree species, stand composition, average tree height of each specie, stand volume, stand basal area, and volume of standard (normal) stands, one can calculate the possible cutting volume and stand indices after thinning. The standards established using approaches and models described in the following Sections can be taken as criteria for normal stands.

4. THE MODULE OF THE MOST PRODUCTIVE FOREST STANDS

The optimal parameters of the stands have been defined and theoretical foundations of the model have been worked out in the Lithuanian Forestry Research Institute (Kairiukstis, 1973; Kairiukstis et al., 1980). The preconditions of modeling the most productive stands are as follows:

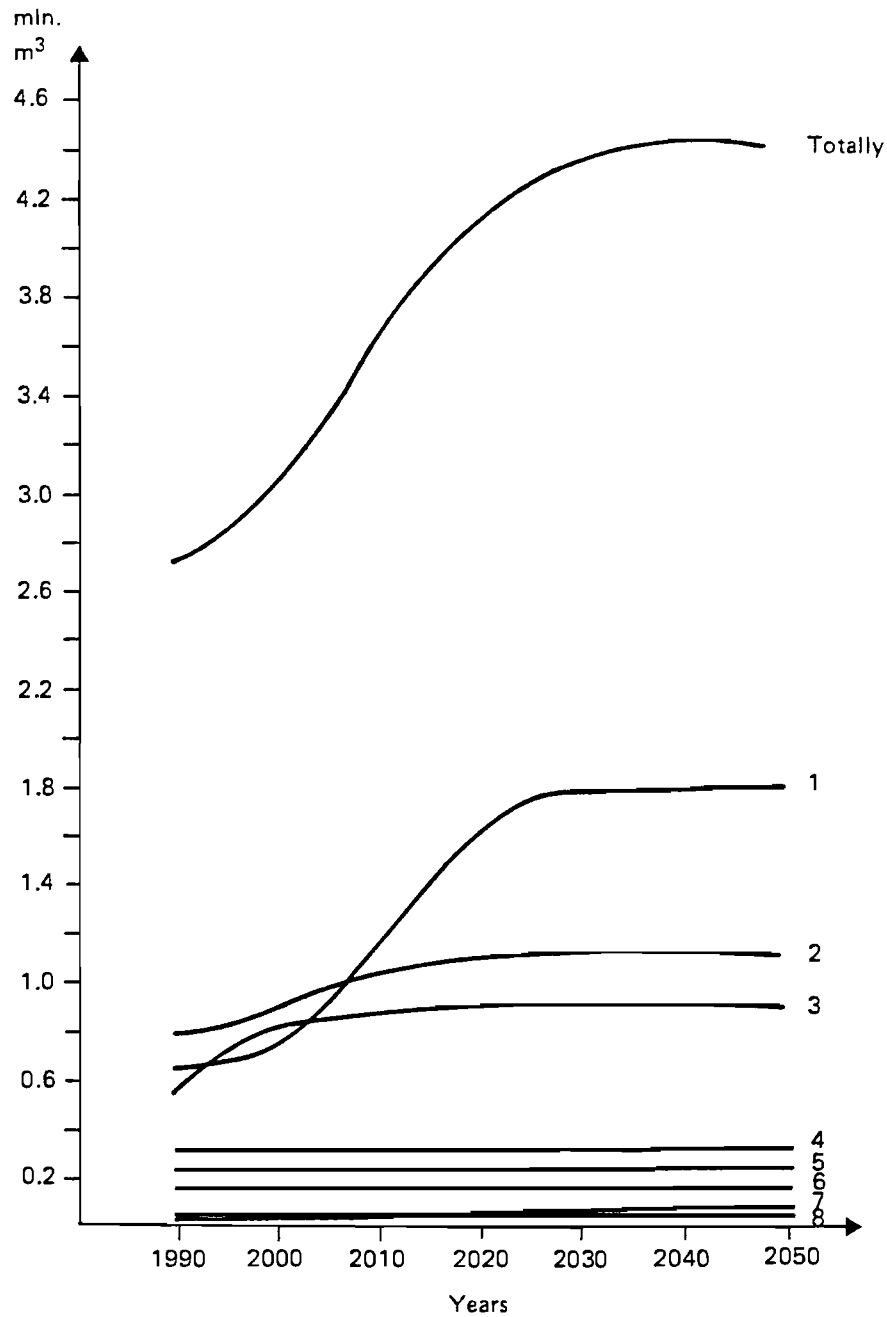
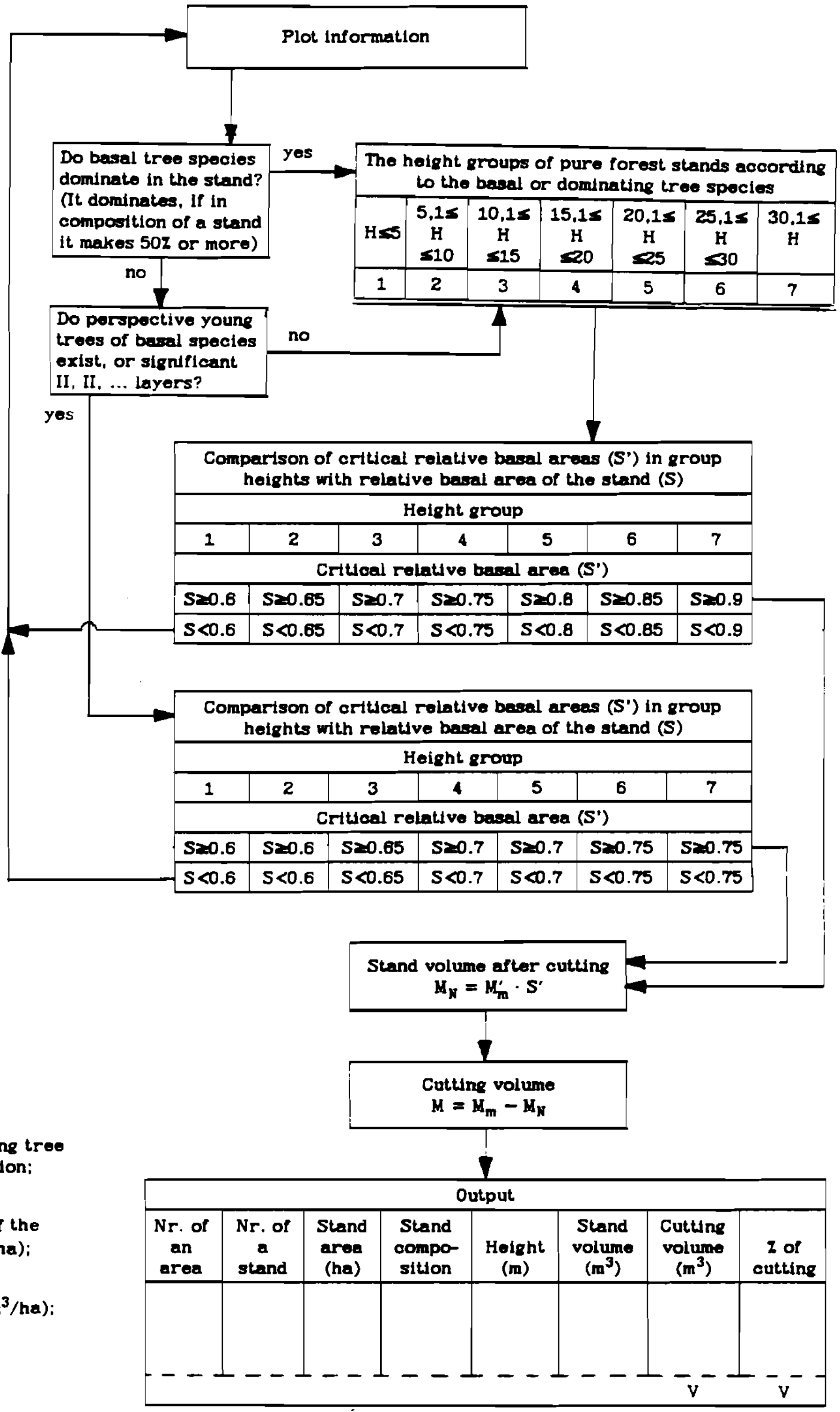


