Consultative Group on International Agricultural Research

Technical Advisory Committee

Priorities and Strategies for Soil and Water Aspects of Natural Resources Management Research in the CGIAR

TAC SECRETARIAT

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

This document comprises:

(a) Extract from "Summary of Proceedings and Decisions", CGIAR Mid-Term Meeting 1996, Jakarta, Indonesia

(b) Letter from TAC Chairman transmitting the Report on Priorities and Strategies for Soil and Water Aspects of Natural Resources Management in the CGIAR

(c) Report on Priorities and Strategies for Soil and Water Aspects of Natural Resources Management in the CGIAR

and two background documents:

(i) Report on a Strategic Review of Natural Resources Management Research on Soil and Water

(ii) Report on a Synthesis of Current Activities in Soil and Water Research in the CGIAR

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June 1997

From: The Secretariat July 1996

CGIAR Mid-Term Meeting
May 20-24, 1996
Jakarta, Indonesia

Soil and Water Aspects of Natural Resources Management Research[1]

Participating Members felt that, given the fundamental importance of research on soil and water, a much greater sense of urgency was needed and warranted than was presented in the TAC study. It was also felt that this area of research should be given greater visibility in TAC's priorities and strategies document than at present. The impact on the environment was considered a central issue, which should be taken into greater consideration.

The move toward an integrated natural resources management framework for research was endorsed and the linkages involved were recognized. It was felt that the linkages between research and diffusion or adoptoin of results should receive greater attention. Participants agreed on the need for more research on the constraints and incentives which affect adoption of sustainable development technologies by farmers. The study noted that, where there has been evidence of success, effective local organizations have participated. The location specificity issue was raised, and it was agreed that, as the study recommended, forthcoming research should be more universal and generally applicable.

1 Extract from "Summary of Proceedings and Decisions - Report on Parallel Session I", CGIAR Mid-Term Meeting 1996, Jakarta, Indonesia.

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SDR/TAC:IAR/96/2.1

CONSULTATIVE GROUP ON INTERNATIONAL AGRICULTURAL RESEARCH

TECHNICAL ADVISORY COMMITTEE

PRIORITIES AND STRATEGIES FOR SOIL AND WATER ASPECTS OF NATURAL RESOURCES MANAGEMENT RESEARCH IN THE CGIAR

TAC SECRETARIAT

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

April 1996

CONSULTATIVE GROUP ON INTERNATIONAL AGRICULTURAL RESEARCH

TECHNICAL ADVISORY COMMITTEE

Donald L. Winkelmann
Chair

15 April 1995

Dear Mr. Serageldin,

I am pleased to submit to you the report of TAC's study on Priorities and Strategies for Soil and Water aspects of Natural Resources Management Research in the CGIAR. The report is supported by two background documents prepared in the course of the study: *A Strategic Review of Natural Resources Management Research on Soil and Water (SDR/TAC:IAR/96/9);* and *A Synthesis of Current Activities in Soil and Water Research in the CGIAR (SDR/TAC:IAR/96/10).* You will recall that the draft versions of all these three reports were made available to the Group at ICW'95 but discussion was deferred until MTM'96.

This study was requested by the Group at MTM'94 in New Delhi in the light of the changing priorities of the CGIAR on natural resources management research. You will recall that at that meeting, the Group discussed its follow-up to Agenda 21 of UNCED, as well as a number of issues related to biodiversity and genetic resources. Consequently, the scope of the attached study was limited to the soil and water aspects of natural resources management research.

In the conclusions of the study, TAC reconfirms that the strengthening and expansion of natural resources management research, and the linking of it with productivity improvement, poverty alleviation and protection of the environment, are essential components in the implementation of the new vision for the CGIAR developed at the Lucerne meeting. TAC concludes that such research should be undertaken using an integrated natural resources management approach, and recommends various criteria for assessing the relative importance of new proposals to strengthen or expand natural resources management research in the System.

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An early draft of the attached report was discussed by TAC at TAC 67 in July 1995 and was subsequently circulated to Centre Directors as well as to a number of non-CGIAR centres active in the field of soil and water management. Many useful comments wereeceived and, to extent possible, have been incorporated in the attached revised draft, which was also discussed by TAC at TAC 69 in March 1996. The study also benefitted from the work of the CGIAR Task Forces on Sustainable Agriculture and on Ecoregional Approaches to Research. TAC was also pleased by the excellent collaboration it had with the leaders of the Soil, Water and Nutrient Management Programme throughout the process of conducting this study. I would like, on behalf of the Committee, to express sincere appreciation for the support received from all those collaborators.

I commend the report to you and to the Group. The views of the Group will be taken carefully into account in finalizing the recommendations on future strategic directions of the CGIAR's work in this area.

I would like to express sincere thanks to Drs. Hans Gregersen and Ted Henzell who served, on behalf of TAC, as co-convenors and organizers of this study. They also served as the principal drafters of the report. The two supporting documents were prepared by a number of consultants in collaboration with the TAC Secretariat. Their names are listed in the report and we gratefully acknowledge their important contributions. Finally, this study could not have been conducted without the excellent support of the TAC Secretariat, which is greatly appreciated.

Sincerely yours,

Donald L. Winkelmann

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PREFACE

This study was initiated at TAC 65 in October 1994 in Washington, with a discussion of a study proposal. The Committee decided that the study should be TAC-led, and appointed two TAC members, Drs. Hans Gregersen and Ted Henzell, as co-convenors for the conduct of the study. At TAC 66 in March 1995 in Lima, the Committee discussed a framework paper prepared by the co-convenors in collaboration with the TAC Secretariat, to guide the study and endorsed its terms of reference. The TAC Secretariat subsequently recruited six consultants (Drs. Inder Abrol, Walter Couto, Malin Falkenmark, Dennis Greenland, Fredrick Muchena and Norman Uphoff) to write background papers on specific themes, which were subsequently integrated in a review paper by two further consultants, Drs. Bernard Tinker and Jock Anderson. Another consultant, Dr. Filemon Torres, compiled the information on relevant Centre activities.

A meeting, attended by the co-convenors and five of the consultants, was held in Rome from 14-16 June 1995 to discuss the background and synthesis papers. The outcome of the meeting led to the preparation of an early draft of the attached report, which was considered by TAC at TAC 67 in July 1995. Subsequently, the draft report and the two annexes were distributed for comments to CGIAR Centre Directors, FAO, the Directors of IBSRAM, IFDC and TSBF and several resource persons. The comments received were incorporated in the next revised draft, which was made available to the Group at ICW'95, and was discussed by TAC at TAC 68 in December 1995. Subsequently, the draft report was finalized and considered by TAC at TAC 69 in March 1996.

The CGIAR Centres, FAO and other international organizations working in the field of soil and water research cooperated fully during the course of this study. In particular, there was constant interchange of ideas between the co-convenors and the leaders of the Soil, Water, and Nutrient Management (SWMN) Programme -- in Zschortau in September 1994; in Rome in December 1994; in Nairobi in May 1995, and in Feldafing and Rome in June 1995. Also, despite the short time available, Centres made a major effort to provide the information requested on current CGIAR activities on soil and water research. Further, the co-convenors were in close contact with the CGIAR Task Forces on Sustainable Agriculture and on Ecoregional Approaches to Research.

While this report reflects the views of TAC, Drs. Hans Gregersen and Ted Henzell were principally responsible for preparing its main body. Drs. Bernard Tinker and Jock Anderson prepared the background document *A Strategic Review of Natural Resources Management Research on Soil and Water (SDR/TAC:IAR/96/9)*, drawing on the work of the other consultants. Dr. Filemon Torres was responsible for preparing the background document *A Synthesis of Current Activities in Soil and Water Research in the CGIAR (SDR/TAC:IAR/96/10)*. Dr. Amir Kassam served as resource person from the TAC Secretariat. The composition of the study group is provided in Annex II.

Jennifer Parise and Ann Drummond were responsible for coordination and preparation of successive manuscripts, and together with Marioara Lantini and Irmi Braun of the TAC Secretariat, provided logistical support to the study.

Guido Gryseels
Officer-in-Charge
TAC Secretariat

SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

This paper presents TAC's conclusions concerning the needs for the soil and water aspects of natural resources management research in the System and the mechanisms for meeting them. These conclusions are based on background studies carried out by an independent panel and the TAC Secretariat, and on TAC's own deliberations during TAC 66, 67 and 68. The background studies are available as separate documents.[1,2] This draft has been commented on several times by CGIAR Members, Centres, NARS and other partners. It represents the evolution of thinking over the past two years.

Objectives and Scope

The linked objectives of sustainable food security, alleviation of poverty and protection of the environment are the overarching concerns of the CGIAR, as indicated and reconfirmed at the Lucerne Ministerial-Level meeting.[3] Within the context of these concerns, the CGIAR System needs to address a broad set of priority issues related to natural resources management and sustainable development.

The focus of the study is on the soil and water aspects of natural resources management (NRM) research in the CGIAR System. TAC fully recognizes that there are other, equally important natural resources and resources management subjects covered within the System, such as forests and forestry, fish and fisheries, and genetic resources. However, these have been the subject of separate, thorough reviews, fairly recently in the System. Thus, TAC decided to focus the present study on research related to soil and water aspects of natural resources management, bringing in the other topics as needed to clarify various linkages. It is emphasized that the absence of discussion of these other topics does in no way imply that TAC sees these subjects as being of lesser importance than soil and water.

Current Soil and Water Research in the CGIAR System

Part of the overall TAC study involved an assessment of the extent and objectives of current work on soil and water aspects of natural resources management research in the CGIAR System. A separate TAC Secretariat desk study[2] provides the detailed results. Keeping in mind that some arbitrary decisions had to be made when classifying various types of research in terms of contributions to NRM objectives, highlights are as follows:

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1 TAC (1995a). *A Strategic Review of Natural Resources Management Research in Soil and Water.* Document SDR/TAC:IAR/96/9, TAC Secretariat, FAO, Rome.

2 TAC (1995b). *A Synthesis of Current Activities in Soil and Water Research in the CGIAR.* Document SDR/TAC:IAR/96/10, TAC Secretariat, FAO, Rome.

3 CGIAR (1995). *A Vision for the CGIAR: Sustainable Agriculture for a Food Secure World.* Ministerial-Level Meeting on Renewal of the CGIAR: Sustainable Agriculture for Food Security in Developing Countries, Lucerne, Switzerland, February 1995. CGIAR Secretariat, World Bank, Washington.

- The CGIAR System is allocating about US$ 49 million, or a little over one sixth of its total resources, to soils and water (S&W) research.

- The proportion of budget allocated by different Centres to S&W research ranges from 5 to 40 percent.

- Over one third (35-40%) of the total CGIAR investment in S&W research is directed towards irrigated lands and rainfed lowlands, which could be seen as proxies for well-endowed lands. The so-called "fragile" or "marginal" lands, the warm semi-arid, savannas and forest margins, each account for around 15 percent of the resources, while the cool semi-arid, highlands and hillsides each account for one twentieth of the total. The rest goes into policy and other research that cannot be attributed easily to any given ecosystem.

- On average Centres devote about three-quarters of their S&W efforts to on-site research. Furthermore, much of the rest appears to be devoted to policy and management research related to natural resources. This implies that very little research is done on the off-site, or landscape linkages, an important component of integrated natural resource management research.

- On average Centres allocate some two-thirds of their S&W budget to research of an applied nature, with a range between 50 and 90 percent. This allocation, taken together with the previous conclusion, suggests a strong concentration of research efforts on location-specific, production systems oriented activities. CGIAR Centres should be working on research of an international nature, i.e., results that have transferability across nations. Many Centres recognize that to meet this requirement when dealing with location-specific research, it is necessary to do comparative research across locations. The extent to which they explicitly build this into their programmes is not at all clear from the data at hand.

TAC's Conclusions and Recommendations

In an overall context, TAC reconfirms that strengthening research on natural resources management (NRM) and environmental issues is needed in the CGIAR, as is a more explicit linking of this area of research to the Lucerne "vision" of the CGIAR contribution to poverty alleviation and sustainable food security. This reconfirmation and recognition of the Lucerne Declaration has certain implications for the scope and orientation of natural resources management research in the System. These implications and the associated conclusions that TAC reaches regarding this area of research, need to be stated clearly at the outset of this discussion.

The System should, with few exceptions, be doing NRM-related environmental research that is clearly identified with the impacts of agriculture, forestry and fisheries on sustainable poverty alleviation and food security. That should be a necessary condition for undertaking NRM research in the System. It derives from the obvious fact that priority should be given to research directly related to the mission and goals of the System.

Since sustainable food security and poverty alleviation - whether for the rural or urban poor - depend directly on the health of the environment and the natural resource base on which all food production depends, their conservation and enhancement serve as central and legitimate themes for CGIAR research.

Both on-site and off-site efforts are a legitimate part of the System's responsibility. Firstly, the off-site efforts of one area used for agriculture, forestry or fisheries can impact on downstream areas used for the same purposes.[4] Secondly, the sometimes damaging effects of agriculture, forestry and fisheries on those who use land and water for other purposes downstream, can cause restrictions to be placed on the use of land for food and wood production. This has happened in industrialized countries and is likely to happen in developing countries, especially with increased urbanization.

The above should be the necessary conditions for the CGIAR undertaking NRM research.

There are other goals for research on natural resources and the environment, e.g. ecosystem health for its own sake or some broader purpose, recreation, aesthetics, global climate change, wildlife management and so on. While there are significant alternative suppliers with competitive advantage when it comes to research for these purposes, it is very desirable for the CGIAR's research to take account of these other aspects of the environment. Research designed for the necessary purposes of the CGIAR can yield results that will assist in achieving other environmental objectives.[5] Every effort should be made to create such win-win situations or at least to minimize trade-offs between agriculture, forestry and fisheries and those other environmental and natural resource values. Such adjustments should, of course, consider the extra costs.

Conclusion: There is a need to improve the state of information on land and water degradation and its impacts on agricultural, forestry and fisheries production

TAC agrees with a variety of experts (cf. Crosson and Anderson 1993[6]) that there is a serious, widespread problem of lack of adequate information on land and water degradation and the state of the environment, and knowledge of the impacts of environmental change (both degradation and enhancement) on crop production, particularly over time. Arguments regarding the seriousness of the problems abound among reputable groups. The arguments arise almost entirely because of deficiencies in basic data and because of differences in interpretations of the scarce data that are available.

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4 Note the point that the downstream impacts of agriculture may lead to significant impacts on upstream agriculture as well as downstream agriculture, e.g., when the downstream effects on people are such that action is taken to curb certain agricultural practices upstream.

5 Examples include: biological control undertaken primarily because of the rising costs of chemical control with increasing resistance, but benefiting also farmer health and the environment; trees grown on farms for food, wood, and forage, but helping to control erosion and, if native species, helping also to conserve biodiversity.

6 Crosson, P. and J.R. Anderson (1993). *Concerns for Sustainability: Integration of Natural Resources and Environmental Issues in the Research Agendas of the NARS.* ISNAR Research Report No.4, ISNAR, The Hague.

Given the need for transnational information and research on the condition of natural resources and the environment, and particularly on the extent and impact of degradation and enhancement of the environment by humans, TAC believes that there is a critical role for the CGIAR System to play in developing a better understanding of some of the linkages between agriculture, forestry and fisheries and the condition of the environment and the natural resources base on which all agriculture depends.

At the same time, it is recognized that the CGIAR System has only a limited role to play in this field, since there are many actors involved, some of whom are much better placed to generate and analyze the necessary data. Since the CGIAR has only limited resources to devote to filling information gaps, it needs to choose carefully what aspects of this momentous task it undertakes. Its focus should be primarily on generating the evidence on the impacts of natural resources degradation or enhancement on future agricultural, forestry and fisheries production and vice versa (see p. 23).

> ***Recommendation 1:*** The CGIAR System should develop improved mechanism(s) by which Centres, collectively, can be involved with other partners in generating and interpreting improved scientific evidence on the extent and magnitude of the impacts of agriculture, forestry and fisheries on the degradation or enhancement of natural resources and the impacts of such degradation or enhancement on agriculture, forestry and fisheries production and food security.

Conclusion: The CGIAR System has Need for an Integrated Natural Resources Management (INRM) Framework for Research

TAC concludes that the CGIAR System could benefit from the introduction of a more consistent, systematic, and environmentally sensitive integrated natural resources management (INRM) framework for research. This framework would serve two main purposes. One is to provide a logical framework for linking the various natural resources management activities in the System. The other is to provide a better means of showing the rest of the world how the System is addressing the interrelated set of environmental and natural resources issues that are of concern when moving towards sustainable agricultural, forestry and fisheries production. Such a framework would involve four sets of interrelated linkages:

- Links between productivity-enhancing and resource conserving research (e.g., crop improvement and natural resources management);
- Spatial or landscape level linkages (e.g., upstream-downstream linkages in a watershed management framework);
- Temporal linkages (e.g., links between present and future, or sustainability considerations);
- Linkages between research and the diffusion/adoption of results from such research.

TAC re-emphasizes that research within this INRM framework incorporates a broad spectrum of disciplines and activities outside the soil and water focus of this study, including those related to forestry, fisheries and genetic resources. These other areas of activity are fully as important and critical to the successful use of an INRM framework as an integrating tool. Thus, they will need to be incorporated into a more operational INRM framework and approach. One example of an INRM framework focusing on the spatial (watershed) linkages is provided by an integrated watershed management framework (see Annex I).

Conclusion: Within the INRM Framework There is Need for Additional Focus on Specific Subject Matter

TAC concludes that most of the areas of research within the INRM framework that are relevant for the CGIAR System already are being dealt with to some extent in the System, but in many cases not adequately in terms of scope and/or quality, nor in terms of the environmental aspects of the four sets of linkages described above (again, note the high proportion of CGIAR resources in natural resources management that is apparently devoted to on-site, on-field research).

TAC emphasizes that the linkages covered within the INRM framework need to be introduced into the CGIAR System not only through Centre activities, but also to a great extent through work in the Systemwide Programmes, essentially those that implement the ecoregional approach. These include the emerging Water Programme and the existing Soil, Water, Nutrient Management (SWNM) Programme, which provide an important means to introduce INRM considerations in a systematic way into the ecoregional approaches to research.[7] The INRM framework is mainly an integrating mechanism that helps to develop full coverage of natural resources management issues and full sensitivity to environmental externalities and linkages.

Water is one area of focus that particularly needs much greater emphasis within an INRM framework. TAC considers water-related issues, including waterborne diseases, to be some of the key ones that will face agriculture, forestry and fisheries even more pressingly in the future. Thus, TAC concludes that water-related research is a priority area in which the System's scope and intensity of work should be significantly expanded, particularly related to water scarcity and competition, and water quality, but also in terms of the broader watershed management activities needed to optimize water availability and use. There is need for greater capacity in hydrology to complement the existing work on water-soil relationships, allocation and distribution of irrigation water, and the role of alternative water users associations and management schemes.

In fact, such expanded work currently is being proposed in the Systemwide Water Programme being organized by IIMI with partners from within and outside the CGIAR System. Whether that initiative alone can cover the needed expansion adequately - both in terms of magnitude, breadth, and quality - remains to be seen. It still is in a very early stage of development. TAC will continue to strongly encourage, support, and monitor such work, recognizing the increased need to understand the various linkages (both ways) between water and agriculture, forestry and fisheries.

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7 Note that the water focus in the SWNM Programme is on water-soil relations, while in the Water Programme, the focus is on broader issues related to water use, competition for water, water allocation, and so forth. There likely will be some, hopefully complementary, overlaps between the two Programmes.

Furthermore, the System and its relevant Centres need to focus on the international aspects of the water-related issues and to provide leadership in developing effective processes for researching, assessing and solving water-related issues. The System needs to build on the work of its partners in research and development. In order to carry out this work, there is need for an increased number of hydrologist/watershed management researchers.

A number of other research priorities (only some of which can and will be covered by CGIAR Centres) have been identified within the context of the four INRM linkages discussed above. They are mentioned below, although not all of them will be undertaken by CGIAR Centres.

In terms of linkages between **productivity-enhancing and resources conserving research** the following topics seem particularly relevant:

- managing water and nutrient supplies for greater efficiency and sustainability; research on the efficiency of water and nutrient use by crops, especially to prevent degradation of irrigated land; both economic and biophysical efficiency should be considered;

- research on the processes underlying the long-term, less obvious forms of soil and water degradation. (This will complement existing production-oriented CGIAR soils research);

- managing soil fertility (organic matter, mineral nutrients, acidity).

In the case of **spatial or landscape linkages**, the key areas include research on:

- the pros and cons of devolution of NRM responsibilities to local government bodies and user groups;

- the physical, economic and social impacts of agriculture, forestry and aquaculture production practices on the quality and quantity of downstream water supplies and on assemblages of aquatic organisms in downstream and upstream water bodies;

- development of acceptable methods for combatting soil erosion (mainly associated with its off-site impact on environment);

TAC also advocates a greater use of the interdisciplinary and systems approaches (including mathematical modelling) in developing research within the INRM framework, and it suggests the need for development of a limited number of carefully selected watershed or catchment studies that can serve as baseline studies within the ecoregional approaches developed by centres and their partners.

In the case of **temporal linkages**, the key area for research is:

- measurement of the rates of change in key dimensions of natural resources (the dynamics of resources management, use, enhancement and degradation); and research on the impacts of such changes on food and water security; and on health.

This work is particularly critical, given the conclusion above concerning the state of knowledge and understanding of the impacts of agriculture on natural resources and the environment and the impacts of land and water degradation on overall agricultural production. (see Recommendation 1 above).

In the case of **linkages between research and diffusion/adoption**, the key area for research is:

- the reason why existing information has not been used more effectively to improve natural resources management practices, for instance in the move from shifting to permanent cultivation; also, research on how to get more effective implementation of existing knowledge for improved INRM, i.e., research on cultural diffusion and adoption of research results already on the shelf, in the context of fostering a participatory approach to improving natural resources management.

TAC is concerned with the fact that there is a great deal of research-generated NRM information that is readily available but unused in practice at present (e.g., knowledge regarding soil conservation technologies and watershed management practices). Further, based on the assessments of the Study consultants and others, many of the past improvements in NRM can be related back to research that was carried out for other purposes. Thus, the links between research and action are weak in such cases.

There is need for increased research to look at why there is a lack of application of known technologies and ideas, why there is a lack of widespread progress in natural resources management using much of the available research-generated information and technologies. This is a promising, potential area of significant gains. TAC believes that there is opportunity for the CGIAR to expand its activity in this area, particularly looking at the NRM technologies and ideas generated in its own Centres, but also at related knowledge developed by its partners. The kinds of research questions which appear to have promise include ones such as: Was the research undertaken in isolation of the needs and incentives of potential beneficiaries? Were the costs of diffusion, adaptation and adoption ignored or underestimated? To what extent were issues of diffusion and adoption ignored? Have the research results not been adequately translated into practical language that is understood by the potential users? Why is it in areas of success, that it appears that strong local organizations are one key factor in effective transfer and utilization. How can existing knowledge and technologies be used more effectively and efficiently to generate gains in terms of natural resources management and conservation? (see p. 24).

> ***Recommendation 2***: TAC recommends that intensified and expanded collaborative mechanisms and activities be developed among Centres, and between Centres and their non-CGIAR partners, to help focus increased research and institution strengthening on issues related to adoption, adaptation, and utilization of existing NRM technologies and knowledge that so far have remained unused.

Again, the above recommendation needs to be focused on a few, well-developed areas in which the CGIAR has an advantage. This recommendation should be implemented through a coordinated effort of the Centres, based on their own ongoing, individual programmes in this area. It is an activity that should become part of every research programme and centre's activities, where it is not already so. TAC does not envision it as a formal Systemwide Initiative but as a reallocation of resources into areas of higher priority.

Conclusion: There is a Need for Uniform and Consistent Criteria for Judging the Priorities for NRM activities/research in the CGIAR Centres and Programmes

TAC considered various criteria for assessing the relative importance of the proposals to strengthen or expand INRM research in the System. TAC recognized that the criteria or factors involved also could be used to look at the desirability for continuing current programmes.

TAC concludes that at least four factors, described in section 4.1, should be considered by those preparing proposals and in judging the relative importance of new research themes. More specifically, priority activities should:

1. Make an identifiable contribution to poverty alleviation and environmental protection or enhancement;
2. Be results-oriented and utilization focused (demand-driven with high probability of use);
3. Make optimum use of existing information and fill knowledge gaps;
4. Build on the CGIAR's international advantages.

TAC also considered various criteria for judging the usefulness of alternative modes of operation for implementing INRM research (see section 4.2). It concluded that seven such factors should be considered in choosing among options:

1. Degree and effectiveness of collaboration with others;
2. Cost-effectiveness/value added of the option;
3. Extent to which stakeholders' interests are considered in defining problems and planning research;
4. Clarify for communicating the importance of the research to CGIAR members and others;
5. Continuity of funding/support;
6. Ease with which acceptable lines of accountability can be established;
7. Standards of planning, monitoring and evaluation proposed.

The above criteria for judging importance and for choosing among operational modes are fully consistent with those that have been adopted for use in the broader TAC Priorities and Strategies exercise related to Systemwide Initiatives and Programmes. In fact, they have evolved from TAC's experience in assessing future funding of the NRM components of Systemwide Initiatives and Programmes, including those based on the ecoregional approach.

1. Introduction and Background

Sustainable food security through the alleviation of poverty and protection of the environment are the overarching concerns of the CGIAR (see *A Vision for the CGIAR: Sustainable Agriculture for Food Secure World.* Ministerial-level Meeting, Lucerne, February 1995). The CGIAR traditionally has contributed to poverty alleviation by focusing on agricultural productivity enhancement, which can directly and indirectly contribute to creating food security for the poor.

In pursuit of this research, the System has considered the natural resources base, but mainly in terms of on-site interactions at the field level. This work is essential to success in developing sustainable agriculture, although increasingly much of it can be done by NARS partners. At the same time, however, research related to environment and natural resources needs to be strengthened, particularly in terms of the off-site impacts of agriculture on the environment and environmental constraints to agriculture due to natural resources degradation.

This study considers existing natural resources management (NRM) research in the System as a baseline for assessing what new, promising areas need to be considered, and how the different NRM research activities in the System might be adjusted and better linked and coordinated. Different approaches currently are being proposed and implemented. The cost-effectiveness and rationale for the different approaches have not been adequately assessed, nor has the potential effectiveness of their proposed forms of interaction. Thus, a number of questions remain, e.g., how do the Systemwide initiatives based on the ecoregional approach relate to the new Soil, Water, Nutrient Management Systemwide Initiative? Are systemwide, disciplinary focused consortia the way to organize natural resources management related research in the System? To what extent does the System now cover the key priority topics that need to be addressed? How should the System relate to other international centres, national research groups in developed countries, and NARS in the area of natural resources management research?

1.1. Scope and Limitations

The CGIAR System fairly recently has studied in some depth certain of the relevant natural resources management issues associated with the CGIAR System, including those related to forestry, agroforestry, fisheries, and most recently conservation of genetic resources in the System.[8] Thus, TAC decided to focus the present study on soil and water aspects of natural resources management, bringing other topics mentioned above into the present study only as needed to emphasize various linkages with the central focus of the study.

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8 *Report of the TAC Panel on Fisheries Research.* TAC Secretariat, 1990. FAO, Rome.
Report of the TAC Panel on Forestry Research. TAC Secretariat, 1990. FAO, Rome.
Expansion of the CGIAR System. TAC Secretariat, 1992. FAO, Rome.
Review of CGIAR Priorities and Strategies. TAC Secretariat, 1994. FAO, Rome.
Stripe Study of Genetic Resources in the CGIAR. TAC Secretariat, 1994. FAO, Rome.

The study has two further components. First, a review paper on the subject of natural resources management research (from both biophysical and socioeconomic perspectives) was prepared by outside consultants (TAC 1995a, op. cit). Second, an inventory of ongoing work in the CGIAR Centres was undertaken (TAC 1995b, op. cit). The background documents (available separately) provided a significant input into this overview "priorities and strategies" paper.

It should be noted that TAC is discussing in this paper research to support improved natural resources management, not just research *on how to manage* those resources, although management research is part of the total package required.[9] Thus, also of relevance is traditional soils research, research on terrestrial and aquatic biodiversity, policy and economics research, plant protection, pest management research, and so forth. Moreover, natural resources such as water should be seen not just as production factors or commodities, but also as living environments and habitats (see section 2.3.1.).

It should also be noted that the concept of an *integrated natural resources management* (INRM) framework, introduced in a later section, is just that—a framework within which one can identify and link the specific research on soils, water, flora, fauna, policy and so forth, needed to guide improved management of land use units, which may be watersheds, farms or fields, or other defined units. The framework provides a linking mechanism, and a mechanism for ordering and prioritizing research, not a research paradigm as such.

Specific catchment area studies carried out by hydrologists fit within an INRM or watershed management framework, in the same way that IPM, irrigation management, soil conservation, watershed management, fit within the framework.

As an additional point, it should be noted that a parallel concept lies behind the TAC's use of the ecoregional approach to research. The term *ecoregional research* is not used. Rather the concept of *approach* refers to research that supports alleviation of poverty, food security, and environmental protection within specific agroecologies regionally defined (Gryseels and Kassam 1994).[10] Thus, the ecoregional concept provides a framework within which to organize research for a given region that has sufficiently homogeneous agroecological characteristics.

1.2. Justification

There is an increased awareness of the need to pursue more sustainable, less environmentally damaging development. This need is particularly relevant and important

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9 TAC uses the term "management research" in the more practical sense of management being a means to an end, or the process of "doing things".

10 Gryseels, G. and A. Kassam (1994). *Characterization and implementation of the CGIAR ecoregional concept.* Paper prepared for the IFPRI Ecoregional/2020 Vision Workshop, 7-9 November, 1994, Airlie Conference Centre, Virginia, U.S.A.

for agriculture, which is widely believed to be a major source of land and water degradation in developing countries. There is ample visual evidence of the impacts of slash and burn farming on tropical deforestation, and of deterioration due to overstocking of a significant portion of the world's grazing lands (which has exposed their soils to the danger of increased rates of wind and water erosion).

Agricultural impact on water supplies

About 70 percent of water withdrawals worldwide is by agriculture. In both Asia and Africa, it is over 85 percent (World Resources Institute, 1994. World Resources, 1994-95).

The off-site or downstream effects of developing country agriculture have not been measured adequately, though it is known from research in developed countries that they may be more costly and serious than on-site effects. One of the major downstream effects is on the adequacy and safety of household water supplies. About one billion of the world's people already are without clean drinking water. Millions of children die in their early years from waterborne diseases.

Another source of concern about current agricultural practices is the growing evidence from field experiments of trends in the condition of soil and water resources that, if not controlled or reversed, are likely to have a higher cost in the future. Many cultivated soils are becoming increasingly deficient in essential plant nutrients from cropping for decades without replenishment, and their physical condition has deteriorated. The declining quantity and quality of water resources, and waterborne diseases, in many parts of the world are an important issue for irrigated agriculture. For example, deteriorating water quality is now an issue for some of the most productive rice-growing areas of Asia. Fisheries also suffer through loss of aquatic productivity due to habitat modification and pollution, and the negative impact of irrigation on human diseases and health has become a source of concern in all developing regions.

At the same time, agricultural output is itself impacted significantly by land and water degradation and deterioration of watersheds protecting agricultural investments such as irrigation systems, e.g., through erosion that leads to silting up of irrigation reservoirs, loss of topsoil and nutrients, inadequate water supplies through drawdown of groundwater by other users, flooding due to misuse of land upstream, salinization, etc. The CGIAR System has been addressing some of these issues more intensively in more recent years. It also has broadened out to include natural resources issues related to forestry and fisheries, as well as increased emphasis on conservation of genetic resources. Many of the positive impacts of the System's research on the sustainability of development and the protection of the environment have been significant (see box), but have not been adequately communicated to the global community.

Surprisingly, although these symptoms of soil and water degradation have been apparent and well publicised for some time past, there is remarkably little hard evidence that such degradation has had any major effect on global food production so far. At least, the losses from natural resources degradation appear to have been greatly outweighed by gains from technological innovation and increased use of inputs such as fertilisers and irrigation water. Whether or not this will continue to be so into the next century, is difficult to say. The contradictions between the economic and biophysical evidence have to be of major concern for the CGIAR, with its focus on food security, and their resolution presents a major challenge to soil and water scientists working in and with the System (see Recommendation 1, p. 23).

At the same time, there is a growing feeling that the CGIAR Centres have not paid adequate attention to many of the problems that now are of central concern. Centres need to pay more explicit attention to natural resources management (NRM) and sustainability of the environment on which all agriculture, forestry and fisheries depend. This study provides a strategic view of why and how such increased emphasis might be given to NRM research in the CGIAR System.

CGIAR Contributions to Sustainability

Examples of the contributions of the CGIAR System's research to environmental protection and sustainability of development range far and wide. Some examples include the following:

* crop improvement on favourable sites has contributed to a reduction in the need to put fragile, marginal lands into production (in India an additional 40M ha. would have had to have been farmed in order to supply the same level of food supply);
* the System has been a major contributor to protection and conservation of genetic diversity;
* the centres have made an outstanding contribution to the knowledge base required to make agriculture more sustainable. The mechanisms underlying plant resistance to drought and to many pests and diseases are better understood.
* long term research has clarified rangeland dynamics, providing clear evidence that "desertification" is primarily related to climatic variability; people and livestock have little influence over such variability.

1.3. Previous Studies that have Recommended Soil and Water Aspects of NRM Research

Some aspects of NRM have been on the System's agenda from the very beginning. Water management and irrigation issues were discussed regularly by TAC from 1971 to 1978, and reports were prepared for the Committee, including one on the importance of waterlogging, salinity and sometimes alkalinity as constraints to irrigated crop production, and the other on plant nutrition and soil constraints. In 1979, TAC recommended to the Bellagio Group that water management research be supported if additional funding were to become available. With regard to plant nutrition and soil constraints, TAC recommended that Centres should pay more direct attention to research on soil fertility.

The broader subject of NRM has been under review in the CGIAR for at least ten years. It featured prominently in the review of CGIAR Priorities and Future Strategies presented to the Group in November 1985. Emphasis was placed on enhancing sustainable agriculture through natural resources conservation and management, and TAC recommended that the proportion of total CGIAR expenditure in this category be increased from 7% to 13%. A TAC paper dealing specifically with sustainability issues was published in 1988.

TAC's examination of NRM issues continued with the preparation in 1990 of a TAC Working Document (TAC 1990)[11]. While the primary purpose was to assess the programmes of the non-associated Centres IBSRAM, IFDC, IIMI, and ICRAF, the

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[11] TAC (1990). *The Role of the CGIAR in Natural Resource Conservation and Management.* TAC Secretariat. FAO, Rome.

document also listed some gaps and overlaps in NRM research in the CGIAR and the non-associated centres (NACs). Watershed management was identified as a topic neglected by both the CGIAR Centres and the NACs.

The TAC 1990 report on Expansion of the CGIAR also concluded that the past neglect of research on NRM must be addressed, and added that a high priority should be given to both technical and socioeconomic aspects of sustainability. There was a compelling case for strengthening both applied and strategic research on soil conservation and management in the System. Less attention seems to have been given in that study to water resource issues, except for irrigation management and aquatic resources management (IIMI and ICLARM became CGIAR Centres). Even then, the term irrigation management was used more narrowly than the term soil and water management.

Other important references to NRM in the Expansion Study included the identification of a lack of a clear global responsibility for strategic research on NRM as a shortcoming of the CGIAR. In addition, more intensive policy research was needed to assess the underlying causes of environmental degradation processes and the potential for reducing them through policy reforms.

Also in the Expansion Study, TAC coined the term *ecoregional* for agroecological zones regionally defined. The ecoregional approach was proposed to: (1) achieve sustainable improvements in agricultural production by balancing commodity improvement with increased research on NRM, (2) rationalize relationships between CGIAR Centres and NARS, and (3) provide an effective linkage with the global research community (Gryseels and Kassam 1994, op. cit.).

Later, and primarily as a follow-up to UNCED and Agenda 21, the CGIAR established a Task Force which reported to MTM'94. It proposed seven topics for special concentration of CGIAR effort: five dealing with marginal and degraded lands, and others on conservation of genetic resources and integrated pest management. Further work was proposed on the use of geographical information systems by the IARCs. At MTM'94, members of the Group also discussed a position paper prepared for IBSRAM on soil water and nutrient management research.

Two important soil and water aspects of natural resource management (SW/NRM) research appear to have received inadequate attention in previous studies. First, some important aspects of water research seem to have been overlooked—property rights and problems of access to a fugitive resource; effects of upstream land management on water supplies for agriculture; effects of agricultural land use on downstream users of water, and degradation of irrigated soils.

Second, important factors in the implementation of SW/NRM research appear to have been neglected. These include the definition of criteria for choosing between the CGIAR's new priorities in NRM research and more traditional lines of soil and water research, and of mechanisms for linking different forms of soil and water research, including socioeconomic with biophysical research.

1.4. Task Force Reports

While this TAC-led study of NRM research was in progress, the CGIAR established two Task Forces, one on sustainable agriculture and the other on ecoregional approaches to research. TAC was invited to attend the meetings of both Task Forces. The conclusions and recommendations/commentaries of the two reports have been taken fully into account in preparing this paper, including the recommended modes of implementation.

Thus, the first recommendation of the Sustainable Agriculture Task Force, in essence to develop programmes related to sustainability issues by adopting an interdisciplinary production-ecological approach which integrates productivity, environment and sustainability concerns, the fourth (to strengthen research on the socioeconomic basis of sustainability), and the eighth (to strengthen research into public policy aspects of NRM) are essential components of the integrated approach to NRM research that TAC recommends for the CGIAR.

Another recommendation from that Task Force, to consolidate soil, water and nutrient management research inside and outside the CGIAR into an integrated programme has also been recommended for support by the System, although TAC notes that further work is needed to explicitly consider the criteria proposed in this paper for use in choosing among the options for strengthening SW/NRM research in the System.

This study is in full agreement, as demonstrated by the Task Force, with the need and possibility to work in close connection with other organizations including NARS, advanced research organizations and specialized international agencies such as FAO, who have significant capacity and interest in NRM. Similarly, there is a need for the individual Centres and the CGIAR System as a whole, as opposed to individual research workers, to participate in professional networks that could allow the CGIAR to make a more effective contribution to Agenda 21.

Recommendations from the Sustainable Agriculture Task Force to strengthen other CGIAR activities related to sustainability, including the management of consortia and networks, relate to topics that are part of TAC's ongoing agenda for implementing Systemwide initiatives and programmes. Planning is also underway for a study on the relative priorities that should be given to issues and opportunities associated with marginal and degraded lands.

TAC offers two observations on the recommendation to earmark an increasing proportion of CGIAR funding for sustainability-related research: (1) This will certainly be examined thoroughly during 1996 as part of the priorities and strategies process for future MTPs, and (2) No specific reasoning is given in support of the statement in the text that the proportion of funds for activities directly related to sustainability be increased gradually to around 30% of total CGIAR funding.

The aspect of the report of the Task Force on Ecoregional Approaches that is most relevant to the present study is the statement that the Task Force views the ecoregional approach as an effective research process for identifying and characterizing current and future problems of resource degradation and their human causes, and for linking relevant component, commodity and policy research for their solution. This too is consistent with an integrated NRM approach.

The CGIAR ministerial meeting held at Lucerne in February 1995 also dealt with issues covered by this study. The CGIAR was, amongst other things, urged to concentrate on protecting the environment and to address more forcefully the issues of water scarcity and soil and nutrient management.