Figure 1: The main use of the forest. The forest volumes of the greatest productivity are taken as: 1 – *Pinus silvestris*; 2 – *Picea abies*; 3 – *Betula verrucosa*; 4 – *Populus tremula*; 5 – *Alnus glutinosa*; 6 – *Alnus incana*; 7 – *Fraxinus excelsior*; 8 – *Quercus robor*.

SCHEME OF THE OPTIMAL THINNING

INPUT

1. Code of the basal tree species;
2. Forest stand composition: $k_1K_1k_2K_2\ldots;\ \sum_1^k = 10$;
3. Middle heights of each species;
4. Stand volume (m^3/ha);
5. Volume of the normal stands (m^3/ha);
6. Relative basal area, i.e., G stand/G normal stand;
7. Do significant II,III,... layer exist? :
   1 – yes;
   2 – no;
8. Do perspective young trees of basal species exist in overlapping of the stand? :
   1 – yes;
   2 – no;



SYMBOLS

- K – code of the tree species;
- k – coefficient of the participating tree species in the stand composition;
- H – middle height of tree species
- M'_m – normal forest stand volume of the dominating tree species (m^3/ha);
- M_m – stand volume (m^3/ha);
- M_N – stand volume after cutting (m^3/ha);
- M – cutting volume (m^3/ha);
- S – relative basal area;
- S' – critical basal area.

Figure 2: Scheme of the module for calculation of the optimal amount of thinning.

- Stands are formed on the basis of mapping forest soils (Vaicys, 1975) from species which under given soil and ecological conditions can yield maximum production of industrial wood during the shortest period of time.
- The optimal growth of a maximally productive stand is based on maximum stand productivity of a definite species on certain soils and is feasible under the following conditions:

  a) maximum energy quantity absorbed by the stand (reduced albedo) and great effectiveness of its utilization by trees and stories after selective thinning (Kairiukstis, 1967);
  b) during the growing process, mutual approach of trees (elementary systems) which form a stand (micro- and meso-ecosystems) is regulated in such a way that negative consequences of mutual tree depression during the ecosystem creation should be minimal
  c) forest cover is formed from maximally productive trees of class A, uniformly distributed over an area; the distance between trees is optimal (Kairiukstis, 1973); and
  d) crown density and homeostatic stand sustainability is maximal.

According to the above conditions, the optimal requirements for lighting of trees of different species and development classes, the stories structure at which the albedo index is at its smallest point, is determined. Within the specific class of trees, those with the most economical use of solar energy for the formation of stem timber increment, have been found and density regulation means have been carried out (Patent Certificate Nr. 409677). The latter enable mutual tree depression in forest ecosystem formation to be avoided.

The main index in the model of maximally productive forests is the optimal quantity of trees, providing the maximum current increment of wood in an area unit of any stand age. It is calculated according to the formula:

$$N_{opt} = \frac{Q}{S(I - \frac{P}{100})} ,$$

where:

Q = maximally possible canopy area amounting to 7-9th m/ha; depending upon the species, age and soil-climatic conditions;
S = mean area of a horizontal crown of a well-developed tree, m;
P = the optimal overlapping of crown amounting to 5-20% of the total crown area depending upon the species and age.

Figure 3 presents a block diagram of the algorithm. The values of the parameters are:

A = age, year;
S = section area in ha;
Q_{plot} = area of the layer projection in the section, in m^2/ha;
Q = area of the layer projection in m^2;

q = area of crown projection of an individual tree without overlapping, in m^2;
q_p = crown projection area of an individual tree in m^2;
q_{opt} = crown area of the optimal projection in m^2;
q_v = mean area of a crown projection in m^2;
N = number of trees in the area unit;
Z_g = increment of stand basal area of a separate tree in m^2;
Z_G = increment of a stand basal area, in m^2/ha;
d = diameter of a tree in cm;
d_{opt} = optimal diameter of a tree in cm;
Z_r = radial increment during a one year period in cm;
P = percent of the overlapping crown;
T = index of a forest type;
η = index of a tree species;
h = height of a tree in m;
h_{opt} = optimal height of a tree in m;
G_A = optimal sum of stand basal area in m^2/ha;
N_{opt} = optimal number of trees in ha;
M_A = optimal volume of a stand, in m^3/ha;
F = optimal form index; and
a = equation parameters.