1.5. The IFPRI Initiative: A 2020 Vision for Food, Agriculture, and the Environment

A careful and detailed analysis of the evidence on the effects of degradation of soil and water resources has been undertaken as part of the IFPRI Initiative, and documented in a number of draft papers by Sara Scherr and her colleagues and in the publication *Population and Food in the Early Twenty-first Century: Meeting Future Food Demand of an Increasing Population*, edited by N. Islam. In this publication, the highly contradictory nature of the available evidence is reflected in the almost diametrically opposed views on future supplies of land and water for world agriculture in the papers by P. Crosson and by L.R. Brown, and in the way that degradation issues are dealt with in the three studies of the outlook for world food supplies into the next century.

In the FAO study, the effects of existing degradation are included in the production models, because they are reflected in the base year yields and fertiliser response ratios (World Agriculture: Towards 2010. An FAO Study, p. 354), but no specific allowance is made for the future. This implies that the proportional loss of productivity is not expected to grow during the period covered (to the year 2010), though there are many cautions in the text. The World Grains Model used by the World Bank does not appear to make any explicit assumptions about future trends in natural resource degradation, though it is stated that crop yields are influenced by land quality. Presumably, the implicit assumption is the same as FAO's.

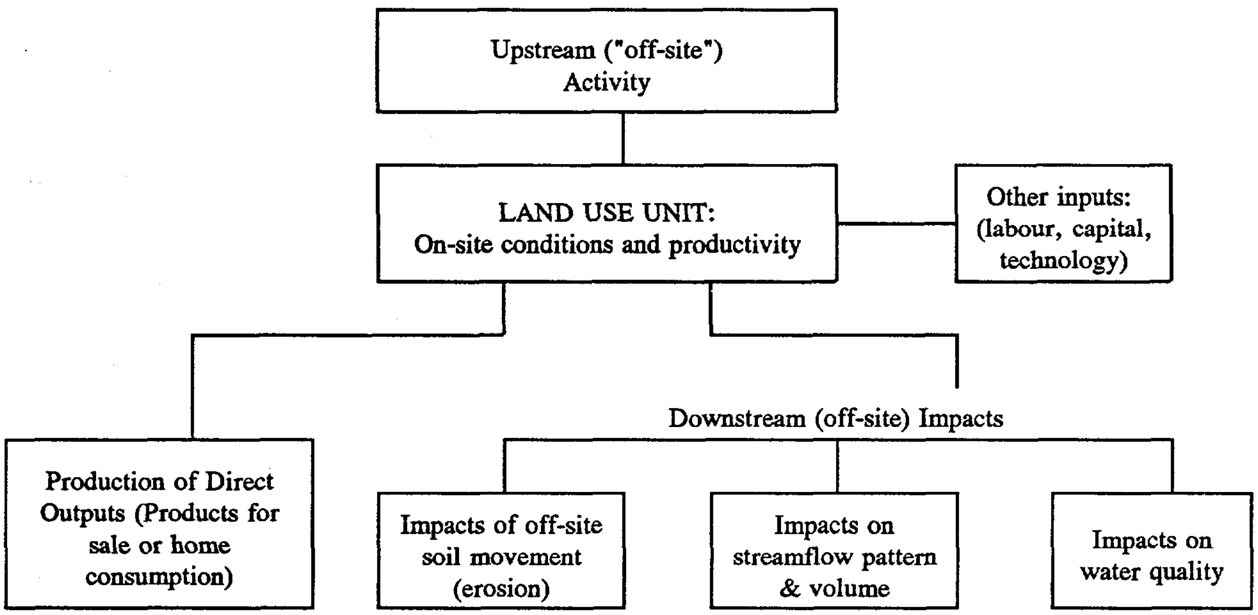
IFPRI did not judge the data to be sufficiently reliable to include natural resource degradation as a variable in its basic IFPTSIM model, but a scenario is presented for a 25 percent reduction in yield growth rate, which it is postulated could arise with continued decline in investments in agricultural development or accelerated degradation of the resource base. This assumption leads to a general contraction of food output.

2. Research on Natural Resources Management

As mentioned in the introduction, the state of the world's natural resources in many areas appears to be declining, particularly in the case of those associated with agricultural production. Hence a need is seen for a much more intensive effort to improve natural resources management, both through intensified research and through policy action to make sure that the best management practices are being utilized in practice. This need is driven by an overriding concern for the health of the planet for future generations (long-term perspective) and by a concern with the sustainability of production of goods and services for the present generation. Basic goals of the CGIAR relate to these needs. Thus, the CGIAR focuses on poverty alleviation through creation of food security and protection of the environment. The latter should include an overriding concern with water security as well as food security.

Improvements in NRM depend, to a greater or lesser degree, on inputs from research. As implied in Figure 1, there is continuum of research levels—from basic or strategic research, through applied research and on to adaptive research. We also can think of the actors in the research system as ranging from major developed country or international research institutions and advanced research institutions in developing countries all the way across to the farmer and village groups carrying out highly adaptive research. The CGIAR Centres obviously fall into the former category. In the present section, we look at the role of different types of research in improving NRM and at the different actors in this field, and where they fit into the picture in terms of types of research on which they should be focusing.

Figure 1: Land Use Production Units (the field or farm) in the Context of a Watershed Management Framework



2.1. Links between NRM and Sustainable Alleviation of Poverty

Sustainable alleviation of poverty involves a complex process of economic growth, development of food and water security, protection of the environment and natural resources, and, in most cases, changes in the distribution of benefits from economic development to favour the poor. Natural resources management relates to all these aspects of poverty alleviation.

Expanding economic growth related to agriculture involves enhancement of productivity and prevention of productivity losses. Both relate to the ingredients of productivity growth:

- increased biological potential of the agricultural plants and animals involved; and
- better management and use of the natural and human resources on which realization of the biological potential depends.

Thus, environmental protection through NRM helps to insure the sustainability of development, and in the process, of poverty alleviation.

Sustainability requires that the concerns in NRM focus not only on short-term, on-site gains, but also on the externalities associated with NRM—both in terms of temporal and spatial externalities. Thus, concern has to focus on downstream impacts of NRM and the impacts that are longer term in nature. These perspectives need to become key elements in the CGIAR's future work in the area of NRM.

TAC notes that the main operational means for dealing with sustainability issues are limited to research that looks for opportunities to avoid unsustainable development. That provides the only means to realistically move towards sustainability, since the latter cannot be identified in practice, other than in the context of the conditions that lead to unsustainable development.

2.2. Lessons from Successes and Failures

A main lesson learned is that there are relatively few well-documented instances of successful improvement of NRM in LDCs that can be directly related to strategic or applied research. There have been a number of failures and perhaps even more cases in which no strong attempt was made to use existing knowledge (often old research results on the shelf) to overcome recognized NRM problems. Generally, the reasons for failure or lack of action have not been investigated systematically, although in some instances the causes are obvious, and mainly relate to policy failures and lack of appropriate incentives for landowners or users.

A further lesson is that, where there have been successes, effective local, participatory organizations are a common feature. All worked in a learning mode to develop and adapt solutions to problems. Many involved outstanding local leadership. Special attention was given to the development of locally appropriate technologies, while diffusion of innovations was more horizontal than vertical ('seeing is believing').

Where government organizations were involved in the successes, a change of thinking through the process of bureaucratic reorientation (Korten and Uphoff 1982)[12] was

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[12] See Korten, D.C. and N. Uphoff (1982). *Bureaucratic Reorientation for Participatory Rural Development.* NASPAA Paper No. 1. Washington: National Association of Schools of Public Affairs and Administration.

important. The outside agencies took a firm interdisciplinary approach and stressed interdepartmental coordination and cooperation.

The lessons learned from examples of success in NRM seem to indicate that knowledge and practices derived from past research may have played an important role in the adaptive process and learning that was critical to success. However, it appears that in few cases was specifically targeted strategic or applied research in either the natural or social sciences required as a key factor in success. In practice, the distinction may not be so clear-cut. Access to existing knowledge and informed interpretation of the literature are embodied in competent researchers, technology and institutions, which for effective communication must be readily accessible to those working to improve NRM.

Thus, although past research results did in some cases play a role in success, it appears that it often was generated for purposes other than achieving the successes it contributed to over time. The implication is that it was technical and policy information on hand from experience or research results on the shelf that were put to use in generating successes, in those cases when the human and institutional constraints could be overcome through community action or extension, policy or other intervention. Moreover, research alone appears to have had little direct influence on the removal of the human and policy constraints, though it certainly has been used to identify and draw attention to them.

Obviously, there are many exceptions to this general conclusion. However, to the extent that it holds, the implication is that the research community should focus some additional research effort on studying the processes by which adoption and adaption of existing research based knowledge is translated into practice. This research should examine the fundamental assumptions on which the CGIAR Centres are working, and be complemented by additional efforts to bridge the gap between research and implementation (see section 3.2 for a recommendation). Indeed, this objective is one of the central themes behind the ecoregional approach being developed and adopted within the System and behind the push to increase the effectiveness of work with NARS.

2.3. The Role of International Public Sector Research in NRM

The CGIAR System should be doing research only in those areas in which it has a special advantage, i.e., ones that relate to the international character of its Centres and its mission and goals. The CGIAR Members have agreed that the System should be working mainly with research that produces "international public goods," and that it should only be investing in research if it has a clear advantage over other potential suppliers in terms of "cost-effectiveness."

"Public goods" are the extreme case of market failure involving positive "externalities." Externalities arise when the total benefit from producing the good (or service) cannot be appropriated by the buyer or by the producer of the good or service. In the more moderate cases of externalities, the person or country producing and/or purchasing the good or service may still have the incentive to produce and/or consume it. Traditionally, ***public goods*** are defined as the extreme of this case, i.e., where so many of the benefits are not appropriable by the producer or purchaser that private costs significantly exceed private benefits or returns to the extent that the good(service) is not produced or consumed without some external interference or organization of the good or service.[13]

Taking this argument one step further, one can identify those goods and services that are ***international public goods,*** i.e., no one country receives sufficient benefits from the production and consumption to provide incentive for production by that country, even though if produced the benefits to two or more countries would clearly exceed the costs involved in production. Thus, some mechanism whereby more than one country/international entity organizes and finances production is called for to remove this international "market" failure.

Given the above, it is clear that the CGIAR - having the attributes of a public entity - should primarily be involved in production of research that fits in the international public good category. However, there also are more moderate cases of externalities where CGIAR production or activity still is justified, *so long as the benefits from such activity accrue to more than one country,* i.e., so long as the internationality condition holds. In such cases, the System brings in a number of other criteria to meet the sufficiency conditions for CGIAR involvement. Thus, there are criteria related to:

- ***cost-effectiveness*** of CGIAR activity in relation to that of other potential suppliers;[14]

  One can think of at least two sub-categories of criteria helping to explain cost-effectiveness. Thus there are:

  - *reliability* in production of results; i.e., another potential source might appear to be more cost-effective, but the reliability of results is much less certain, or the time delay would be such that there is clear advantage in the CGIAR producing earlier results; and
  - *lumpiness* or *economies of scale* in production; i.e., a country or other potential producer might have the incentive to produce the results, but due to lumpiness in research requirements (or economies of scale in production of results) the CGIAR can produce it in a more efficient fashion.

- ***externalities*** from the CGIAR Centres' activities, e.g., in terms of informal on-the-job training of local scientists and provision of ideas for local NARS and other groups, and in terms of inputs and benefits to advanced research institutions.

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13 Economists say that the ***"non-exclusionary"*** principle applies, i.e., it is impossible to exclude from receiving benefits, those who do not contribute to the costs of production. Obvious examples are military defence and flood control. A further attribute of public goods is the existence of ***"non-rivalrous consumption,"*** i.e., consumption by one individual/group does not affect the consumption by others (e.g., as in the case of watching the sunset, or a weather forecast).

14 Note that the term "comparative advantage" is no longer used to justify research in the System, mainly because it has a very strict meaning in economics, and it has traditionally been used incorrectly in the CGIAR discussions, creating misunderstandings and confusion.

In sum, as TAC has emphasized previously, international research initiatives—including particularly ones in the natural resources management area—should:

- Produce research results of an international public goods nature, i.e., they provide benefits (either directly or through externalities) across national borders. Public goods are difficult and/or undesirable to make proprietary and are characterized by non-rivalrous consumption, i.e., one individual *consuming* them will not reduce the amount available for others to consume (typical of knowledge outputs).

- Globalize (or standardize) methodologies used in local studies to ensure comparability of results across ecoregions, and for use in researching common themes or problems within ecosystems; this should include methodologies that integrate biophysical and socioeconomic research.

- Involve locally relevant and responsive research within ecoregions (or watersheds), but with a global perspective to (1) take advantage of economies of scale in research, (2) maximize use of spillovers from research, (3) reduce transactions costs in doing research, and (4) allow efficient movement up the learning curve. (Hence a key issue for the CGIAR is to balance its allocation of resources to natural resources management research between ecoregional and global perspectives. A similar balance is required in public policy and public management aspects of natural resources management research.)

- Be multisectoral and multidisciplinary in nature and scope, recognizing the different sectors and disciplines dealt with across the CGIAR System. (Thus, for example, the CGIAR Systemwide SWNM Programme, or the proposed Water Programme should be explicitly linked to ecoregional activities, to germplasm improvement and commodity research activities of selected Centres, and to various policy related research issues pursued by such Centres as IFPRI, e.g., in the area of water policy and common property resource management).

- Take advantage of complementary activities of different suppliers of research, both within and outside the CGIAR System and contribute to the work of others, both NARS and advanced institutions.

Strategic international research should be process-oriented, both biophysical and socioeconomic research, i.e., focused on researching the processes by which positive changes can be made, or negative ones avoided (e.g., maintenance research). It should be looking at the issues of dynamics of natural resources systems, where each component depends on the others. Despite these needs, Figure 1 presents only a static view of the world. We recognize that we need to introduce a more dynamic dimension in order to address the issues associated with process-oriented research.

In other words, international institutions have a special advantage in ensuring the development of the research on processes for management, use and conservation of natural resources, and for designing technologies to create more sustainable soil and water conservation and use situations.

Such process research (strategic or applied) involves consideration of changes over time, comparability of results across ecoregional production systems, and mechanisms for translating results through adaptive research done by NARS. Such considerations need to be introduced into the framework when looking at research priorities for the CGIAR System.

2.3.1. The Role of the CGIAR

The CGIAR is one of the premier international research systems involved in NRM research. As such, the considerations in the previous section apply to it. The CGIAR System is distinguished from most other international NRM research entities by the fact that it has a proven, long-term track record of actual research in developing countries. Most other international entities either provide only funds for international research, or, like many universities have fixed-term projects that typically last no more than five to ten years. The CGIAR System has permanent Centres. As such, the CGIAR Centres can attract high quality scientists who are interested in careers, not just short-term project employment, and undertake long-term experimentation and develop strategic reference databases. This can lead to more effective and productive relationships with local researchers. Because of their established, long-term reputation and stability, they also often can act as the best convenors of research consortia and other groups that build on each other's strengths to gain research advantages.

In an overall context, TAC reconfirms that the CGIAR has an increased role to play in research on natural resources management (NRM) and environmental issues. It is not necessarily so that new and expanded funding is needed. Rather, resources need to be redirected so they cover critical topics; and some of the work currently done by the CGIAR centres might logically be transferred to NARS partners and others.

The work in natural resources and environment needs to be linked more explicitly to sustainable poverty alleviation and food security for the poor, if the new vision for the CGIAR developed at the Lucerne meeting is to be realized. This explicit recognition of the Lucerne Declaration carries with it certain implications for the scope and orientation of natural resources management research in the System. They are as follows:

1) *Sustainable poverty alleviation and food security depend directly on the health of the environment and the natural resources base* on which all food production depends. Thus, conservation and enhancement of the environment *in that context* serve as central and legitimate themes for CGIAR research.

2) TAC reaffirms and emphasizes the point made above: *The System should with few exceptions only be doing environmental and NRM related research that is clearly identified with the impacts of agriculture, forestry and fisheries on sustainable poverty alleviation and food security.* In other words, that should be a necessary condition for undertaking natural resources management and environmental research in the System. Quite logically, priority should be given to research directly related to the mission and goals of the System. This implies nothing about the importance of other priorities, other missions and goals, and other organizations and their focus on the environment.

3) Agriculture, forestry and fisheries interact with the environment in a dynamic context, where the impacts of agriculture, forestry, and fisheries on the environment, are just as important as the impacts of environmental conditions and changes on agriculture, forestry and fisheries (see Figure 1, p. 8). In fact, sustainable agriculture requires consideration of both these perspectives, i.e., a consideration that all except the extreme upstream and downstream land use units in a watershed are both the receivers of impacts from upstream and the creators of impacts downstream. TAC confirms that *research on both aspects of land use impacts - on-site and off-site - are priority areas for research in an integrated natural resources management (INRM) research framework such as is needed in the System.*[15]

4) TAC recognizes and emphasizes that there are *significant non-traditional alternative suppliers* with comparative advantages when it comes to research focused on other goals associated with natural resources and the environment, such as ecosystem health and services for broader purposes, recreation, aesthetics, global change, and wildlife management.

5) TAC concludes that once the necessary condition has been met, i.e., the proposed research is identified in a positive way with impacts on sustainable poverty alleviation and food security, then adjustments in specific research may logically be made to take into account potential benefits in terms of other aspects of environmental improvement and health. Such adjustments should, of course, consider the cost implications. In fact, much of the research undertaken by the System does contribute to these other goals (even though such research was initiated in the System only because of its links to sustainable poverty alleviation and food security through agriculture, forestry and fisheries).[16]

2.3.2. A Synthesis of Current Activities in Soil and Water Research in the CGIAR

As part of this study, a background analysis of the current and planned research work of the CGIAR Centres on soil and water (S&W) was undertaken by the TAC Secretariat (TAC 1995b, op. cit). This desk study attempted to answer three questions concerning the current S&W-related research:

1. Which types of agricultural lands are the main targets of CGIAR research?
2. Where in the systems scale are the Centres concentrating their research efforts?
3. What research strategy are the Centres pursuing?

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15 Note the point that the downstream impacts of agriculture may lead to significant impacts on upstream agriculture as well as downstream agriculture, e.g., when the downstream effects on people are such that action is taken to curb certain agricultural practices upstream.

16 Examples include: biological control undertaken primarily because of the rising costs of chemical control with increasing resistance, but benefiting also farmer health and the environment; trees grown on farms for food, wood, and forage, but helping to control erosion and, if native species, helping also to conserve biodiversity.

The results of the desk study indicated that:

1. *The CGIAR System is allocating a substantive proportion of its total resources to soils and water research (17 percent, or US$ 49 million),* which is equivalent to funding two large Centres the size of IITA.

2. *The average proportion of funds allocated by Centres to S&W research is around 14 percent of their budgets,* but differences among them range from 5 to 40 percent.

3. *Thirty-five to forty percent (35-40%) of the total CGIAR investments in S&W research are directed towards irrigated lands and rainfed lowlands,* which could be seen as *proxies for well-endowed lands.* Among so-called "fragile" or "marginal" lands, the warm semi-arid, savannas and forest margins each account for around 15 percent of the resources, while the cool semi-arid, highlands and hillsides each account for 5 percent.

4. *On average Centres focus about 75 percent of their S&W efforts to research on-site, ranging from 30 to 90 percent.* This may be seen as an expression of weak attention to the spatial or landscape linkages, an important component of the framework for integrated natural resources management research advocated by TAC.

5. *Judging from the share of resources allocated to activities at the field and farm scales, there appear to be good linkages between productivity-enhancing and resource-conserving perspectives,* a major set of linkages mentioned in TAC's framework for integrated research.

6. *On average Centres allocate some two-thirds of their S&W budget to research of an applied nature, ranging from 50 to 90 percent.* This allocation, taken together with that of three-quarters to on-site research, suggests a strong concentration of research efforts on location-specific activities, rather than on the strategic research required to focus on issues of an international public good nature.

2.3.3. CGIAR Links to Other Suppliers in NRM Research

The CGIAR accounts for a small part of the total global research on NRM, even if one only looks at that associated with agriculture, forestry and fisheries. TAC's earlier studies used as background for assessing the expansion of the System (and the entry of additional, natural resources focused Centres) indicated at least qualitatively the great number of entities, both public and private, that are alternative suppliers of research results in the NRM area. Such entities range all the way from small NGOs focusing on highly adaptive research to major corporations and large government agencies and universities. Many of them are quite different from the agencies and groups with which the CGIAR traditionally has interacted in the agricultural sector. In order to ensure effectiveness and efficiency, the CGIAR System needs to link with selected research groups, including those working on traditional NRM practices, that can complement the work of the CGIAR Centres.

3. An Integrated Approach to NRM in the CGIAR

In the real world there will be severe limits to what is achievable at any time in research for a particular NRM domain. These practical limits will be imposed by availability of resources, both human and physical, and especially by organizational and managerial skills. Research to help improve NRM is complex and tends to be more difficult to conduct successfully than commodity improvement research. Since there is no proven model that can be transferred from elsewhere, the CGIAR and its partners have a lot of learning ahead of them. TAC has already made this point about the ecoregional approach.

3.1. Integrated Natural Resources Management

For soil and water management research in the CGIAR, TAC advocates the adoption of an integrated natural resources management approach, analogous to the IPM approach in pest management, or the watershed management approach with its focus on water and land relationships in a watershed. Indeed, both are part of integrated NRM (INRM). We stress that INRM provides a framework for planning and conducting NRM research, and for presenting research findings in an integrated form that can be used by practical people for improving NRM.

The following examples help to illustrate the relationship between the integrated approach and more traditional ones:

- A main focus in water engineering research tends to be on infrastructure (dams and delivery systems) in an irrigation project, whereas the more holistic natural resources management perspective also introduces the concepts and principles of upstream watershed management to protect the investment in the downstream irrigation system.

- Again, in dealing with irrigated crops, agronomists might concentrate on crop\soil\water interactions at the field scale and on the water requirements of particular crops, while the broader INRM perspective might focus on how rapidly the water table is being drawn down by pumping and over how wide an area. At a more macro scale, the focus also would be on the comparison between irrigated crops in terms of water requirements and water balances over time.

- Agronomic research on upland agriculture might concentrate on the effects of erosion on on-farm productivity, whereas the broader natural resources management research perspective, using an integrated watershed management framework, would also focus on off-site, downstream damage caused by soil loss from farmers fields.

- Soil fertility problems are often "solved" by simply determining the amount of nutrients to add for a given crop, whereas in a more integrated approach crop residue (organic matter) management is controlled to achieve breakdown and a pulse of available nutrients in synchrony with crop demand, reducing the amount of fertilizer needed and increasing the efficiency of its uptake. The linkages between organic matter conservation and fuel needs are a key component.

  Research on such systems should be highly process-oriented, providing an understanding of biophysical processes linking soil and landscape both with crop and animal production processes. These processes are common across a wide range of environmental conditions. This application requires environment-specific adjustment, usually by farmers themselves.

INRM is not a proposal for gigantic research programmes that would be quite unmanageable in practice and shallow in substance. The same point was made in the earlier framework paper for this study, where the watershed was used as the framework to integrate thinking about key aspects of soil and water research. This was widely misinterpreted as advocacy of all-embracing experiments on whole watersheds.[17] Rather, TAC's argument was that focused pieces of research on soil and water processes needed to be planned and interpreted in the watershed context.

An integrated natural resources management framework needs to be used as an organizing framework within which to consider a number of critical linkages and subjects in the natural resources area that should be incorporated in CGIAR research. When emphasis is given to water issues, then an integrated watershed management framework may be appropriate. If the focus is on insects, then an IPM model may be appropriate.[18]

The concept of a *framework* for planning and prioritizing research was stressed in section 1.1. As discussed there, linkages are a key concern in any model of integrated natural resources management research, since *everything relates to everything else* in ecosystems as well as in economies. Linkages also are a key concern in this study, particularly in terms of building up the justification for NRM research as a priority for international CGIAR research. The linkages of relevance in an INRM framework are discussed below.

Links Between Productivity-enhancing Research and Natural Resources Management Research

An important set of linkages involves those between productivity-enhancing research and natural resources management and policy research. In fact, recognition of the importance of these linkages was a major factor in the development of the ecoregional concept and

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17 The reader interested in further discussion of the watershed management framework is referred to TAC's April 2, 1995, discussion draft: *Study of Strategic Natural Resources Management Issues and Research Needs in the CGIAR, with Emphasis on Soil and Water.* TAC Secretariat, FAO, Rome.

18 *Report of the TAC Panel on Crop Protection Research.* TAC Secretariat, 1990. FAO, Rome.

approach to research in the CGIAR. On the one hand, population growth and persistent poverty have generated a need for increased food production, and the need for high quality water supplies for people has grown in both rural and urban areas. On the other hand, the condition of soil and water appears to be deteriorating, sometimes to an alarming degree, over major parts of the developing world.

The feasible solution to many of these problems lies not in expensive soil remediation or water treatment processes but in reducing or preventing their development in the first place. This is a powerful argument for more closely linking productivity-enhancing and resource degradation-reducing objectives in the conduct of CGIAR research. The two have to go hand-in-hand.

There is one particular linkage between productivity-enhancing research and natural resources management that often is associated with CGIAR research on yield increases in favoured areas. This is the impact that such increases have in terms of taking pressures off less favourable, fragile and often marginal areas. This indirect linkage is important.

Spatial or Landscape Level Linkages

Spatial or landscape linkages, and particularly upstream-downstream linkages, are critically important within the ecoregional framework for research. Agricultural and forestry production practices, because of the large areas covered and large amounts of water used, are frequently the dominant upstream land uses that determine downstream impacts. The sustainability of irrigated agriculture on the plains is directly influenced by the effects of land management practices in upland water catchments, e.g., in terms of the amount of sedimentation build-up in dam reservoirs as a result of erosion from farmers fields and in the frequency and intensity of major floods. Upstream land management practices also increasingly determine the quantity and quality of urban water supplies.

Inland fisheries depend on the quantity and quality of water in streams and ponds, both of which are strongly influenced by upstream agricultural and forestry management practices (as well as by the management of forms of land use that lie beyond the scope of this study, such as mining and parks). Sometimes the results of upstream interventions are totally unexpected, as with the damage suffered by Mediterranean fisheries when the silt load of the Nile was reduced by the building of the Aswan Dam. Logically, the downstream spatial linkages in INRM should be extended to include the effects of run-off on coastal waters.

Temporal Linkages

In addition to spatial linkages, it is important to consider linkages between present and future, with future generations that may want to utilize natural resources currently being depleted by the present generation. Intergenerational concerns is an important concept that is becoming more important as people see the speed with which the uses of resources and their conditions change.

The key area in the case of temporal linkages is the lack of knowledge of the rates of change in key dimensions of natural resources (the dynamics of resources, management, use, enhancement and degradation); and on the impacts of such changes on food and water security; and on health.

This is particularly critical, given the conclusion above concerning the state of knowledge and understanding of the impacts of agriculture on natural resources and the environment and the impacts of land and water degradation on overall agricultural production.

Linkages Between Research and Adoption

A fourth set of vital linkages is between research and the adoption of its results. The realization that development often is limited by political, policy, and socioeconomic factors more than by technical ones, has led to the broadening of the CGIAR's agenda to integrate in a major way policy research into the ecoregional approach. In many cases, the key obstacles or constraints to the application of existing knowledge for good soil and water management are related to national policy failures or voids.

The four types of linkages mentioned above need to be considered in designing sound and relevant integrated natural resources management research. Centres need to integrate the perspective of focused agronomic, field level research with the broader perspective needed to encompass the various natural resources issues and linkages discussed above.

Because of the size of the CGIAR System, its Centres have the unique ability to tackle major, complex research problems and tasks, often in a joint fashion and working with other research groups, including NARS. Because of the track record and the reputation of the scientists in the System, and the long-term nature of its commitment, it often can establish cooperative relationships with a variety of other scientists that would be difficult for other groups to establish.

3.2. Priorities for Soil and Water Research

Several of the previous studies have recommended priorities for soil and water research, generally or for the CGIAR in particular. The TAC 1990 Working Paper (TAC 1990, op. cit.) listed, in a section entitled overview of gaps and overlaps, a number of diverse soil and water research topics that were under consideration at that time. Then, at MTM'94, much more detailed arguments were presented by the Task Force on Agenda 21 for research on a group of agroecologies and land use problems under the heading "Marginal and Degraded Lands". These included the Desert Margins Initiative for the drylands, marginal and degraded lands caused by tropical deforestation, sustainable mountain development, policies to sustain the resource base and productivity growth in fertile lands, and a network for management and conservation in tropical forests.

MTM'94 also discussed IBSRAM's Position Paper (Greenland et al. 1994)[19], which concluded that there was an urgent need to develop indicators or early warning signs of

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19 Greenland, D.J., G. Bowen, H. Eswaran, R. Rhoades and C. Valentin (1994). *Soil, Water and Nutrient Management Research - A New Agenda.* IBSRAM Position Paper.

resource degradation. Lists of high priority research components and high priority research areas were given. Several of the latter categories overlapped with the Agenda 21 priorities. The research areas identified at MTM'94 have since evolved via the Zschortau Plan and the Feldafing Consultation into the four subject matter themes of the Soil Water and Nutrient Management Initiative.

The current study deals with both socioeconomic and biophysical research priorities. A number of research priorities have been identified within the context of the linkages discussed earlier, each one having both a biophysical and socioeconomic policy dimension.

In terms of linkages between productivity-enhancing and resources-conserving research the following topics seem particularly relevant:

- managing water and nutrient supplies for greater efficiency and sustainability; research on the efficiency of water and nutrient use by crops, especially to prevent degradation of irrigated land; both economic and biophysical efficiency should be considered;

- research on the processes underlying the long-term, less obvious forms of soil and water degradation. (This will complement existing production-oriented CGIAR soils research);

- managing soil fertility (organic matter, mineral nutrients, acidity); the understanding of soil biological processes is a key to the effective management of soil fertility, with the "control" mechanisms being carbon from the local resource inventory, and nutrient inputs from off-farm resources.

In the case of spatial or landscape linkages, the key areas for research include:

- the pros and cons of devolution of responsibility for NRM to local government bodies and user groups;

- research on the physical, economic and social impacts of agriculture, forestry and aquaculture production practices on the quality and quantity of downstream water supplies and on assemblages of aquatic organisms in downstream and upstream water bodies;

- development of acceptable methods for combatting soil erosion (mainly associated with its off-site impact on environment); and

In the case of linkages between research and adoption, the key area for research is:

- the reasons why existing information has not been used more effectively to improve NRM, for instance in the move from shifting to permanent cultivation; also, research on how to get more effective implementation of existing knowledge for improved INRM, i.e., research on cultural diffusion and adoption of research results already on the shelf, in the context of fostering a participatory approach to improving NRM.

In the case of temporal linkages, the key area for research is:

- measurement of the rates of change in key dimensions of natural resources (the dynamics of resources management, use, and degradation); and research on the impacts of such changes on food and water security;

Finally, a greater use of the systems approach and mathematical modelling in NRM research, and the carrying out of a limited number of carefully selected watershed or catchment studies, is advocated.

TAC also encourages IIMI and other Centres to move ahead as rapidly as possible with the development of the already approved Systemwide initiative for water.

TAC proposes that the CGIAR should now move the emphasis to implementation of these priorities. Further evaluation of priorities in soil and water research related to INRM will be needed, but there is also urgency to now learn from experience.

4. Implementation Options

There are two stages in making choices among proposed INRM initiatives for inclusion in the CGIAR portfolio. The first involves an assessment of the relative importance and relevance of themes or topics for inclusion. The second involves choice of the mode of operation or organization for the work involved in addressing chosen themes. Each of these is outlined below.

4.1. Criteria for Assessing the Relative Importance of the Substance of Proposals for INRM Research in the CGIAR System

The following criteria are proposed to guide the allocation of scarce resources in this potentially vast field of research. They are not absolute and will not apply equally to all research proposals, but they should be taken into account in deciding relative priorities:

- **The research should contribute to poverty alleviation and environmental protection and/or enhancement.** Preference should be given to soil and water management problems or opportunities that are likely to have a significant impact on poverty alleviation. One way is through increased food and water security, especially for very poor people. Research results that lead to lower prices or more stable food outputs can contribute to this goal. So can results that lead to increased off-farm employment, e.g., in various postharvest production and marketing activities or in various natural resources related activities.

  Similarly, research results that lead to a stable or improved environment and natural resources base can contribute both directly and indirectly to poverty alleviation over the longer term. For example, there is no doubt that improvements in management of irrigated crops, such as the improvements that played such an important part in the green revolution, are of high priority.

High priority also should be accorded to preventing those forms of degradation which are likely to be most costly or difficult to repair, since ultimately such degradation has an impact on food production, water availability and quality, and thus poverty alleviation. It may be beyond the resources of poor farmers to overcome some forms of degradation, such as loss of topsoil from sloping lands or waterlogging and salinization of irrigated lands, whereas it may be feasible, though not necessarily easy, for them to remedy soil nutrient deficiencies or to regain vegetative cover on overgrazed land.

Alternatives need to be considered in the context of overall contributions to poverty alleviation in combination with environmental improvement. For example, can scarce research and development funds be better invested in intensification of more favoured areas rather than in seeking sustainable development options for marginal areas—the savannas of South America rather than the hillsides or forest margins; the subhumid and humid lands of West Africa rather than the desert margins? What are the trade-offs in terms of total number of poor people affected, impacts on the environment, and so forth? Each instance will, of course, be different in terms of the trade-offs involved.

- **The Research should be results-oriented, demand-driven, and utilization focused.** A realistic assessment of the likelihood that research results will be adopted in practice (i.e., that the research is demand-driven) is proposed as one of the most important criteria for enhanced CGIAR support of SW/NRM research. TAC's review of successes and failures in improving NRM has led to the conclusion that nontechnical factors are often the primary constraint. This strongly suggests that the CGIAR should concentrate its effort in regions where there is good evidence that the importance of improving NRM is accepted and that there is a political and community will to do something about it. Biophysical and technical research alone has very little leverage if the human factors are not propitious.

  This is not to say that research on trends in the condition of natural resources cannot help to change public opinion, and that research on socioeconomics, public policy and public institutions cannot help to identify constraints to effective community action. Further, the link between NRM and production-oriented researchers is particularly important, because of the need to modify production practices in the interest of greater sustainability, but also at an acceptable cost. Incentives are often required to help landholders over the initial costs of changing to more sustainable practices.

- **The research should make optimum use of existing information and contribute to filling knowledge gaps.** The integrated approach to NRM which we strongly advocate, requires access to a wide range of expertise in both the natural and social sciences. It seems from the record of successes and failures to date that good access to existing knowledge is more important than current research results, though that may not be true in all cases.

  While continuing to research the control of those forms of soil and water degradation that are known with certainty to be damaging (water erosion on sloping lands, salinization and waterlogging of irrigated lands), an effective proportion of research resources should be assigned to answering the question: is there a growing threat to world food security in the early twenty-first century? The reasons why food production has not been affected more severely by obvious forms of soil and water degradation in the past should be analysed (or is the economic evidence flawed and the impacts of new technology and inputs would really have been much larger, if it were not for existing degradation, as some have suggested).

> ***Recommendation 1:*** The CGIAR System should develop improved mechanism(s) by which Centres, collectively, can be involved with other partners in generating and interpreting improved scientific evidence on the extent and magnitude of agriculture, forestry and fisheries on the degradation or enhancement of natural resources and the impacts of such degradation or enhancement on agriculture, forestry and fisheries production and food security.

The suggestion made earlier in this paper, that a higher priority be given to research on longer term, less obvious forms of degradation is also relevant to gaining a better understanding of the future threat. This point has been made by a number of experts in the field. A specific example illustrating the general problem of lack of adequate information on degradation and the state of the environment comes from a recent paper by Gill (1995):[20]

To sum up, an unfortunate combination of bad science, misleading statistics, and, to be frank, environmental scaremongering has led to serious mistakes in "knowledge" as incorporated in technology, human resources (foresters), institutions (government and donor agencies), and policies. The most fundamental issue in natural resources management in South Asia must be to achieve a major breakthrough in the understanding of the state of the environment, of the processes that are changing it, and of the underlying causes. (p.12)

While Gill was referring specifically to misconceptions about land degradation in Nepal, the experience is clearly of wider relevance in NRM.

A number of authoritative sources, including the IBSRAM position paper and several consultancies carried out in support of this study conclude that there is a lot of existing scientific information that could be adapted for the practical improvement of NRM. Some of it comes from strategic soils research for improving agricultural and forestry production, but in other cases there has been a long history of work in support of better NRM, for example on options for maintaining soil fertility with growing population in areas traditionally under shifting cultivation. This appears to be true also for maintenance of soil productivity in the highlands of East Africa. It is very important for the CGIAR

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[20] Gerard J. Gill (1995). *Major natural resource management concerns in South Asia.* IFPRI: Food, Agriculture and the Environment Discussion Paper 8.

to promote research on constraints to the better use of this existing knowledge, and to make sure that scientific *wheels* are not reinvented.

Based on the conclusions above (which take into account lessons from successes and failures) and on an assessment of the most recent SWNM proposal, which takes on board many of the recommended areas of focus listed above, TAC makes the following recommendations:

> ***Recommendation 2:*** TAC recommends that intensified and expanded collaborative mechanisms and activities be developed among Centres, and between Centres and their non-CGIAR partners, to help focus increased research and institution strengthening on issues related to adoption, adaptation, and utilization of existing NRM technologies and knowledge that so far have remained unused.

The fundamental knowledge creation, diffusion, adoption and assumptions on which CGIAR Centres currently are working need to be reassessed in the NRM area through a sound research programme that will involve biophysical as well as social scientists. Such a collaborative activity should be a coordinated effort involving both NARS partners and Centres. Activities should focus on the incentives and other policy tools needed to get effective, widespread adoption of appropriate NRM knowledge and technologies.

Biophysical scientists often expect too much of policy research. Policy research alone may be able to do relatively little to remove constraints to application of existing technology, especially political ones. In any case, their existence may be obvious from general socioeconomic understanding, without the need for new research. Also, people sometimes have unrealistic expectations of the capacity of new areas of science, such as biotechnology, to overcome barriers to development.

Although there is a great deal of existing information that can directly be put to the test in practice, there also are many key knowledge gaps that need to be filled by research. Priority should be given to addressing these deficiencies in the knowledge base. Some of the priorities have been identified by the present synthesis review. First, there is a need for rigorous investigation, rather than just anecdotal reports, of failed attempts to improve NRM, as has apparently occurred with soil conservation programmes in SSA, SE Asia and elsewhere. In other intriguing cases, such as soil fertility maintenance with intensification of cropping in areas of shifting cultivation, it is not clear that adoption has ever been seriously pursued.

Second, insufficient attention is being given to water research. Irrigation played a major part in the success of the green revolution, but the System gives little attention to making more efficient use of irrigation water for crop growth (there is already growing competition for water from nonagricultural users) and to preventing further degradation of irrigation land through waterlogging, salinity and alkalinity. Also, there are difficulties with establishing property rights in water which adds to the challenge of improving water management.

Third, a number of important soil and water linkages (section 3.1) appear to have received inadequate attention in production-enhancing research. They include the spatial or landscape linkages, for example the linkage between upstream agricultural and forestry production practices and downstream water supplies, especially for urban communities, and temporal linkages. More attention needs to be given to understanding the processes causing longer-term, less obvious forms of soil and water degradation.