The algorithm of the model consists in the determination of the maximum density of the layer, the calculation of the area of the horizontal projection of the optimal crown, the determination of the optimal overlapping percent of the optimal crown, the calculation of the number of trees at a certain age. For the determination of the maximum density of the layer (Block 2), one should use experiment plots in the possibly dense stands in all the range indicated in the constraints and to draw the plan of tree locations and crown projections. The whole area of the crown projection (q_p) and area q, except overlapping, are presented separately for each tree. These measurements are necessary for the determination of the area of inevitable glades in the stand and calculations of the optimal crown overlapping. If the stand contains "windows" (or squares) the area which is greater than that of an average tree crown, a certain quantity of trees is artificially included in them and their crown are included into the initial information. The maximum density of the layer in 1 ha area is found by the computer. This is the sum of the crown projection areas without overlapping.

In order to determine the optimal crown parameters, the correlation between Z_g and g_p at a particular age is being sought. The crown productive maximum wood increment in the area unit is considered optimal. Having the optimal crown parameters at a certain age interval, we find its relation with age in all the age ranges (Blocks 4, 5 and 10).

When the maximum layer density and the optimal crown area are know, the optimal number of trees in the area unit can be found. For this purpose, however, the optimal distance between the trees must be found. In the model, this distance is established in terms of the optimal crown parameters and the percent of optimal crown overlap. The calculation of optimal percentage of crown overlap is described in blocks 11-14. As a result of

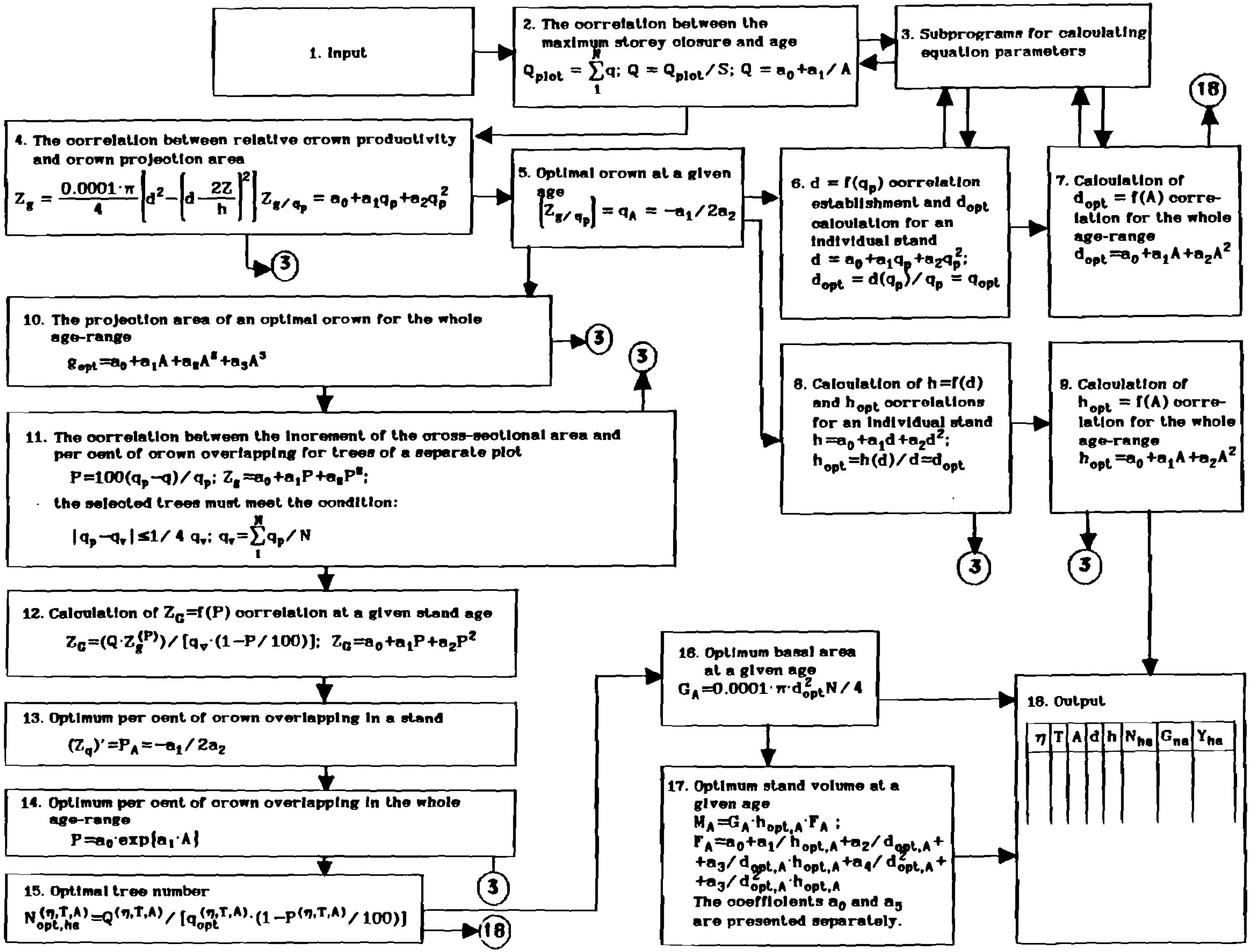


Figure 3: A block scheme of automatic systems for model construction of maximally productive stands.

the calculations, the optimal number of trees, the optimal stand base area and volume affecting the maximum wood increment are obtained for the given type of forests and tree species.