Finally, it will be necessary to allocate some resources to monitoring trends in the condition of soil and water resources in order to define needs and to assess potential improvements from research more precisely. Establishing baselines now will be essential for the future evaluation of the impact of the CGIAR's investment in INRM research. Thus, research contributing towards defining optimum means to develop monitoring and evaluation systems also contributes indirectly towards the overall goals. A further benefit from this type of research will be increased knowledge that will help us distinguish between natural causes of *degradation* and human causes of degradation, e.g., as in the case of erosion and siltation problems downstream from younger mountain ranges such as the Himalayas.

The lack of criteria for distinguishing between *traditional* kinds of soil and water research that have been carried out in the System and the kinds that should be strengthened in the interests of broader soil and water sustainability and environmental improvement probably has been a contributing reason why the System has broadened its approach to NRM research more slowly than some stakeholders, including particularly donor constituencies, would have liked. Consideration of the factors listed above should help the System to distinguish more clearly between *business as usual* and the new, broader INRM research agenda.

It should be pointed out that the focus of many international discussions of SW/NRM research has been predominantly on downside risk, that is on degradation of soil and water resources below some *natural* level. Some analyses of population growth and future food needs, including the Inter-Centre Review of Rice, have concluded that it would be risky to rely entirely on plant varietal improvement for future increases in food production and that it will be necessary to narrow the *yield gap* as well. Improved NRM (enhanced soil fertility, more efficient water use, and better control of pests, diseases and weeds) is likely to be a key to narrowing the gap between actual (on-farm) and potential yields. The results of good research aimed at understanding the fundamental processes of soil and water degradation also are likely to meet the needs of sustainable intensification of agriculture.

- **The research should build on the CGIAR's international advantages.** Section 2.3 provides a detailed discussion of the nature of the international advantages that should be associated with CGIAR research. Existence of these advantages would be a firm requirement for CGIAR involvement in INRM research. It is noted that in many cases, research themes that on the surface appear to be mainly local in nature can have an international dimension, e.g., through the development of widely applicable methodologies, or the development of new insights or new understanding through high quality comparative research.

There must be potential efficiency gains from sharing the costs across countries and the results (in so far as they can be predicted) should be widely applicable (section 2.3). There is a special need for international agencies engaged in INRM research to focus on the search for generic understanding and to reduce the location specificity of results from this type of work.

Once a research area or topic has satisfied the basic requirements of having potential to contribute to CGIAR goals and having an advantage for CGIAR involvement, then the next step in the process is to assess alternative modes of implementation. The CGIAR is not the only international agency engaged in INRM research and to warrant continued donor support it has to provide a superior service, including cost-effectiveness (see below).

4.2. Operational Factors to Consider in Assessing the Relative Merits of Alternative Approaches

The previous discussion has identified a number of factors or criteria that need to be considered in choosing among the options for implementation of an expanded programme of research in the CGIAR related to INRM. Some of them relate to new directions in which the CGIAR is moving—towards greater openness, involvement of others, transparency, and accountability for impacts. Others relate to the aim of increasing the efficiency and effectiveness of the ways in which the CGIAR does business. Below, some of the main factors or criteria to be considered are briefly described. The following section then provides TAC's assessment of the different options, considering the various factors or criteria.

- **Degree and effectiveness of collaboration with others (linking, openness, involvement with NARS and other suppliers of NRM research).** The CGIAR needs to become more involved with other suppliers of NRM research, including both developed and developing country NARS and other research groups (universities, etc.). How do the different implementation options compare in terms of this factor or criterion?

- **Cost-effectiveness/value added of the options.** Different implementation options offer different potential benefits and costs. Some have relatively higher transactions and management costs than others. However, the relative effectiveness of the higher cost option may outweigh the additional costs. How do the options compare?

- **Participation of potential beneficiaries and other stakeholders in the definition of research problems and priorities.** Openness and effectiveness both depend on getting the research problem properly defined and prioritized relative to the various other problems that could be tackled by research. How do the options compare in terms of the relative ease of encouraging and accepting stakeholder participation?

- **Clarity in communicating the importance of the research to CGIAR members and other actors.** It is important that research in the INRM area has identity and that both the processes followed and the results obtained can be communicated in an appropriate fashion to the various stakeholders. The identity of this type of research is not as clear as traditional crop improvement research, where productivity differences generally can be associated almost directly with production increases for farmers. Influential people in countries that contribute to the CGIAR often hold strong views on the importance of environmental issues. How do the potentials for effective communication with them differ for the different options?

- **Continuity of funding/support.** NRM research often involves long-term investments to achieve productive results. It is essential that funding opportunities be stable and have the best prospects possible for continuity over the minimum needed lives of the research programmes. How do different options compare in terms of funding continuity?

- **Ease of accountability.** Some options are quite different than others in terms of how they encourage and facilitate a sound and effective accountability for funds spent. Accountability is an essential ingredient in the context of the CGIAR funding, especially when it is shared with organisations outside the System. How do the options compare?

- **Standards of planning, monitoring and evaluation.** Characteristically, CGIAR investments in research have high standards in terms of planning, monitoring and evaluation. Such high standards are easier to develop in some cases than in others. How do the options compare in terms of this factor?

While it is not possible to quantify all of these criteria or factors, an overall qualitative assessment of different options can provide a critically needed perspective on the relative advantages and disadvantages of different options.

4.3. Alternative Structures

TAC considered four structural options for implementing INRM (S&W) research in the CGIAR System: Centres, regional partnerships, Systemwide coordinating committees, and professional networks.

- **Centres** — The need for very close links between productivity-enhancing and SW/NRM research makes it desirable to work through the existing Centres, rather than through centres dealing specifically with SW/NRM research. At the same time, the location specificity of much SW/NRM research and the need for links to adoption make it essential to develop strong regional and national partnerships (next point).

- **Regional Partnerships** — In this study, we have concluded that socioeconomic and institutional factors are often the primary, immediate constraints to better NRM. If correct, this indicates that regional political and community participation is essential and that CGIAR research should be closely integrated with national research. This is one of the major objectives of the ecoregional approach.

- **Systemwide Coordinating Committees** — These would work entirely through existing structures and would have very limited influence unless they also controlled funds. TAC has argued elsewhere that it is inefficient to set up another layer of management in the CGIAR.

- **Professional Networks** — There are a number of well-tried models, such as the international scientific unions, for communication amongst professional people working on NRM problems. The IARCs have long been involved with networks that include NARS scientists, but there is the opportunity to improve communication with others working on NRM, especially from advanced institutions and NGOs.

TAC's view is that the first priority should be to establish partnerships between the main groups of natural and social scientists working for INRM at the regional level. There is a lot to be learned about how to facilitate the development of such partnerships (consortia) and how to operate them effectively without the transaction costs being too heavy. Then the research consortia need to maintain good communication with the people working to improve NRM in practice. This is for two main reasons—to make sure that good use is made of existing information, and to receive early notice of problems requiring further research.

The 1990 Expansion Report floated the possibility of establishing a global council to link ecoregional mechanisms. TAC does not favour any form of coordinating committee that adds a layer of management to those already existing in the Centres, NARS, and advanced research institutes. However, there need to be effective mechanisms for evaluating proposals for partnerships in INRM research and for funding those that are approved. This is part of the current move in the System for a part of the donor funding to be allocated to programmes rather than directly to Centres.

There is some uncertainty about the present effectiveness of professional scientific networks in subject matter areas that are important in the CGIAR's SW/NRM research, especially for communication with leading scientists in advanced research institutes in developed countries. The inclusion of communication networks (consortia) in the SWNM Initiative should help to strengthen such links.

5. Concluding Comments

The ideas represented in this TAC assessment of natural resources management research in the CGIAR, with a focus on soil and water resources, have been evolving over a considerable period of time. When the study started, the SWNM and Systemwide water initiatives were merely ideas in the minds of a few people. The System has been moving very rapidly in natural resources management research, searching for the important researchable issues and for those for which the CGIAR has a competitive advantage in terms of international research. The TAC study has taken this rapid transition into account. The study attempts to assess the direction of change that is in fact taking place in the System, as well as the strengths and weaknesses of past and current activity.

As such, this study represents TAC's evolving ideas on soil and water research priorities and strategies for the System; and the study results will be fully integrated into TAC's current priorities and strategies activity. Further, TAC will use the study as a framework against which to judge future work on soil and water research in the CGIAR.

ANNEX I

AN INTEGRATED NATURAL RESOURCES MANAGEMENT (INRM) FRAMEWORK FOR WATERSHED MANAGEMENT RESEARCH IN THE CGIAR[1]

Development activities in most cases are confined within political boundaries, with little regard for natural system boundaries. However, the forces of nature ignore political boundaries. Water flow, landslides, erosion, fish migration, and water pollution take place within watershed boundaries. Hydropower, irrigation, and transportation systems influence, and are influenced by, the natural processes of watersheds. Most upland activities in a watershed eventually have some impact downstream, often affecting different political units and different countries.

Watershed management has evolved as an organizing framework within which political units can deal with the various biophysical issues involved (see Table 1 for an overview of watershed management objectives and measures). With

Table 1: Watershed management objectives and measures

	Measures	
Objectives	Vegetative Measures/Land Use Management	Structural Measures
Maintain or increase land productivity	* encourage appropriate agroforestry and soil conservation practices * afforest and reforest on a sustainable basis to meet fuel, fodder and fiber needs * control grazing to sustainable levels * stabilize slopes and terraces * control salinity buildup and waterlogging * encourage appropriate forage species * choose appropriate crop species	* contour terraces * erosion control structures * install and maintain irrigation facilities * water harvesting measures * water spreading
Assure adequate quantity of usable water	* encourage or require low water consuming species * use appropriate land use measures to protect reservoirs and channels	* water harvesting systems * reservoir and water diversion structures * wells * irrigation facilities * encourage new, water saving technologies * desalinization
Reduce flooding and flood damage	* revegetate or maintain vegetative cover to enhance infiltration and water co consumption by plants * zone/regulate flood plain use * protect and maintain wetlands	* reservoir flood control storage * water diversion structures * levees * gully control structures * clearing channels for better water flow (channelization)
Assure water quality	* maintain or establish vegetative cover in key areas and protect streambanks * protect groundwater and water catchments from contamination by controlling waste disposal * use natural forests and wetlands as secondary treatment systems of wastewater * control grazing and develop guidelines for riparian systems * control human and livestock waste	* water treatment facilities * develop alternative supplies

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1 This discussion is adapted from the following sources: 1) Brooks, K., P.F. Ffolliott, H. Gregersen, and K.Wm.Easter. Forthcoming. *Policies for sustainable development: The role of watershed management.* EPAT Policy Brief. Environment and Natural Resources Policy and Training Program. Midwestern Universities Consortium for International Programs; 2) Gregersen, H., K. Brooks, J. Dixon, and L. Hamilton (1987). *Guidelines for economic appraisal of watershed management programmes.* FAO Conservation Guide 16. Rome: FAO of the United Nations; and 3) Brooks, K. N., H. M. Gregersen, P.F. Ffolliott, and K.G. Tejwani (1992). *Watershed management: A key to Sustainability.* In Managing the world's forests, ed. N.P. Sharma, 455-87. Dubuque, IA: Kendal/Hunt Publishing Company for the World Bank.

knowledge of the interactions and the costs and benefits from alternative practices in hand, political forces have an easier (although generally not easy) time negotiating with each other and developing the policies that assure a more productive and sustainable use of the resources in major watersheds.

Watersheds are logical planning and management units from an environmental viewpoint. However, political boundaries are logical from a political viewpoint. To achieve sustainable development, the two have to be harmonized. This requires integrating the two viewpoints by adapting watershed management and upland conservation to economic and political realities, since ultimately the latter will dominate decisions (Box 1).

Managing Watersheds: An Integrated Approach

Thus, the policy challenge in developing any type of Integrated Natural Resources Management (INRM) Framework is to 1) understand and plan for the biophysical interactions among resources and their uses, and 2) integrate these biophysical realities with the reality of the political/economic world that determines their uses and misuses. The basic principles of integrated watershed management provide one such attempt.

Box 1.
The Polynesians who settled the Hawaiian Islands organized their political and economic systems on the basis of watersheds. They defined these watersheds as areas extending from the highest mountain peaks to the coast and into the coral reefs below the watershed outlet. Chiefs had full responsibility for their watershed. They considered each an economic, political, and environmental unit that provided food, water, and natural resources. They managed uplands for forests, used moderate slopes for upland crops, and planted lowlands in taro. They used streams to irrigate taro without polluting the fish-rearing coral reefs. They recognized that wise resource management and land use that avoided erosion and water pollution meant greater wealth for the political unit. (From J. R. Morgan. 1986. Watersheds in Hawaii: An historical example of integrated management. In Watershed *resources management: An integrated framework with studies from Asia and the Pacific*, eds. K. W. Easter, J. A. Dixon, and M. M. Hufschmidt, 133-44. Boulder: Westview Press).

Policies for INRM should promote land use practices that *prevent land and water degradation in the first place*. Rehabilitation costs more than protection and prevention.

The *objectives* and *principles* of watershed management provide a framework for organizing development activities involving land and water resources. This framework helps integrate the biophysical and socioeconomic aspects of natural resources management that also helps avoid environmental problems. Thus, it can provide an organizing framework for some of the CGIAR's research within the broader Ecoregional Approach adopted by the System.

Land use management and soil and water conservation *practices* provide the tools for activity within a watershed management framework. These practices include nonstructural actions (changes in land use and vegetative cover) and structural measures that can achieve objectives such as:

- **Maintain or increase land productivity**
  - encourage appropriate agroforestry and soil conservation practices
  - afforest and reforest to meet fuel, fodder, and fiber needs
  - stabilize slopes and terraces

- control salinity buildup and waterlogging
- encourage appropriate forage species
- build terraces
- construct gully control structures
- install and maintain irrigation facilities
- develop water spreading systems

- **Assure adequate quantity of usable water**
  - encourage or require low water consuming species
  - use appropriate land use measures to protect reservoirs and channels
  - develop water harvesting systems
  - construct dams for reservoir and water diversion
  - develop wells
  - construct irrigation facilities

- **Reduce flooding and flood damage**
  - revegetate or maintain vegetative cover to enhance infiltration and reduce surface runoff
  - zone/regulate flood plain use
  - protect and maintain wetlands
  - construct flood control dams
  - develop water diversion schemes
  - construct levees
  - construct gully control structures
  - develop/encourage flood-proof structures

- **Assure water quality**
  - maintain or establish vegetative cover along stream channels and protect streambanks
  - treat/control disposal of wastewater
  - control grazing and develop guidelines for riparian systems
  - control human and livestock waste
  - develop water treatment facilities
  - develop alternative supplies

These practices also provide the basic applied and adaptive elements towards which much of the research should be aimed within this particular type of INRM organizing framework. The integration will take place mainly through the policy and socioeconomics research that needs to be incorporated in the framework, i.e., the policy context provides the basis for integrating the practices to accomplish basic land and water management and conservation objectives.

Integrated Watershed Management Components of Relevance to the CGIAR

Figure 1 in the text provides an overview of a watershed management model of relevance to the CGIAR with its focus on land and water use. As noted, upstream activities impact land use units downstream, which in turn have their own impacts not only on-site, but also further downstream. Annex Figures 1, 2, 3 and 4 provide the details of the potential on-site and downstream impacts of the application of watershed management practices. Together with Figure 1 in the text, these four annex figures provide the basic building blocks for an integrated watershed management framework of relevance to the CGIAR.

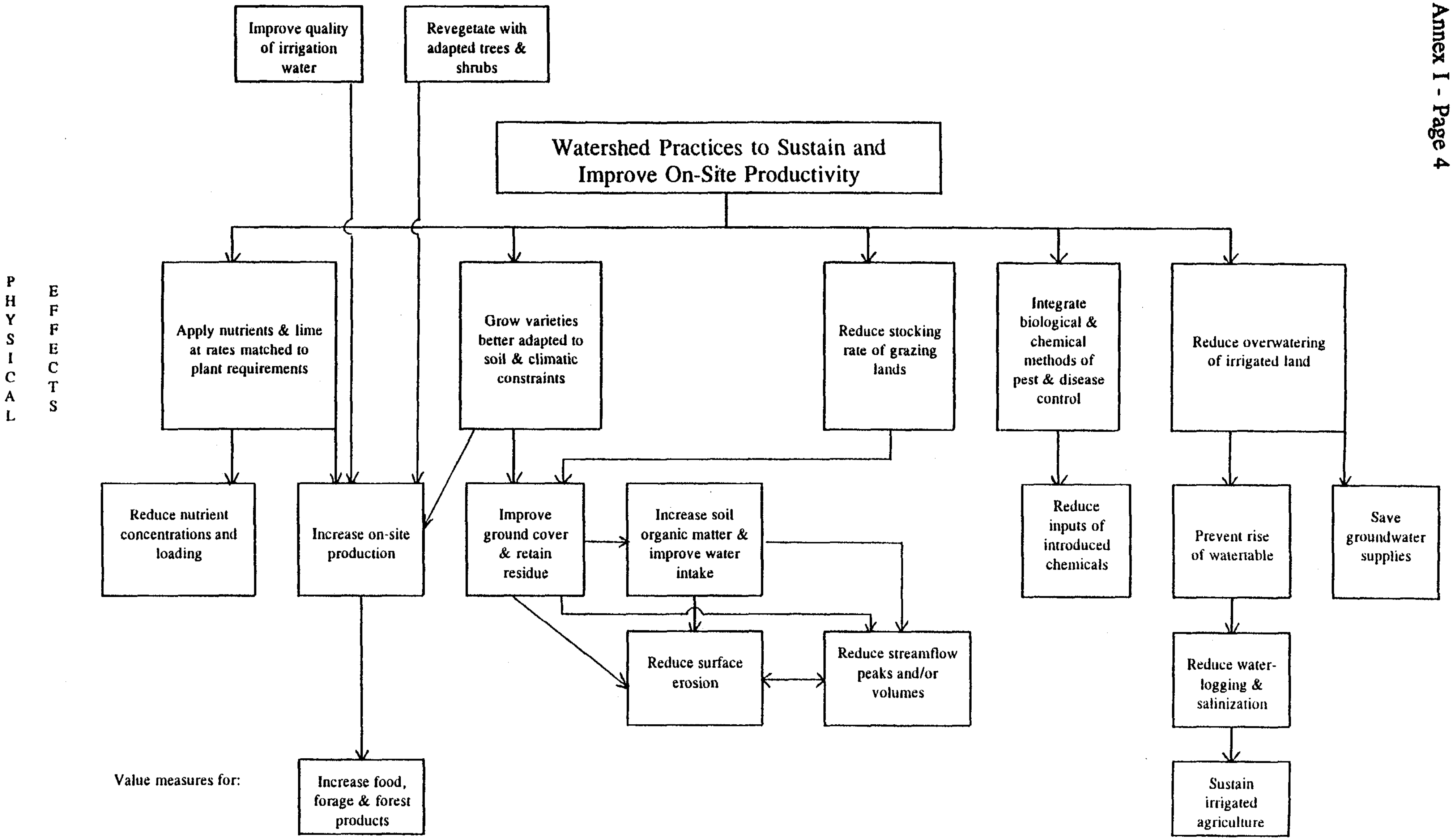

Figure 1: Priorities related to sustaining or increasing on-site productivity

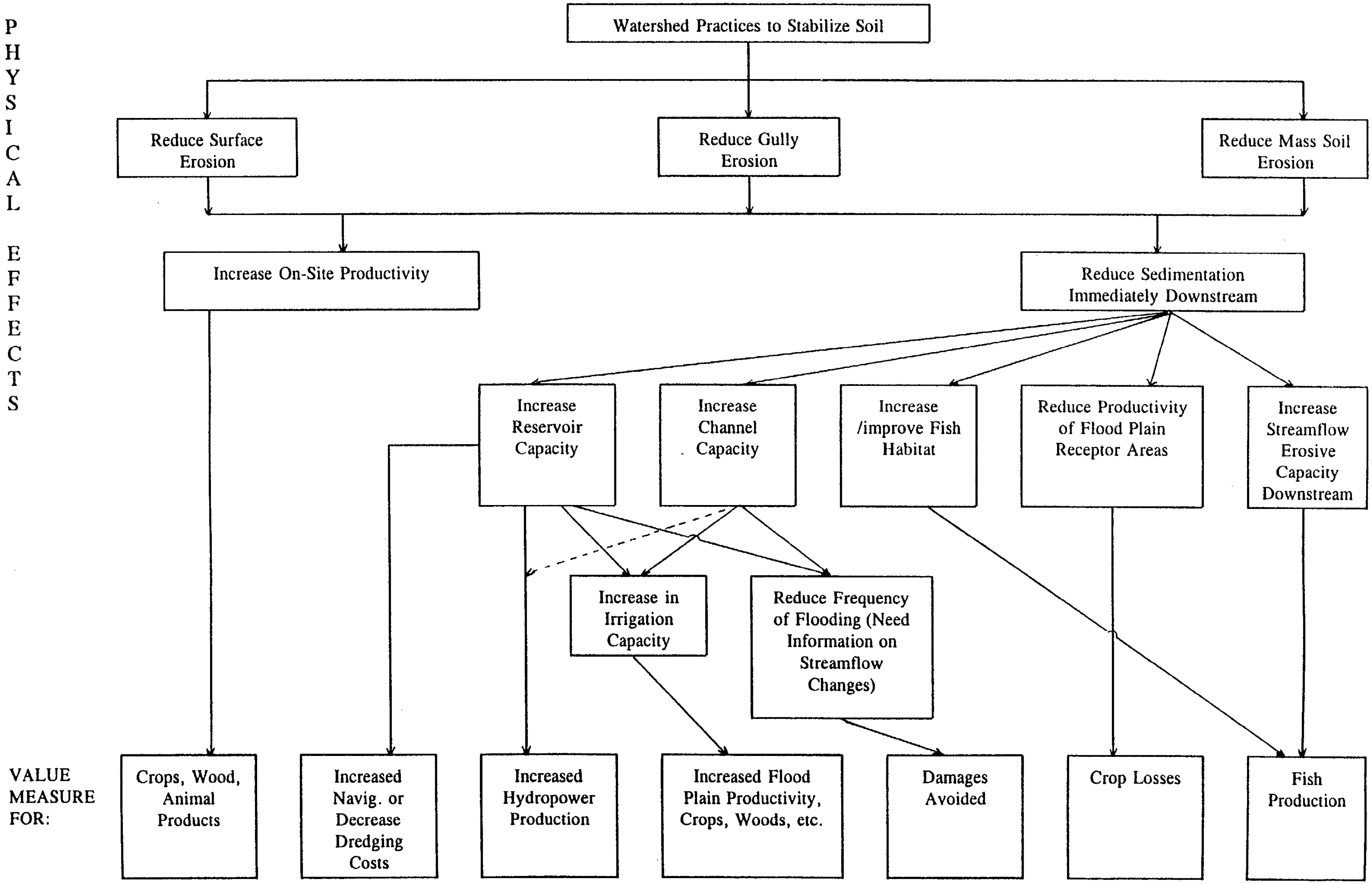

Figure 2: Priorities related to increasing soil stability (from Gregersen *et.al.* 1987).

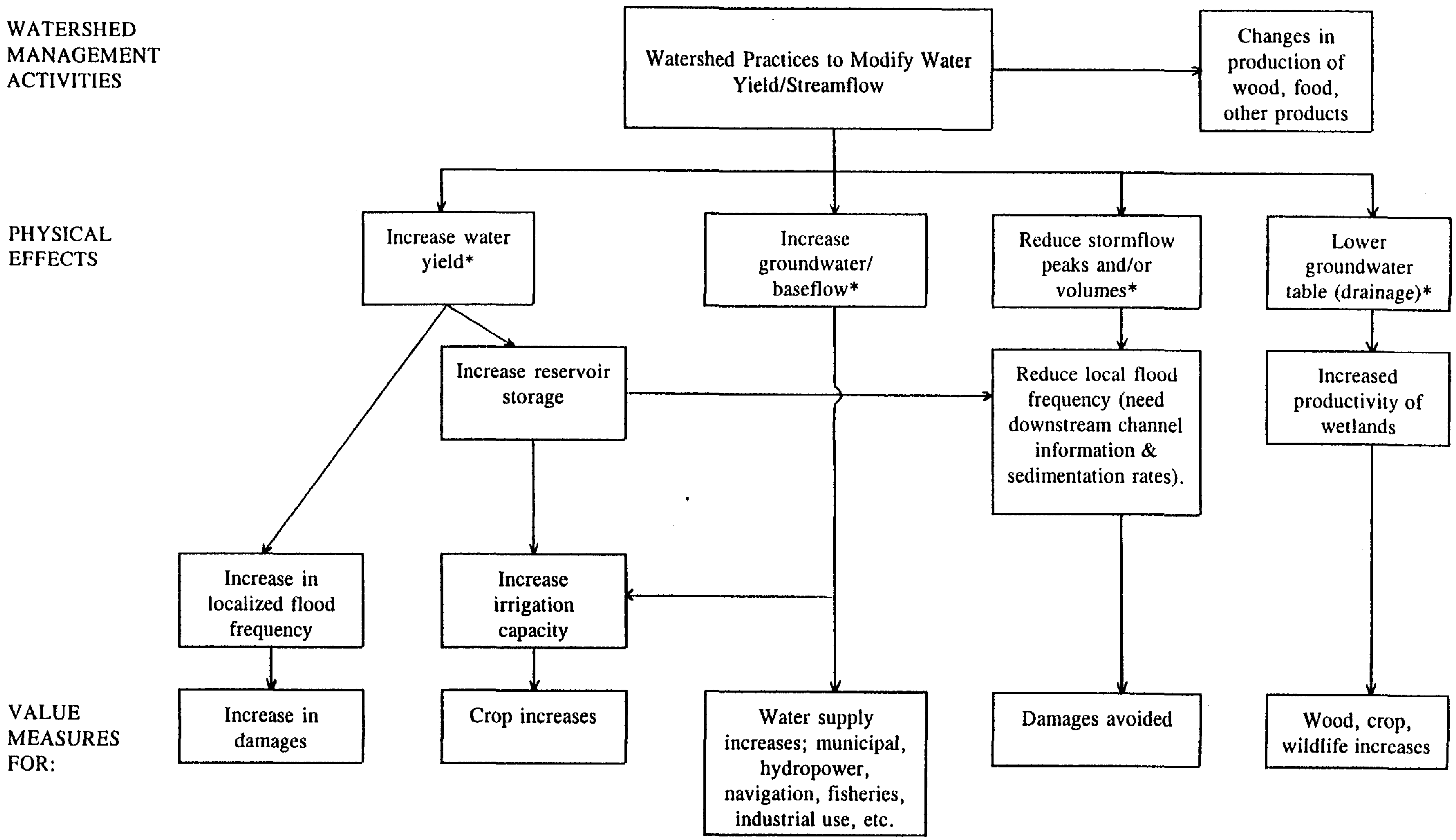

Figure 3: Priorities related to improving streamflow pattern and volume (from Gregersen *et.al.* 1987).

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*Note: Some practices can result in the opposite effects resulting in different benefits or costs which must be identified and valued.

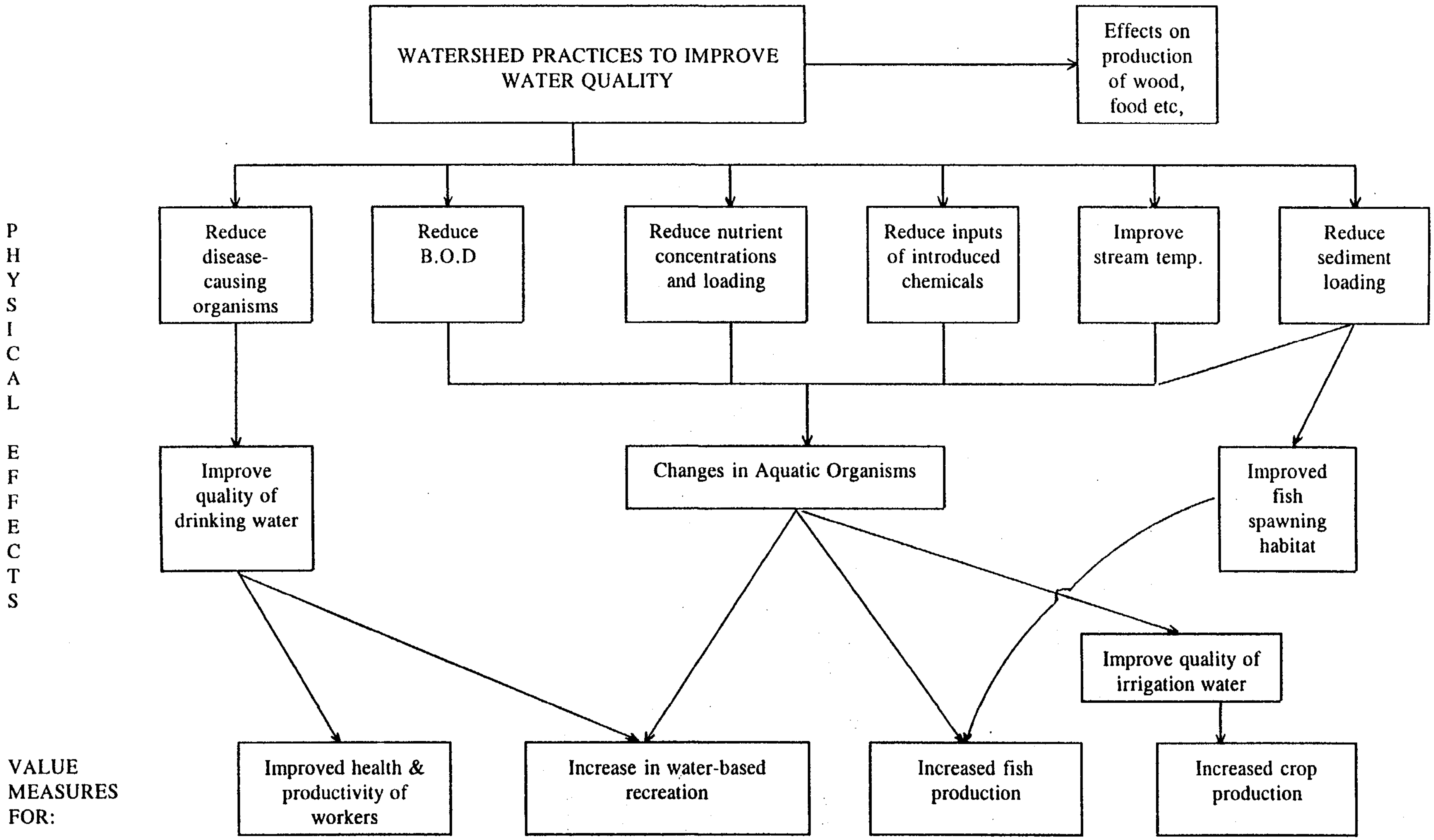

Figure 4: Priorities related to maintaining or improving water quality (from Gregersen *et.al.* 1987)

Modifying land use can achieve benefits in both uplands and downstream areas that translate into economic benefits to society (Box 2).[2] Indirect benefits of environmental quality also can occur through protection and enhancement of biological diversity, wildlife and fish habitat, and water quality.

Box 2.
Improved management of a watershed in northern Morocco that drained into a major irrigation reservoir showed an economic rate of return of 15.9 %. Economic rates of return on investment in watershed management and soil conservation-related projects financed by the World Bank have been calculated between 15 to 21 %.

In sum, long-term goals of upland conservation and watershed management can be achieved if societies develop appropriate INRM technology packages and the complementary policies that:

- Recognize the fundamental need to protect the environment and natural resource base on which all production ultimately depends.
- Incorporate in decisions the values of environmental services not presently traded in the marketplace,
- Reconcile the conflicts between natural and political boundaries.
- Provide for public investments, regulations, incentives, and taxes that recognize the links between upstream and downstream water and land use activities.
- Equitably distribute costs and benefits among political units, communities, and individuals according to who pays for and benefits from watershed management policies and the resulting actions.

Research - from strategic to adaptive - is required to accomplish the objectives incorporated in an INRM framework.

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[2] Brooks, K. N., H. M. Gregersen, E. R. Berglund, and M. Tayaa (1982). *Economic evaluation of watershed projects—an overview methodology and application.* Water Resources Bulletin 18(2):245-50; and World Bank (1984). *Annual report on FY84 Bank and IDA lending for agriculture and rural development.* Washington, D.C.: The World Bank.

ANNEX II

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SDR/TAC:IAR/96/9

CONSULTATIVE GROUP ON INTERNATIONAL AGRICULTURAL RESEARCH

TECHNICAL ADVISORY COMMITTEE

A STRATEGIC REVIEW OF
NATURAL RESOURCES MANAGEMENT RESEARCH ON SOIL AND WATER

TAC SECRETARIAT

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

April 1996

TABLE OF CONTENTS

1. Introduction

1.1. Scope

The underlying thrust of CGIAR research has always been towards the improvement in agricultural productivity. Productivity requires the economically appropriate use of germplasm, crop protection techniques, and also the careful management of soil, water and nutrient inputs. For best results, this necessarily includes protection of the on-site natural resources, so productivity and on-site short-term sustainability have always run in parallel where a farmer has a long-term interest in his land. However, the concept of sustainability has now expanded in terms of both space and time. All consequential environmental damage, including off-site or even global effects, is to be controlled, and the maintenance of the resources must be considered over long timespans, certainly into the next generation. There is a recognition that all these conditions must be in place to allow truly productive and sustainable agriculture to be carried out, whilst bearing in mind that the underlying purpose is to improve food security for the poor, at a time when the population of the less-developed countries is increasing at the rate of about 1 billion per decade.

TAC has now decided to mount a review of research needs in the management of soils and water, including within its scope the broader issues mentioned above. The field of review is therefore complex, and a number of issues are involved that have varying interpretations and definitions. For this reason several of these issues have been identified and discussed as part of this Introduction, in order to set the review in context.

Degradation of natural resources, in particular of the soil, is proceeding at an increasing rate (James et al., 1992). There are several causes leading to different types of degradation (Oldeman et el., 1990), but a particularly pervasive underlying cause is poverty (Shaikh et al., 1995). The poor are to be found in many parts of the world but, overwhelmingly, they are still located in rural areas of the less-developed world. These people are directly dependent on rural natural resources, of which they themselves are the key managers--users, custodians and exploiters. Their poverty, aided and abetted by their insecure tenure, frequently obliges them to take an extremely short-run view of their custodial responsibilities, and their decisions individually and collectively often result in their resources becoming degraded, sometimes in dramatic and socially unacceptable ways. Land and water (as well as forest and fishery) degradation is thus importantly driven by rural poverty, in turn determined by many factors, ranging from population growth and rural-urban migration, to rural-industry diversification, infrastructural development and employment, as well as resource degradation itself. Understanding better the nature of these poverty-resource management links is thus a central element of any NRM research portfolio, including that of the CGIAR Centres working with their local and national research partners. Interventions, including research-based technology and policy improvements, that assist in alleviating poverty or increasing sustainability will thus have strongly synergetic effects and are best seen as necessarily complementary approaches.

For environmentally sustainable agriculture, the whole resource base has to be protected and enhanced. Within this, the CGIAR paper "A Research Agenda for the Future" of 6/10/94 noted the increasing importance of efficient water use, and stated five major research thrusts for the CGIAR System: water and irrigation management; "ecosystem (including watershed and river basins) management; ecological foundations of sustainable production (including soil/water/ nutrient/plant/animal relations); ecosystem conservation and restoration; and common property resources." More recently, the February 1995 Lucerne Action Plan requests CGIAR to "Address more forcefully the international issues of water scarcity, soil and nutrient management, and aquatic resources." The main report of this study (Document No: SDR/TAC:IAR/96/2.1) has set out in more detail the background to NRM research within the CGIAR.

Various recent initiatives are in progress or in planning within the CGIAR System that contain an emphasis upon soil and water. This includes work under most of the Ecoregional and Systemwide programmes which have started in the last few years. The Soil-Water-Nutrient (SWNM) Programme is now being planned by a group from CGIAR and other institutions, and was printed as the —"Zschortau Plan" (DES/IBSRAM, 1995). These initiatives are very relevant to the subject of this paper. However, the review prepared by the TAC Secretariat (Document No: SDR/TAC:IAR/96/10), specifically reviews all ongoing CGIAR work in this subject. The references to ongoing work in this paper will therefore be mainly in relation to new developments in research, and are not intended to be comprehensive.

1.2. Objectives and Focus

The sustainability of natural resources includes many environmental issues, in which CGIAR will have an interest. However, it is essential that this review should maintain a clear focus, and TAC has specified that this study should concentrate most on soil and water as explained in the main report; to quote the Framework paper TAC (1995) which was prepared to guide the study: "TAC decided to limit the present study to terrestrial ecosystems, and more specifically focus on the use and conservation of soil and water resources for the sustainable benefit of humans, particularly through the contribution of these resources to sustainable agriculture and livestock production." In practice, this requires the inclusion of plant nutrients, because of the role of the soil in supplying them.

This requires consideration both of the practical use of these resources in the production of food and fibre, and the consequences of that use for the quality of the resources. Any damage to the resources then impacts upon both the further production of food, and on other environmental and sustainability issues. Some of these are directly relevant to the CGIAR, such as water quantity and quality for water supply, fish farming, agricultural biodiversity, forestry and marine impacts, though they are not main subjects of the study. A number of other issues may also be touched upon, which are not close to the interests of the CGIAR, but which are regarded as important in that they were identified in Agenda 21 as related to natural resources management (NRM). This includes general biodiversity, biogeochemical cycling processes, landscape value, leisure uses and processes that are important for global change. As noted in the main report, NRM with a strong emphasis on sustainability can appropriately be defined as Integrated Natural Resource Management (INRM).

The intention is therefore that this study should be holistic, not in a philosophical sense, but on the practical grounds that soil and water problems are so closely interwoven and so pervasive that any single-issue solution may cause more harm than good by unforeseen interactions and impacts, unless these linkages are taken into account. The solutions must therefore contribute to the overall sustainability of agriculture. In particular, the study will include detailed consideration of off-site problems, which have sometimes been neglected in favour of excessive concentration upon on-site productivity.

The many interlinked aspects of NRM make it difficult to prioritise research. However, this is an essential part of this study, and the paper concludes with a list of research subjects which need expansion if better resource management is to become possible.

1.3. Sustainability and Productivity

Sustainability is a central issue for this study, but it is by no means a clear or generally agreed concept. In "A Research Agenda for the Future" the CGIAR stated that agricultural outputs would have to be doubled in the next 30 years, and that this has to be done without damage to the environment. Following this, the CGIAR appointed a Task Force to study Sustainable Agriculture (Report of 14 April 1995). There are many definitions of sustainability (Pearce et al., 1991; Munasinghe and Shearer, 1995; Crosson and Anderson, 1993), but the following definition (Tinker, 1993) is used here, as it agrees well with that used by the Task Force. It is also close to that adopted by Smyth and Dumanski (1993) in considering the evaluation of sustainable land management. A sustainable agriculture must be:

(a) economically viable;
(b) must aim to protect its supporting natural resources;
(c) must be broadly acceptable to the population at large, including all off-site problems.

Economic viability is obviously essential, but it is difficult to generalise about because it is so open to change through market instability and government policy, sometimes on a very short-term basis. The protection of natural resources is most relevant to this study. Even this is not absolute: soil salinity is generally accepted as being highly damaging, but it becomes much less so if it were intended to grow only a fully salt-tolerant crop variety. Acceptability to the population covers a great range of factors, from religious beliefs to health concerns, animal welfare and popular environmental issues, all of which are often country- or region-specific.