Finally, based on the above-mentioned, the standards of the most productive stands for pure stands and main groups of species' composition and site conditions have been elaborated. These standards expressed optimal indices of stands in different periods of their growth. The standards reflect optimum stand density and structure at any age.

In the process of standard forest formation in practice, the assessed indices of the specific stand at a certain height must be compared with the corresponding indices of standard stands calculated by the model for the Doon Valley forest, as has already been done for Lithuania (see Table 3). In the planning of intermediate cuttings, the volume or stand basal area in the forest is compared with the corresponding indices presented in the program. The main goal of the thinning system is to achieve highly productive stands at the time of final cutting. Table 4 presents an example of the average volume and stand basal area of the most productive stands at the time of final cutting in the Lithuanian case.

5. INTEGRATION OF THE FOREST SECTOR INTO A REGIONAL (NATIONAL) ECONOMY

Optimizing forest growth, for different purposes on specific geographical landscapes, the elucidation of the role and place of forests in the regional (national) economy as well as in the whole land use system, and determining the predominant function of the forest on a specific territory have appeared during the last decades to be important problems in regional (national) development and physical planning.

To solve such problems, four separate regions are presently feasible only for a whole complex of scientific and projecting organizations engaged in geographical, ecological, forestry, economic demographic, social, genetic and other investigations as well as planning on the given territory. For example, in the Soviet Union and other countries where land is state-owned, the allocation of functional landscapes among the main branches of the national economy (agriculture, forestry, urban development, etc.) as well as the integration of the forest sector into the national economy, are mainly solved with the aid of regional physical planning. Moreover, when optimizing land use in integrated economic development of separate regions, rather intricate problems arise in achieving an adequate improvement of living conditions of the local human population and development of separate industrial branches.

To reach a more or less optimal decision in regional development, a set of models should be used. The cycle being modeled is the following: the economics change the environment (air pollution, decrease in woodiness, soil erosion, etc.); due to environmental changes an impact is noted on the factors of production and on those of the non-productive sphere, including man. The consequences of this change by the feedback influence the economy and social development of society. The modeling goal is that planners may have opportunities to evaluate the state of branches of the

Table 3. Program of the most productive spruce stand formation under the condition that opening the crown cover and clearing occur every five years, while thinning and intermediate cutting occur every ten years.

Mean Height of well-developed trees, m	Assessment indices of trees left after thinning in different forest types					
	Myrtillosum, aegopodiosum mixtoherbosum			*Myrtillosum-oxalidosum*		
	N ind/ha	G m^2/ha	V m^3/ha	N ind/ha	G m^2/ha	V m^3/ha
2	2230	0,3	3	2410	0,2	2
3	2310	0,9	5	2400	0,7	3
4	2290	2,0	6	2390	1,5	4
5	2250	3,2	9	2370	2,6	7
6	2200	4,8	15	2320	4,1	14
7	2140	6,6	25	2270	5,9	24
8	2080	8,8	40	2210	7,9	35
9	2000	11,4	59	2140	10,0	51
10	1920	13,9	78	2070	12,4	68
11	1830	16,5	101	1980	14,6	89
12	1740	19,2	128	1890	17,1	112
13	1640	22,1	158	1800	20,0	139
14	1540	24,9	188	1700	22,6	165
15	1430	27,7	222	1590	25,1	196
16	1330	30,0	225	1490	27,2	228
17	1220	32,4	287	1380	29,5	256
18	1120	34,5	321	1280	31,3	289
19	1020	36,3	352	1180	33,5	320
20	920	37,9	384	1080	34,7	352
21	830	3,92	415	980	35,9	380
22	740	40,3	443	890	37,4	410
23	650	41,1	470	800	38,3	435
24	580	42,0	483	720	39,3	458
25	510	42,8	517	650	40,2	485
26	450	43,5	540	590	41,0	510
27				540	41,7	534
28				490	42,1	554
29				470	42,5	576
30				450	43,1	595

Table 4. Average volume and stand basal area of maximum productive stands at the time of final cutting.

Tree species	N	M	ΣG	$D_{1,3}$	H	V
Pine	540	472	39,3	30,5	26,7	0,874
Fir	504	655	49,3	35,3	28,7	1,300
Oak	274	405	32,2	38,7	27,9	1,478
Ash	393	296	25,6	28,8	26,7	0,753
Beech	599	283	26,4	23,7	25,3	0,472
Alder	639	319	31,9	25,2	20,8	0,499
Asp	934	304	28,5	19,7	23,1	0,326

economy (including the forest sector), of the environment and of people at different regional development strategies. This approach can also be used in the case of the Doon Valley.

5.1 An Interbranch Level

The system of models used for inter-branch analysis embraces the branches of the regional (national) economy and territorial levels. The basic tool used to undertake numerical calculations to forecast economic development of the region (republic) on the national economy level is the model of analysis and prediction of a reproduction process of gross national product. The model was constructed at the Institute of Economics of the Lithuanian SSR Academy of Sciences (Rutkauskas, 1980). In the model, the multi-branch economic system is described by equilibrium equations. For the gross output prediction of branches, the productive functions are applied. The rate of growth of net output was chosen as a criterion of the optimum.

The branches of the forest sector are united into a complex which includes the timber industry, wood processing and cellulose-paper industry. For a disaggregation of the forest branches in the model and in order to single out the branch of logging and timber sorting, the following data is used:

- the coefficients of direct expenditures;
- productive function of the gross output;
- branch structure of capital investments;
- lack of capital investments;
- the main production funds at the end of the pre-plan period.

The coefficients of direct expenditures are determined according to the data of inter-branch production balance and output distribution.

The model of reproduction of the gross national product can work with productive functions of the gross output of Cobb-Douglas type and with linear functions. These two functions of the gross output for the enterprises of the Ministry of Agriculture and Timber Industry of the Lithuanian SSR are presented below.

Cobb-Douglas function:

$$y = 2.4765L^{0.3516}\ 0.3516F^{0.4714}$$

The linear function:

$$y = -2729.7 + 1.9L + 0.8F\ ,$$

where:

y – annual gross output, in thousand roubles;

L – personnel engaged in industry and production;

F – the main production funds, in thousand roubles.

The coefficients of the formulae were determined by processing dynamic rows of the corresponding indices. The branch structure of the capital investments showing the part of production of individual branches is the following: industry – 0.52; construction – 0.42; other branches – 0.06. A lack of capital investments indicates delay in putting the main production funds into operation. Currently, we have only data on the remainder of the uncompleted construction at the end of every year. In case the remainder is invested the following year, the capital investments in construction of a two-year lag will be: the first year: 0.79; the second year: 0.21. These data enable the branch of logging and timber sorting to be singled out in the model and the main indices of their development to be predicted. However, in the inter-branch model of gross national product reproduction, ecological factors are not considered. Therefore, additional indices are introduced into it. They characterize reproduction, the use of natural resources and constraints imposed by scarce resources. The principal task of the models of national economy (inter-branch) is to establish the basic proportion of economic development and to preserve stable ecological systems for a long time. The data obtained is concretized and disaggregated in the model of individual branches and regions.

5.2 Branch Level

At the branch level, the development of individual branches and of their whole complex is being modeled. The production volumes, ascertained in the model of the national economy must be in agreement with the possibility of a branch and the environment. These tasks are being solved here. The problems being tackled by a system of models of the forest sector are the following: determination of demand for forest resources, singling out of specialized sectors of wood growth, prediction and optimization of reproduction of forest resources, establishment of the development of logging and timber sorting as well as forecasting and optimizing of wood processing.

Demand for products of branches of wood processing as a whole is ascertained in a balance inter-branch model. It is further detailed in the block of demand determination for production of wood processing and the demand for timber resources is calculated through the model of the development of wood processing. The requirements for non-wood forest resources (berries, hunting fauna, etc.) and for those resources which form the environment are established as a function of the dynamics of population number and other indices predicted in the models of the regional (national) economy.

In a study undertaken at IIASA, it was suggested that the determination of demand for wood (E) as a function (g) of the gross national product (G), population number (P), prices of wood products (P_t) and from prices of their alternatives (P_s). An analogical principle is used to predict the requirements for forest resources in LSFM. Having applied this principle to ascertain the requirements in the recreation sector, the following multifactor equation was obtained (Riepsas, 1981):

$$y = 11.55 + 1.25\, x_1 + 0.041\, x_2 - 0.115\, x_3 + 0.026\, x_4 \quad ,$$

where:

- y - recreation, million visitors days/year;
- x_1 - duration of holidays, in days;
- x_2 - number of private cars;
- x_3 - number of population, in thousands;
- x_4 - percent of townsmen.

The equation approximates well enough the changes in the number of people who vacationed in forests in the past and gives a real forecast for the future.

In the whole system of models of the forest sector one part of the data on demand is obtained from the models of a regional (national) economy; the other part comes from "The Forest Fund" data bank.

5.3 Growth of Speicalized Forest Stands

The distribution of forests into specialized subsectors is an essential condition for the modeling of forest resources reproduction. A specialized subsector comprises a complex of stands, territorially isolated and united by the major objective of wood growing and similar management. In the Lithuanian SSR, there are five main functions of landscapes: agricultural, timber-industrial, recreational, urbanized, conservational. In each of these there will be similar management peculiarities within the whole functional zone. Depending upon the zone to which forests belong, they form the corresponding subsector of wood growth. The essential group of factors subjected to analysis in modeling singling out of specialized sectors is as follows: the initial structure of land use, demand for production of land using branches, restrictions imposed on the use of natural resources for environmental protection, suitability of territories for different functions, expenditures and losses of transforming one territorial function into another. The major problems of establishing territorial functions are tackled in the models at the inter-branch and regional levels. Making use of the comparative evaluation of forests with different functions, one can determine the optimal purposeful distribution of forests.

We have singled out the following forest subsectors in the republic: exploitative (52,7%), agricultural-protective (18,4%), recreational (11,2%), conservational (10,6%) and sport (recreational) hunting (7.0%) forest subsectors. In optimizing large regions on the basis of the dominating function of a territory with different kinds of land uses (agricultural lands, forests, water areas, etc.), specialized subsectors may include different forest categories although there is only one leading function.

For the forests of the Lithuanian SSR for example, the standards for wood growth for each separate forest subsector is being worked out.

5.3.1 Standards for Industrial-Exploitative Forests (including plantations) of Maximum Productivity

Standards of the most productive forests have been calculated using the module of the most productive forest stands. In the subsector of industrial-exploitative forests, all silvicultural operations contributing to more simple, inexpensive and rapid wood growth for consumption are being implemented. In purely industrial-exploitative forests, clear cutting prevails. In mixed forests, shelterwood is applied. In these forests, the elk and deer population is decreased to that level which causes least damage to the forests, while the number of boars is close to the ecological density limit.

Experience has revealed that due to the growth of industrial-exploitative forests according to the program mentioned above, the industrial wood increment is increased by 20-25%, its utilization from an area unit is significantly augmented and its cutting cycle is noted to be much shorter.

5.3.2 Standards for Agricultural Protective Forests

Standards for agro-protective forests are being established in conformity with the forest which maximally prevents erosive processes and creates better micro-climatic conditions for the adjoining agricultural fields. The forest management goal in these stands is the preservation and increase in their protective peculiarities. Dense, many-storied, with undergrowth and natural regeneration standard forests serve this purpose.

Under the conditions of Lithuania, such stands exert a favorable influence on the microclimate of fields at a distance of 500-600 meters from the forest. Thus, precipitation is distributed more equally, surface run-off decreases up to 65%, deflation reduces greatly, crops lie flat to a lesser extent, and the yield increases by 10%. Such forests are of paramount importance in hilly regions where woodland is scarce.