It is obvious from the above definition that all socioeconomic and biophysical factors must be of critical importance for Natural Resource Management (NRM) research. Interference with the world's biogeochemical cycles, such as net carbon flow to the atmosphere or nitrogen flow to the sea must be controlled. Impacts on biodiversity, measured on both regional and global scales of importance, must be minimised. Decisions about how strict these standards must be is very difficult to take, but progress is being made.

"Sustainable development" was made popular by the Brundtland Commission. It did not, however, define how much development is sustainable, or for how long. No one can foresee what will be considered essential after a long time span. Sustainability is not an absolute, but varies with time and place, and each case needs careful analysis. For example, improving agricultural productivity has a general value in preventing environmental damage, in that it lessens the pressure for the development of more fragile land and water resources. In this way intensification can actually improve over-all sustainability.

An appropriate precautionary approach in natural resource management is, where possible, to prevent degradation and pollution rather than to remedy it (Lal and Stewart, 1992). It is unavoidable that damage will occur in some cases, and much attention must be given to the linked questions of reversibility and resilience. If any environmental damage that is caused can be reversed relatively easily by stopping or reversing the action causing it, then some degree of damage may be acceptable for a period. But if the damage is irreversible, such as the total extinction of a species, or massive erosion of a mountainside, then all efforts should be directed towards immediate prevention. Reversibility will depend upon the type of action, its intensity and duration, and the resilience of the natural resource acted upon. Resilience implies the ability to return to its initial state after being stressed (Lal, 1994). The concept is more complex than appears at first, because resilience is not a single value. For example, the water quality of a river may show high resilience, because as soon as the pollutant source is removed, the river water returns to a pure state. However, the physicochemical resilience may not be matched by the biological resilience, because the river biota may have been destroyed during the pollutant incident. These various forms and degrees of complexity in the concepts of reversibility and resilience (Conway and Barbier, 1990; Conway et al., 1994) require a careful and critical approach, because many subjective judgements are involved.

There is a rather widespread belief that high productivity and sustainability are in some way incompatible. However, it is easy to find examples to show that this is not so: both low and high productivity systems can be both sustainable and non-sustainable. Thus over-grazing of hillsides is both unproductive and unsustainable; traditional long-fallow shifting cultivation is unproductive but sustainable; high intensity rice or wheat with careful agronomy is both productive and sustainable, whereas careless use of irrigated land is productive but unsustainable. Sustainability always demands care, and the higher the productivity needed, the greater the care demanded, and this is a problem that research has to solve.

1.4. Land Use

A holistic approach to natural resource use, such as is involved in a combined demand for productivity and sustainability, must involve the concept of land use and its allocation. The mosaic of topography, soil and water within a landscape, watershed or region can be used in many ways. These will have a scale of priorities in socioeconomic terms, by being in greater demand or producing a greater profit, but they also have to be tested against biophysical principles. The problems that can arise are best seen in the pressing demand for farm land in some less-developed countries, which leads to the use of almost any land, however unsuitable. Some 250 million people in the tropics still depend on some form of shifting cultivation, which is gradually becoming less and less sustainable as the fallow periods decrease (Crosson and Anderson, 1994). The question of which form of land use will succeed this is of extreme importance (as studied in the Alternatives to Slash and Burn Programme of the CGIAR). A detailed study should be able to generate a set of recommended or ideal land uses, which may be different from those in place at that time. Unsuitable land uses will in the medium to long term prove to be unsustainable, and the sooner this can be determined, the less damage is likely to be done.

It is a relevant question how much work on land capability research that the CGIAR Centres should do. There is still a strong need for better biophysical research underpinning of the physical classification of land and water resources, especially exploiting the rapidly growing synthesis opportunities afforded by GIS methods and cheapened microcomputer databases. Demographic and socioeconomic information is also critical to such work, and the data and trends that drive them are rather local and national in scope and nature. Indeed, the responsibilities for such knowledge assembly and interpretation normally lie within national planning agencies, and execution within local and national governments.

1.5. Global Change

Most medium- and long-term planning of agricultural research in the past has tacitly assumed that the state of the atmosphere and the climate will remain constant, and most of our assumptions about agricultural sustainability depend upon this. This can no longer be taken for granted, because of the anthropogenically caused global change, the three drivers for which are land use change, atmospheric change and climatic change. The increase in concentration of carbon dioxide in the atmosphere is a proven fact, and it will continue to increase for many years, even on optimistic assumptions (IPCC 1990). The direct effects are likely to be benign, with increased growth rates likely in many plant species, but there are many uncertainties about the impacts

The main dangers lie in climatic changes, in mean values or in variability (Parry, 1990). Such changes could well start to occur within the next 20 years, and even small changes could cause serious agricultural problems, at a time when the rate of population increase is maximal. No specific actions are possible at present, but precautionary planning should include these possibilities (Tinker and Ingram, 1995). CGIAR would have a vital role in regard to climate change impacts in the tropics if and when it happens.

Several mathematical models have already been constructed to predict the effects of climatic and atmospheric change (Rosenzweig and Parry, 1994; Darwin et al., 1994; Mendelsohn et al., 1995?). These have generally concluded that the less developed countries in the tropics would have the greatest problems in dealing with these changes.

1.6. A Watershed Approach

This study places considerable emphasis upon the concept of the watershed, and its use in NRM research. We stress that the watershed approach is not relevant in all situations, and good research may be done without invoking it. Nevertheless, most land is part of an identifiable watershed and, depending on the size of the watershed, the concept can give a deeper and clearer perspective on sustainable agriculture, and soil, water and land use. For our purposes we define a water shed as the land area from which drainage runs to a single defined river and its tributaries.

The basic natural resources for agriculture are climate, geology, landform (topography) and the soils that develop from them, together with the biota that contributed to soils formation, and those (and their genetic resources) that are used for agricultural purposes. Soils and landform develop together, and in many parts of the tropics both are very old. A watershed is a very appropriate way of looking at these resources within ecoregions, because it shows the spatial linkages very clearly. It is the logical unit for consideration of hydrological questions, including water demand and supply, irrigation, water quality and quantity, because the total size of the water resource initially available in the watershed can be precisely defined. A watershed will in effect be a cross-section or sample of the whole landscape. It will therefore include examples of all major landforms, apart from the overall constraint of the total altitudinal range within the watershed. For similar reasons, it will include examples of most major soil types found in that climate, subject to the distribution of rainfall across the watershed.

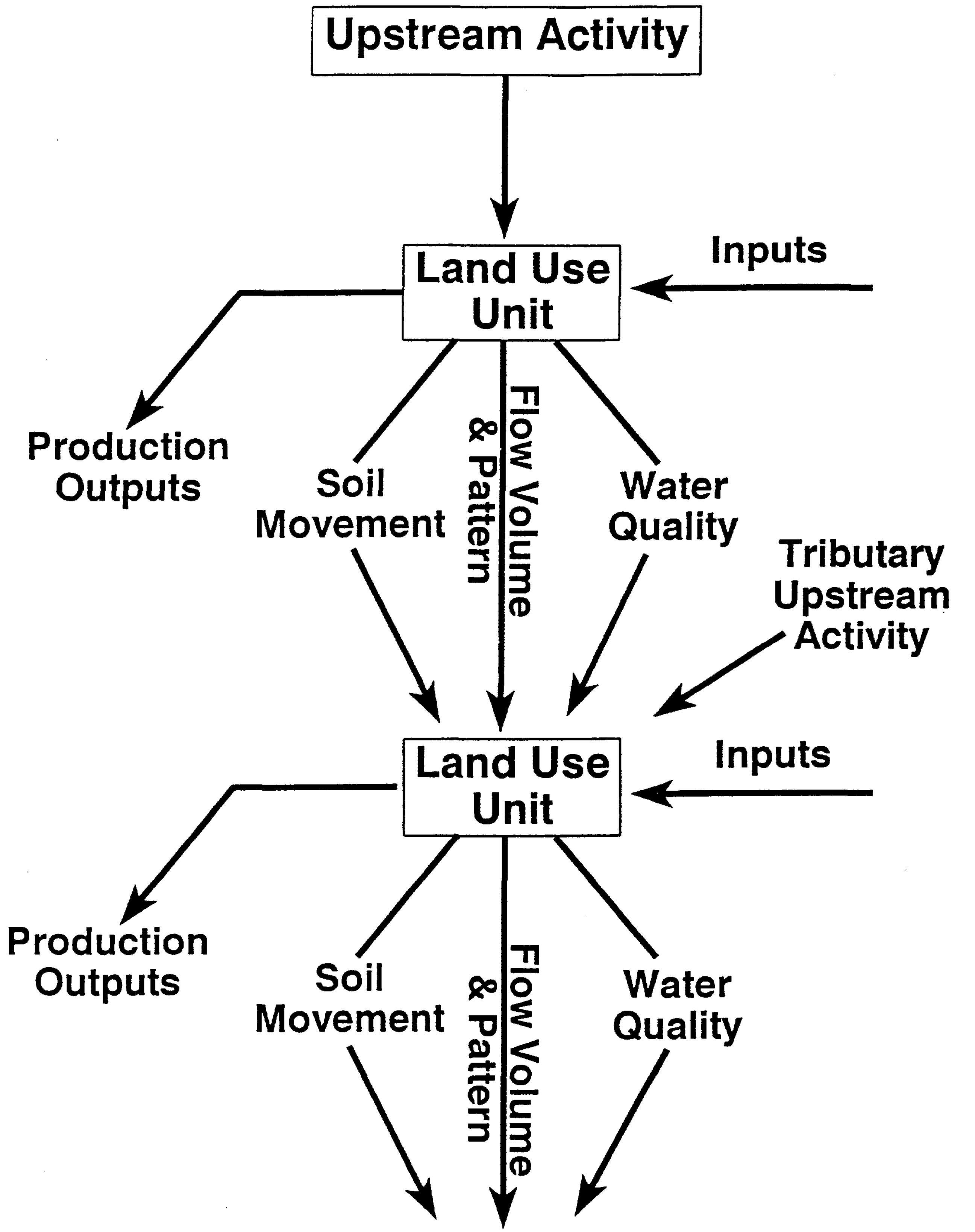
In terms of landform and soils, a watershed is therefore likely to be a very heterogeneous unit. Its value lies precisely in providing a sample of the total landscape, rather than a homogeneous block, when the interactions between various parts of that landscape are to be investigated. For similar reasons Greenland et al. (1994) classify the spatial dimension for cropping system research as the field plot, for farming system research as the field-village, but for NRM research as the watershed-region.

The further subdivision of a watershed is therefore a very important step in the planning of research, in which topography, climate, geology, soil type and farming systems will all be taken into account. It is therefore necessary to define the "land use unit": an area within which the climate, soil, farming systems, land cover and socioeconomic conditions are so homogeneous that any solution to a land use problem is probably applicable over the whole unit, and similarly defined units elsewhere (Figure 1). A typical very large watershed would include many different land use units, and indeed components of several ecoregions, whereas a small (sub)- watershed might lie wholly within one ecoregion and have only a very few land use units.

The transferability of results from watershed to watershed is possible, between a set of homogeneous and comparable watershed subdivisions. The "catenary" concept is particularly important, because this states that certain soil types (and by implication land use units and farming systems) will recur across the landscape in topographically equivalent positions (Sanchez, 1976, 1994). Where this applies, the results obtained in one watershed should be applicable in others.

The watershed approach allows an overall view of the water resource in a systems approach. The land use in a given part of the watershed affects the partition of water between run-off and infiltration, and between evapotranspiration and recharge. The physical reasons for this are well understood (see below). It is therefore possible to compare the advantages of using a finite amount of water in different ways, for trees, irrigated crops or for industrial or domestic purposes. The quality of the water in

Fig. 1: Land Use Units - Linkages in a Watershed



different parts of the watershed can also be monitored and to some extent controlled. This is important for health reasons, e.g., it is believed that up to 3.5 million children die each year from water-borne diseases.

The focus on watersheds in relation to land use is by no means new, though few if any earlier projects have attempted the wide scope of the work discussed here. Recent studies have included Lal and Russell (1981), Pereira (1989) and Gregersen et al., (1987). The earlier East African work is particularly relevant. Pereira (1989) suggested that CGIAR should strongly emphasise this approach. The interest in water supply and use within the CGIAR System at that time ultimately led to the setting up of IIMI by a group of donors, but the focus on the watershed did not materialise. There appears to be only one significant watershed experiment in the CGIAR System at the moment, namely the relatively small SCOR project run by IIMI in Sri Lanka.

One task of this study is to determine whether the CGIAR System could use a watershed approach with advantage, how it would strengthen the ecoregional approach, and whether the new developments and techniques in such an approach will allow research to advance beyond what has been done before. It would be very easy for an NRM study to lose its way in masses of detail, due to the inherently site-specific nature of soil/water research. An emphasis on the watershed is only of value if it can act as an organising and simplifying tool for marshalling such diverse soil/water problems, i.e. if it can act as a framework.

The main discussion in the paper is therefore organised according to Figure 1 and Figure 2 (see later), and includes a series of the main soil/water problems in an idealised catchment containing examples of major topographies and climates. Conceptually, the study considers four outputs or impacts (Figure 1):

(i) Production of direct outputs from the land use unit;
(ii) Off-site impacts in erosion and soil movement;
(iii) Impacts on stream flow volumes and patterns;
(iv) Impact upon downstream water quality.

It must make sense to work at the watershed integration level for many projects involving both movement of soil and water, and their efficient utilisation and stability, within the watershed landscape. It is quite likely, however, that even in some countries that lie within a large watershed, there may be other elements of integration, such as social, ethnic and political organisational arrangements, that deserve more explicit consideration than the fact that everyone is in the same watershed. This will apply, for instance, to policies that cross sectoral boundaries, and macroeconomic policies that have direct impact on the rural sector, in which case a type of rural area management paradigm would be more applicable, such as has been adopted in some of the Collective Action programmes discussed in chapter 3.

With situations involving different nation states that share (perhaps just parts) of a watershed, aspects of international cooperation and dialogue on understandings may form a critical element of policy dialogue together with the biophysical aspects of watershed management. In some cases, nations states that share parts of a watershed may not even be contiguous in geographical boundaries, and yet are linked by important physical flows of water and soil, the classic case being Nepal and Bangladesh. The degree of achievable policy dialogue within a watershed of this geopolitical distance is thus something of an issue that transcends most boundaries of ordinary policy dialogue and poses worthy challenges for international agencies to explore potential interventions, hopefully from a research-informed knowledge base such as can only be enhanced through international effort blended with national counterpart knowledge and experience. The Nepal-Bangladesh case provides an excellent reason to work with the watershed framework for all the countries involved to be linked.

2. Critical Biophysical Processes

2.1. The Nutrient Cycle and the Chemical Fertility of the Soil

There are two, perhaps three, basic cycles in which the main plant nutrients circulate. The first consists of the uptake of nutrients from the soil, their incorporation into plant tissue, and their direct return to the soil. This natural cycle dominates in almost all natural vegetation, and is one of the biophysical bases of shifting cultivation. In agriculture there is an additional loop, in that nutrients may be removed in harvested material, but partly returned in human or animal wastes. In far too many parts of the less-developed world this nutrient cycle is no longer efficient, because the duration of the fallow period has become too short. Finally, all vegetation has an external open "cycle", where nutrients escape to the atmosphere or to rivers or groundwater, and are indirectly and partly replaced from the atmosphere or soil mineral breakdown. This external "cycle" increases greatly during soil degradation. It is also a main component of soil acidification, which is due to loss of cations from the soil profile (Uexkull and Mutert, (1995).

Where the social and economic conditions are such that nutrients in harvested produce are not returned to the field because it is sold to cities or abroad, the harvested nutrients become part of the external cycle also. The removal in the harvest from intensive agriculture can be very large, up to over 200 kg/ha of N or K. It is then necessary to replace these losses with fertilizer. Such heavy cycling is difficult to control accurately, which is the main reason for the losses in this type of agriculture. Considerable advances have been made in modelling movement of N in plants and soils over the past 20 years, so that control can now be improved (Addiscott et al., 1991). A key requirement is that nutrients, particularly nitrogen, shall be supplied as far as possible at the time when they are required by the growth of the plant, so that they are taken up relatively rapidly. This is particularly important where heavy rainfall and light-textured soils lead rapidly to leaching. However, the unknown local variations in growth, yield and naturally present soil nitrogen mean that precise control is still difficult. The decision on the correct amount of fertiliser for a particular piece of land under a particular crop is still very open to error, even in highly developed agriculture.

The very low fertility of soils under shifting cultivation found in much developing-country agriculture mean that yields and nutrient offtakes are correspondingly low, and are often decreasing (Table 1 and 2). As the fallow period shortens, the internal nutrient cycle becomes still less effective. It is imperative to import nutrients as manure, residues or fertilisers in such cases. There are many ways in which the nutrient cycle can be more tightly closed, such as by recycling all plant, animal and human residues, applying hedgerow or agroforestry prunings, and the use of legume crops, but this does not make the soil productive if it starts from a severely depleted state. Even the best-managed cropping will have some losses through the external cycle, which have to be replaced. Nitrogen is a special case because it can be fixed from the atmosphere, though this is often not sufficient to meet crop needs. Cropping of a soil which is continually losing nutrients, particularly phosphorus and potassium, is ultimately non-sustainable (Smaling, 1993). This is the basic argument for the use of fertilisers. The challenge is to use these for intensification so skilfully that the pollution problems seen in temperate (and some tropical) agriculture are avoided, and that their use becomes sustainable. It is even more challenging to do so in economical and affordable ways for resource-poor farmers with small farms, especially in Africa. Nutritional problems are often severe in shifting cultivation systems as these become more intensive. Table 1 shows several classifications, all based essentially on the ratio of cropping years to the total cycle length, emphasizing the importance of this ratio for the productivity of the system. The way in which productivity decreases as the system moves from Phase 1 to more intensive states depends greatly upon the soil type and its resilience. Very few soils will stand continuous removal of nutrients in continuous cultivation. Table 2 contains some excessively low yield values, that are presumably largely due to nutrient depletion. Nutrients contained in organic residues are very valuable, and should be used as extensively as possible, both to enhance nutrient cycling, and because they have slow-release characteristics that may in some circumstances make them more efficient than fertilisers for the same total amount of nutrient. Their prime drawback is that the quantity is limited.

It is argued above that higher production will eventually require the use of fertilisers, which are sometimes considered suspect on grounds of sustainability. Potassium and phosphorus are produced by extractive industries, and their supply is therefore not indefinitely sustainable. In fact, the potential reserves of potassium are about 1000 times greater than the annual production, and phosphate rock resources are about 450 times greater (Louis, 1993). Also, nutrients from fertilizers may escape from the local nutrient cycle, and cause pollution of water ways and groundwater, with eutrophication and health hazards. This problem can be largely controlled by careful agronomy, and this must become a larger research topic in less-developed countries in the future. (Nye, 1992)

This consideration of nutrient cycles and balances suggests that greater efficiency in uptake by plants is of only partial utility, because nutrient must at some stage be resupplied if it is to be taken off in crops. However, more efficient uptake does allow the soil in a field to be operated at a lower nutrient concentration than otherwise, and this will tend to minimise losses. Low soil concentrations of nitrogen also encourage resupply of nitrogen by associative or symbiotic fixation, which can supply all or part of the requirement. Associative fixation had an uncertain record at one time, but it appears that some grasses can fix important amounts. The fungal mycorrhizal root associations can improve the uptake ability for phosphorus, and thereby make more of the soil phosphorus available at a given plant growth rate (Sieverding, 1991).

Table 1: Proposed Divisions of Shifting Cultivation Systems

Shifting cultivation land **L>10***	**Recurrent cultivation land** **Long. medium. short** **L=7-10 L=5-7 L=3-5**		**Permanent and semi-permanent land** **L<2 or=2-3**	**Allan, 1965**
Phase I Simple shifting cultivation Dwellings and land move together	Phase II Recurrent cultivation May be complex	Phase III Recurrent cultivation with continuously cultivated plots Always complex	Phase IV Continuous cultivation	Greenland, 1974
Extensive shifting cultivation R<15**	Intensive shifting cultivation R=15-30	Semi-permanent cultivation R=30-50	Permanent farming R=70-100	Ruthenberg, 1976
Forest fallow	Bush fallow	Short fallow	Annual/ multicropping	Boserup, 1981

* C= number of cropping years/cycle. F= number of fallow years/cycle, L=(C+F)/C..
** R=100C/(C+F).