A selected cutting system prevails in the management of agricultural protective forests. Shelterwood cutting is an exception. Intensive intermediate cutting is directed towards the reduction of spruce (in view of its low resistance to wind and poor protective qualities) in stand composition, in the restoration of deciduous species and pine as well as towards a continuous maintenance of protective features of these forests. While in agro-protective forests the quantity of deer is greater, the boar population density is regulated on the basis of damage which it inflicts on agriculture.

5.3.3 Standards for Recreational Forests

The standards of recreational forests were set up in conformity with the highest sanitary, hygienic and aesthetic levels. The forests were formed with changing stand density and species community areas, clearings and meadows with water basins. Approximately 70% of the whole recreational territory is to be forested. Scotch pine (*Pinus silvestris L.*), European white birch (*Betula verrucosa Ehr.*), oak (*Quercus robur L.*), maple (*Acer platanoides L.*), with underwood of common juniper (*Juniperus communis*), and ash-tree (*Fraxinus excelsior L.*) predominate in the composition of pure or mixed stands.

A systematic selection of individual trees depending upon their state, cutting favoring the formation of the best landscape view and forest stability as well as intensive sanitary fellings are applied in the management of recreational forests. Forest road construction, parking areas, foot-paths, etc., are of great significance. The great density of hunting fauna, intensive sport hunting and its management are typical of recrational forests.

5.3.4 Standards for Conservational Forest

The standards established meet the goals of the most valuable stands from a scientific and nature protection point of view. Such forests are composed of game preserves, reservations and national parks. They preserve the genofund of the main species, primeval environment, the vanishing vegetation, animals and their cenoses. Management activities in these forests are entirely forbidden or strictly limited. Statutes and protection measures for each object are worked out by scientific organizations and approved by state departments. In conservational forests a great number of fauna is kept; this may reach an optimum ecological level.

5.3.5 Standards for Sport Hunting (Recreational) Forests

The standards for sport hunting (recreational) forests exclusively answer the goals set for intensive hunting management. Silvicultural operations applied in these forests contribute to the increase of forage and protective measures for hunting game. Depending upon fauna type, these forests are reconstructed for roe deer, red deer and elk rearing. Only one of these animal species is considered prevailing, while the rest are minor. Hare and wild boar distribution occurs in all forests.

While specializing the forest hunting areas, significant attention is focused on the percentage of the territory which is covered by wood, the average size of forest areas, the predominant soil types, stand composition, and the recurrence of forested and non-wooded areas. The ecological density limit of all the main game species is determined by direct dependency on fertility of the prevailing soil types, deciduous species in stand composition, percentage of territory covered by wood and the scale of forest areas.

Cutting is directed towards the increase in lighting under cover and reproduction and development of forage plants as well as towards the securing of hiding places for game. The creation of plantations containing oak (*Quercus robur L.*), horsechestnut (*Aesculus hypocastanum L.*), wild apple (*Malus silvestris L. Mill.*), pear (*Pyrus malus L.*), mountain ash (*Sorbus hybrida L.*) and goat-willow (*Salix caprea L.*) is therefore of great importance.

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ELEMENTS OF A PROPOSED METHODOLOGY FOR ENVIRONMENTAL IMPACT ASSESSMENT OF THE DOON VALLEY

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It has been established that in the Doon valley, various economic activities are interlinked through ecological processes. Therefore, the traditional sectoral approach here to analyze the contribution of each economic activity to economic growth and development of a society will be incomplete and, hence, inaccurate (Bandopadhyay et al. 1984). Utilization of one natural resource in the generation of one economic activity may adversely affect certain othel activities and thus impose hidden costs. The one resource approach under-estimates the actual costs while inflating the benefits from the individual economic acitvity. Thus, in order to take rational policy decisions on such issues as regional economic development, a systems approach is the most scientific method to adopt.

The ecosystem under consideration involves complex interlinkages among natural and socio-economic phenomena. Therefore, we need a management model to help us make decisions about managing the Doon valley ecosystem. The overall model may contain several sub-models which may be of analytical or simulation type or a combination of both (Hall & Day 1977, p.7). The two methods used for solving management models are 'trial and error' (or simulation) and 'optimization' methods (Shoemaker 1977, p.105). In the trial and error approach, the predictive equations relating components of the system must be solved, analytically or numerically, for each new value of the decision variable. For a complex model for which many alternatives exist, it is usually too expensive to test each admissible policy. One may first choose a few of the policies that appear most promising and then go ahead and test their outcomes by simulation. Unfortunately, the best policy can be overlooked in this procedure.

The alternative approach using optimization technique calculates directly the policy which maximizes an objective function. Numerical methods have been developed to calculate optimal policies. The best method to use depends upon characteristics of the problem being studied, that is, whether the problem is linear, nonlinear, continuous, stochastic or constrained. One of the methods most used to determine the optimal management of systems described by a set of linear equations is linear programming (Shoemaker 1977, p. 106).

Linear programming (or LP) is a very powerful optimization tool because it can be used for systems with a very large number of variables. Solutions can be obtained for different objective functions and sensitivity of the solution to one or the other variable can be investigated. Its major limitation is that it is only suitable for models with constraints and criterion functions that are linear. Another disadvantage of LP is that it is not applicable if the relationships among variables are stochastic.

It may be mentioned that even if some of the conditions presumed in applying LP are not satisfied by a particular problem, we can still attempt to use it as a first approximation. If some components of the problem exhibit random behaviour, we may substitute averages for these components. Nonlinear behaviour among components can be approximated with suitable linear relationship.

The Doon valley system includes several relationships which involve estimating economic externalities in quantitative terms. These are difficult to measure even roughly as these are characterised by market failure and, hence, absence of relevant economic information (Heller & Starrett 1976, p.10). There are several ecological relationships such as between forest cover and flood control or reduction in atmospheric pollution which are equally difficult to quantify. Estimation of the coefficients representing these relationships within a reasonable range of error will be the most formidable task in developing the management model for the Doon valley ecosystem. Using complicated techniques such as dynamic programming or input-output procedure for solving a model with very rough equations is not likely to provide better solutions. Therefore, developing a robust model should be the priority and using a simpler method of solving it might be a suitable approach to begin with.

The relationships among variables in the ecosystem have to be determined and expressed in the form of linear mathematical equations. For instance, linear equations could be developed for the possible impacts of forests on various activities as pointed out in Table 1 of the previous section. Similar interlinkages will exist for other resources *vis-a-vis* economic activities in the Doon valley. These will have to be specified and quantified appropriately. In addition, we shall have to identify our objective function (i.e., the function being maximized or minimized) and a set of constraints to which it is subject.

The constraints will be of physical, economic or political nature. Some will be of the form such as: (i) the sum of the land area under different land-use should not exceed the total area of the Doon valley; (ii) the area under forest should exceed certain minimum such as prescribed by the National Forest Policy; or (iii) the amount of forest within a certain distance from villages be no less than that required to meet their fuelwood, grazing and timber needs, etc. In general, the constraints will be such as to ensure that the ecological status of the valley does not become unacceptable.

The objective function can be of various forms, depending on the choice of the policy makers. Some of the possible objective functions can be: (i) maximize the total human population of the Doon valley so as to define the carrying capacity of the region beyond which the ecology of the valley will deteriorate for the given level of technology; (ii) the total income of the valley residents be maximized; (iii) introduce income distribution aspect by treating rural and urban categories of population separately and maximize a weighted average of income earned by the two kinds of population; or (iv) the net value of the produce of the valley be maximized.

Different scenarios can be used to simulate the impact of different objective functions and parameters. The final policy decision can be taken on the basis of the results provided by the model above, subject to various assumptions and approximations made in the process of its formulation.

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HUMAN-ACTIVITY MODELING OF DOON VALLEY FOR EXPLORING ADJUSTMENT STRATEGIES

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In a systems modeling approach, the Doon Valley needs to be characterized in such a way that all the dynamic variables are captured. Static parameters such as area and location provide a frame of reference. Dynamic variables, e.g., population growth, could be policy-dependent or policy-independent. The interdependence of the dynamic variables needs to be examined first.

Figure 1 illustrates major activites in the Doon Valley. Every activity has its resource requirements and environmental implications. There are policies that need to be considered, some of which are aimed directly at resource utilization, some at the activities themselves (e.g., industrial policies) and some at the environmental effects (e.g., pollution monitoring).

Instead of discussing all the activities and resources, the example of energy will be described in detail. It should be mentioned that a similar approach has been tried for Bangladesh successfully and therefore, a skeleton framework exists, although it needs to be modified a great deal for the Doon Valley. Figure 2 illustrates the components involved.

Deforestation is a symptom caused by many activities, *only one* of which is fuelwood gathering. To that extent, alternative energy supply becomes relevant. In particular, the fuelwood problem which is related to the energy question, needs to be examined in this light. In rural areas, biomass is used for food, feed, fuel and fertilisers. Thus, the biom ass and energy flows are essential for characterization of Doon Valley. Energy balances for the Doon Valley need to be worked out to show the structure of energy consumption for different purposes and different energy supplies. The flow of energy is given in Figure 2, but numerical values need to be obtained for each box.

The rural population of India gets 90% of its energy from biomass-based sources, i.e., fuelwood, agricultural waste and animal dung. Biomass resources are under severe stress because of the conflicting demands for food, fuel, fodder and fertilizers.

Different income groups have different energy consumption patterns. Energy flows for the Doon Valley need to be identified for yet another reason. This is for estimating air pollutant emissions. A schematic Figure 3 illustrates various end uses and typical energy sources that could be used for those end uses. Actual values for this will need to be worked out. In this connection, it is important to separate the requirements of the local population from those of the tourists.

Linear programming approach will be developed which is based on resource requirements for different socio-economic activities and consequent environmental impacts. For example, the resources required for each activity listed in Figure 1 require certain land, energy, labor, capital, etc. Each of them also has pollution impacts which could be quantified to some extent. The objective function of maximization of income-generation with a number of resources and other constraints, including minimization of pollution, could characterise development objectives of Doon Valley. Since all the uses of biomass are included, carrying capacity of Doon Valley will be one of the natural outcomes of this model, not in a static, but in a dynamic sense where adjustment mechanisms could be explored.

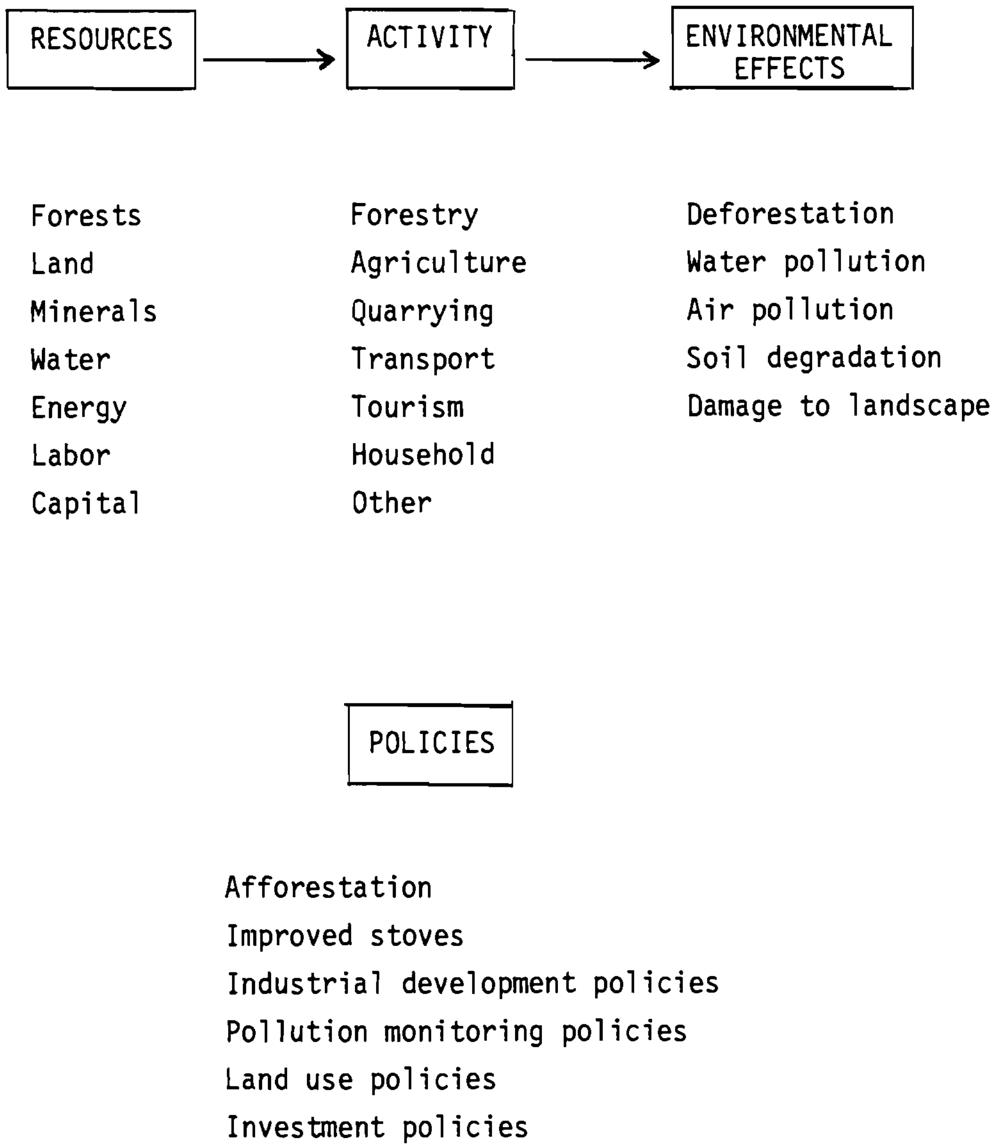

Figure 1 Activity-oriented systems modeling for Doon Valley

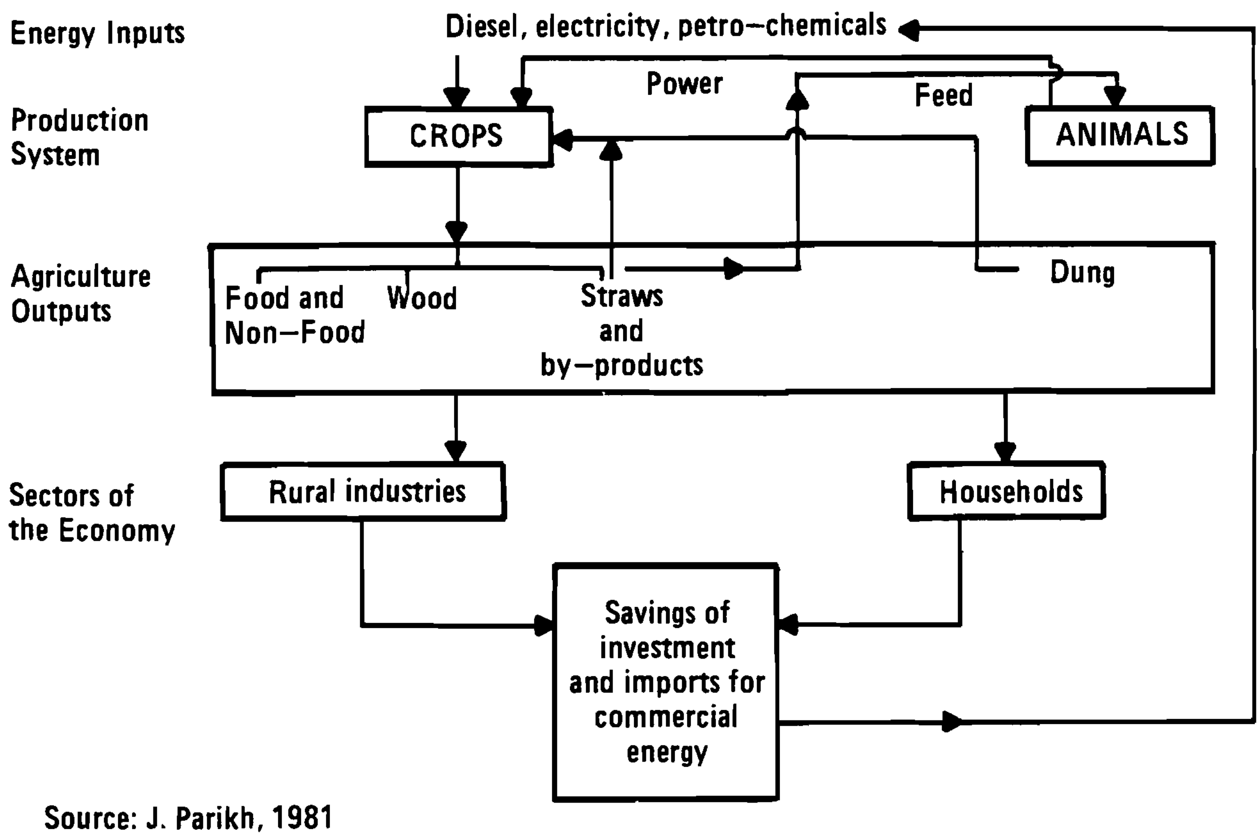

Figure 2 Biomass and energy flows in rural economy

	Fuelwood	Animal Dung	Agricul. Waste	Oil Products	Electricity
Households					
Cooking	x	x	x	x	
Lighting				x	x
Heating	x	x	x		x
Hot water	x	x	x		x
Industries					
Quarrying					x
Lime kilns	x			x	
Other					
Transport					
Trucks				x	
Cars					
Auto rickshaw/ scooter				x	
Agriculture					
Machinery					
Irrigation pumps				x	x

Note: The needs of tourists and local population could be separated if the data is available.

Figure 3 Energy flows in Doon Valley

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