Table 2: Yield per Unit Area (kg/ha) of Some Major Staples in Some African Countries

(selected data from FAO Production Yearbooks)

Country	Crop	1961/65	1969/71	1979/81	1989/91	1993
Côte d'Ivoire	Rice	890	1168	1171	1174	1334
	Maize	680	773	700	713	831
	Cassava	2500	3300	5266	5680	4521
	Sorghum	500	507	538	563	600
Ghana	Maize	550	982	1078	1300	1509
	Cassava	8500	7419	8647		7226
Kenya	Wheat	1678	1678	2011	1747	1579
	Maize	1100	1489	1360	1300	1249
	R&T		7722	7993		8077
Niger	Millet		422	435	383	357
	Sorghum	480	445	432	280	153
Nigeria	Maize	920	869	1350	1300	
	Sorghum	850	652	634	1093	967
	R&T		9585	9728	9930	10193
	Cassava	6200	10592		11150	10500
Sudan	Millet		567	397	166	
	Sorghum	900	808	725	534	509
Tanzania	Maize	1180	813	1306	1340	1404
	Sorghum	870	503	763	970	1102
	R&T		4902	9491	8280	8223
	Cassava	4100	4854	12071	10830	10400
Uganda	Cereals		1069	1551		1528
	R&T		4449	5802		6594
Zaire	R&T	12100	6795	6901	7562	7906

The worst understood part of soil science and plant nutrition today is almost certainly the soil microbial population and its functions in relation to higher plants (Lynch, 1990). Very few of the microbial species are identified, the systematics are fragmentary, and the functions are known accurately only for a limited number of specialist organisms. Many of the soil processes that they carry out are essential for plant nutrition, soil structural stability, and several of the most important biogeochemical cycles. Considerable strides have been made in the past decade, but the introduction of new molecular biology techniques should allow accurate identification of both species and function in the future.

2.2. The Structure and Physical Protection of the Soil

Soil structure is still not well understood at a fundamental level, and much of the science is largely empirical. It is still not possible to describe 3-dimensional structure or porosity in fundamental terms, and a great deal of reliance has to be placed on inferences from the moisture characteristic and the hydraulic conductivity. The strength and impedance of soils are closely allied to structure and texture, but cannot be predicted in a mechanistic way. The quantity and behaviour of the particular clays in the soils (low-activity kaolinites or active smectites) together with the amount of soil organic matter are critical. In particular, it is difficult to predict the degree of resilience of a soil following structural damage. This rather weak theoretical basis means that much of the work in these subjects must be empirical, applied and adaptive, though absolutely essential.

It is extremely important to preserve structure, otherwise capping, loss of infiltration, wind and water erosion, and root impedance easily occur. The general field methods of preserving structure and porosity are well known from long experience; maintain soil organic matter levels, maintain vigorous plant growth, prevent heavy loads, prevent large raindrop impacts at terminal velocity, and cultivate with care at the right time. Even so, the immediate strength of the soil structure, and the speed with which it regains structure after damage (resilience) are not properly understood (Greenland and Szabolcs, 1994). Even soils with similar textures may show great differences in the persistence of structural damage. Research must therefore aim at better practical and site-specific methods of preventing damage, or remedying it in suitable cases, and a great deal of progress has been made in this way. Social aspects are important. For example, even when the value of mulching is recognised for structure protection, there are often alternative uses for the vegetable material which have priority.

Wind erosion can be devastating, and is a critical component of the loosely defined process called desertification. Once soil movement starts it helps to loosen more soil, and dust storms rapidly develop. The essential control measure is to maintain a sufficiently dense vegetation cover, so that soil does not start to move, which is why intensive grazing is so dangerous, especially under variable rainfall regimes and socioeconomically driven high herd and flock numbers.

Water erosion can occur as sheet, rill, gully or river-bank erosion, depending upon the topography, soil type, rainfall intensity and erosivity, infiltration capacity and length of run. Some erosion losses always occur, even under natural conditions, and less than 2 t/ha/y are usually regarded as acceptable, depending upon the assessed rate of formation of fresh soil at the bottom of the soil profile. However, in serious cases the loss may be over 100 t/ha/y. The provision of planted or natural strips of permanent vegetation along field contours and river banks is useful in lessening river silt load, though the latter may not affect the actual erosive process on the field itself. A variety of erosion models exist, but the whole process is extremely time and site-specific, and a more precise ability to predict the effects is needed. The pathway of the eroded material further down the catchment is often irregular and difficult to follow, so protective measures may be needed closer to the place where off-site damage is occurring while erosion continues.

Cultivation techniques are therefore very important. Mixed- and inter-cropping has the advantage that the soil is very rarely left completely bare (Greenland and Lal, 1977). Zero tillage has obvious attractions, assuming that a layer of residues is left on the soil surface, and was shown to be beneficial in West Africa and elsewhere (Greenland, private communication). However, there are reports from East Africa that cultivation produced better yields than zero tillage, while the soil structure was maintained. It seems likely that these differing reports are a typical case of the site-specificity of soils work, and a consequence of less erosive rainfall and different soil types in East compared to West Africa. The question is whether understanding of the processes is sufficient to predict where zero tillage will or will not be superior to other techniques, and Lal (1983) has identified certain characteristics that favoured no-till systems. The clear definition of soil types and their properties in the cultivated state is an essential pre-requisite for this type of work.

2.3. Soil Organic Matter and the Carbon Cycle

Soil organic matter (SOM) occupies a crucial position with regard to soil fertility and its ability to grow crops. The microbial breakdown (mineralization) of SOM provides nitrogen, phosphorus and sulphur as plant nutrients - in the absence of fertilizer or organic wastes, this is the only source. SOM can also increase the ability of the soil to hold other nutrients such as potassium. The structure of soil is also dependent upon SOM, which cements and stabilizes soil aggregates and thereby makes the structure more porous and more stable. The increased porosity is valuable in holding water in the soil. The presence of adequate SOM is associated with the level and activity of the soil biological population, which is essential for soil health. The ability to maintain an adequate level of SOM is therefore critical for soil as a medium for plant growth (Woomer and Swift, 1994). Models are now available that can predict the future SOM level from the environmental conditions, the inputs of vegetable material and the soil type, but these still require improvement and testing.

In the last decade the behaviour of this reservoir of carbon in the SOM has become of heightened importance because it partly determines the carbon dioxide level in the atmosphere. World soils contain roughly 1500 Gt, with about 750 Gt in the atmosphere and about 550 Gt in the land biota (almost wholly vegetation), so the possibility of carbon storage in standing vegetation or in the soil is of great interest. However, the most immediate question is how much carbon is lost from deforested and newly cultivated soils, currently thought to be about 2 Gt per year (IPCC, 1990). However, the most recent work suggests that tropical forests are in total net absorbers of about 0.9 Gt carbon per year (Grace et al., 1995). Much work on this subject is still needed.

2.4. The Plant Water Relationship

No plants can grow without losing water, because of the need to take in carbon dioxide for growth through their stomata, though some plants have various mechanisms for water sparing or drought resistance (Smith and Griffiths, 1993). The weight of water transpired for unit weight of dry matter formed (the transpiration ratio) varies widely both with the plant species and the climate, but is usually of the order of 200-1000. This ratio is likely to be decreased by the steadily increasing level of carbon dioxide in the atmosphere, but the detailed effects are still not clear.

The total amount of water that can be transpired by a crop during its growth cycle is determined by the climate, the radiation interception, the canopy structure, and the internal physiology. If that amount of water is not available, as rain, irrigation or water stored in the profile, the yield is lowered. In rain-fed agriculture, the amount of available water stored in the profile is critical, and depends upon previous rainfall, the water-holding capacity of the soil and the partition between infiltration and run-off (Passioura, 1988). The extent and ramification of the root system determines how much of this water in the soil profile can be utilised, and at what rate. The water not used in evapotranspiration or in run-off is then available for percolation and groundwater recharge - the second point of partition.

Water is also lost from the soil surface during plant growth, at a rate dependent upon the surface soil water content, and the rate at which radiant or adventive energy reaches the soil surface. Where the crop canopy is sparse, a large part of the total water may be lost in this way, and dryland crops often transpire less than half the rainfall (Le Houerou, 1984). The use of mulch may improve this, but a thick mulch can retain rainfall, and allow it to be evaporated without reaching the plant roots. The frequently poor utilisation of water by crops in dryland environments offers a number of possibilities for improvements. These include concentrating rainfall into a fraction of the land area to increase depth of percolation (a form of water harvesting), or use of intercropping to give a more complete or a longer-lasting canopy. However, there has to be a compromise between using the rainfall for immediate cropping, and allowing it to recharge the groundwater or maintain the river flow.

The total water use by a stand of plants on a given soil with given rainfall varies with the structure of the canopy, which determines the "surface roughness," and thereby the interaction between canopy and atmosphere. It also depends upon root penetration, so that the profile can be dried out to different depths. This is the cause of the general finding that woodlands transpire considerably more water than do short crops or grasslands. The replacement of one type of land use by another can therefore sharply alter the amount of water that can be left in the profile, or percolate down and recharge the groundwater or maintain river flow.

All these processes have been built into a number of models, based upon the single-dimension Soil-Vegetation-Atmosphere-Transport (SVAT) models and the Penman-Monteith equation, which has been extended to deal with incomplete canopies. At larger scales these are coupled to above- and below-ground water transport models (see below), incorporating variations in soil type, vegetation structure and topography if necessary (Wallace, 1995a). These are often large and complex, but are becoming steadily more accurate. In the limit such models are being built into the Global Circulation Models used for climate prediction. The theoretical underpinning is therefore strong, with the weakest part probably in the simulation of the distribution and function of root systems in relation to soil properties.

One of the most difficult situations to research and to understand is that with controlled competition between two or more species, as in intercropping or agroforestry (Wallace, 1995b). The mechanism of competition may be for light, nutrients or water, of which the last is likely to be important in all systems in which there is a net water deficit. The measurement of how and to what effect the different species and plant individuals divide the limited available water supply is technically complex, but obtaining a net benefit from having two or more species present depends upon this partition process. Most research in more-developed countries has focused on the monoculture situation, even in work on forests. Advances are being made at ICRAF in this subject, but much more work will be needed.

2.5. Other Hydrological Processes

Climate is defined by the annual means, the distribution of the variables according to season, and the between-year variability. All are critical for rainfall, because this determines the amount of precipitation, its intensity and the frequency of extreme events. These affect infiltration, runoff and erosion, horizontal and lateral transport and storage in soil profile, drainage and groundwater recharge, and associated questions of water quality. Groundwater is a most important component, and its lateral flow towards the rivers helps to maintain their volume. Lateral flow of groundwater may cause transfer from one watershed to another, but it is unlikely to be a major factor. The underlying theory of water transport in soil is strong, but the accurate measurement of the actual soil parameters in the field situation can be difficult.

The basic understanding of the movement of fertilisers, pollutants and other solutes is good, but work in the field is difficult because of the heterogeneity of soil structure. Strongly structured soils often have a bimodal porosity, which means that during rapid percolation, when large pores are waterfilled, the rate of penetration of solutes can be much faster than expected. When rivers are contaminated by such chemicals, the water quality will fairly soon return to normal if the sources can be controlled. Contamination of groundwater is potentially far more serious, in that groundwater may take decades or centuries to be replaced.

Watershed research is heavily dependent upon the application of computers and mathematical modelling, which are now used in data storage, real-time control systems for river management, simulation models for pollution of rivers, and large models of subsurface flow, groundwater behaviour and total watershed hydrology (Maidment, 1992). The SHE (Système Hydrologique Européenne) is an example of such large and data-hungry models for predicting water movement over considerable areas.

The use of modelling in controlling large irrigation schemes is one aspect of this type of work, which is made more difficult because high salt and sodium contents can change the hydraulic properties of a soil markedly. Other uses are in predicting the water relationships in watersheds under different forms of land management (Gregersen et al., 1987). There is a large hydrological modelling programme for the whole Mississippi basin operated by a part of the World Climate Research Programme. There are also now programmes that aim to connect hydrological models to other spatially arranged models, such as the modelling system for hydrology, farm economics, land use, ecology and water quality that has been constructed for two river basins in the UK (O'Callaghan, 1995).

The subject is advancing rapidly, partly due to the increasing power of computers. Whilst most of the underlying theory is strong and dependable, the problems are in the sheer spatial and temporal complexity of natural systems, and the consequent possibility of error. Careful validation of models is therefore necessary. Little such work has been done thus far in the CGIAR System, with the major cases being the small-watershed management models developed at ICRISAT.

3. Critical Socioeconomic Processes

3.1. Introduction

The range of socioeconomic themes that could usefully be broached here is wide indeed, ranging over treatment of externalities, non-market values and valuation, conflict resolution, etc. We can economise on space and coverage here because of the longer treatment of some of these matters in the companion review on "Perspectives on Policy and Management Research in the CGIAR." One focused starting point in thinking about public management and institutional issues in natural resource management is to recognise that natural resources are heterogeneous and present different management issues, limiting generalisation about such issues with regard to "natural resources." Some of the differences with respect to management, especially those related to social cohesion and information status can be conveniently summarised in a simple tabular form as is done below. This portrayal distinguishes, on the one hand, whether the resource in question is (a) relatively known and predictable, or (b) little known and/or unpredictable, and on the other hand, whether the resource users are (a) an identifiable and coherent group, or (b) lacking group identity and structure. Some examples of important NRM situations can thus be tabulated:

Matrix of Illustrative NRM Situations

	Natural Resource is:	
Users-Managers are:	**Known and predicatable**	**Little Known and unpredictable**
Identifiable and Coherent Group	(I) Irrigation Water Management	(II) Coastal Fishing (done by resident fisher groups)
Lacking Group Identity and Cohesion	(III) Forest Management	(IV) Rangeland

In situation (I), the prospects of user-managers taking responsibility for the sustainable and beneficial management of the resource are greater, other things being equal, whereas in situation (IV), getting responsible user behaviour (with regard to the long-term viability of the resource) is more problematic. Situations (II) and (III) are intermediate in this regard. Management of inland fisheries, for example, is likely to be somewhere near the middle of the matrix. In some "traditional" range management situations (such as IV), however, informal institutions and strong cultural norms have evolved, particularly with regard to conflict resolution, so that grazing resources can be managed close to some optimum (Sandford, 1983).

As Sandford and others have reported, when governments and donor agencies have tried to intervene to introduce (or impose) their own rules and institutions in situations such as (IV), these have been usually unsuccessful, unless building on the traditional patterns and norms of resource management. It should be no surprise that probably the NRM area where self-management by resource users has been most widespread and successful is with respect to irrigation water (Uphoff, 1986a; Meinzen-Dick et al., 1994).

Soil conservation resembles situation (I) but it presents some different cost and benefit patterns, as discussed below. These make collective action to protect soil less attractive to users of this resource. Watershed management has characteristics of (II), (III) and (IV) and is therefore more complex analytically and also operationally more difficult. "To the extent that the resource and the users are well known and identifiable, local institutions become more viable. Conversely, when the resource is more uncertain and the set of users ill-defined, higher level institutions have a greater role to play in NRM." (Uphoff, 1986b).

The concern when looking at either set of institutions with regard to NRM is not with the institutions themselves so much as with their implications for behaviour by the same set of persons, most simply referred to as users. These are the persons who have some right to extract benefit from the resource in question, whether it be formal-legal or by common law or tradition. This question of different kinds and degrees of resource tenure, referred to loosely as ownership, will be returned to below, as it is one of the most important institutions that affect user behaviour.

The above discussion focusing on social cohesion and information should be seen against a broader backdrop of rural NRM operatives, largely resource-poor farmers in much of the less-developed world, responding as best they can to pressures on their scarce resources arising from increasing population pressures, and to changes in the policy environment to which they are subject. Increasingly, with the globalisation of the world economy, the liberalisation of trading arrangements, and varying responses of national governments as they struggle to adjust to the newly emerging trends, the policy environment is wide geographically, dynamic and not always easy to predict. As farmers are thrown to the mercy of the international market place, it is reasonable that they should be supported in their managerial tasks by policy decisions that underpin their security of tenure, foster the supply of relevant planning information, perhaps smooth out some of the more extreme fluctuations in commodity prices, ease some of the pain of dealing with natural calamities such as drought, and so on.

The rural natural resource management task has doubtless become more difficult for the majority of the world's farmers in recent decades, notwithstanding the assistance that has been received from the availability of new technology. Needless to say, the prospects in store make the future management challenge even more daunting, not to mention inevitably more demanding of better technologies, especially in the NRM arena, and of better policies for the rural sector to help it play its needed role in development. Research surely has a crucial part to play in all these aspects, and the contribution of social-science research will be vital to guiding and implementing technological interventions as well as forging progress in the policy domain. These themes, together with their implications for socioeconomic work under the CGIAR are taken up at length -- more so than is possible here -- in the companion strategic review "Perspectives on Policy and Management Research in the CGIAR" , which should be read in conjunction with the present review. Since, however, it will largely be the billions of resource-poor farm managers themselves who will actually be doing most of the work that will be needed, it is as well now to ponder some of the social mechanisms they will be using.

3.2. Collective Action and Common Property Resources

Two bodies of literature in the social sciences -- on collective action (CA) and on common property resources (CPRs) -- have spoken directly to behaviourial issues in NRM (Jodha, 1992, 1995). Unfortunately, the two have often suffered in their interpretation through confusion with the "tragedy of the commons" argument of Hardin (1968). In fact, the respective analyses speak to similar behaviourial dynamics and motivations, but they speak to different sets of concerns. One reading of the literature says that there is no reason to expect sustainable NRM by the public if the resources are held as property in common. The conclusion drawn is that the best prospects lie in looking to management by public (state) institutions or to private-property solutions. A more recent reading of the literature is that, under enough conditions to make the conclusion important, resource users collectively can be trusted, often better than state or "official" private managers, to utilise soil, forest, grassland and other biological resources well.

The feasibility and sustainability of CA was first and most effectively challenged by Olson (1965). He proposed that voluntary group action to achieve/maintain some common good was unlikely to occur or be sustained because it was "rational" for individuals to be "free riders," not contributing their share to the cost of creating the desired public good. Individual net benefit would be maximised by "shirking" while getting nevertheless the benefit of what was created by others' efforts.

Kimber (1981) showed how this supposedly "rational" analysis is itself illogical and internally inconsistent. It rests on the assumption that only the "free rider" is rational, and all others irrational, willing to create a common good that the shirking individual can enjoy without cost. Since individuals recognise the fallacy of such logic, Kimber argued, they (or at least most, or a sufficient number) are willing to make their expected contribution as long as their benefit from the common good exceeds their personal cost. This is consistent with observed behaviour, though it is also the case that, in many instances, collective action does not occur and possible public goods are not created because individuals prefer to let others bear the disproportionate "start-up costs" of collective action.

This analysis was extended to the NRM domain by Hardin, who contended that natural resources would be overutilized, to the point of degradation because, by the same kind of logic, it was rational for individual users to exploit a resource such as grassland or forests at the expense of others. They would get the full benefit but bear only a fraction of the cost of any incremental resource extraction.

For a while, this argument cast a long shadow over the whole NRM enterprise, and it prompted calls for privatisation of forest, range and other resources, or for the arm of the state to be made longer and stronger. The Prisoner's Dilemma analysis from the field of game theory was invoked to explain and support Hardin's pessimistic conclusion. But just as the CA argument was overstated, so did social scientists find flaws in the prediction of "tragedy."

First, there were many empirical examples of effective and even long-standing collective action regimes to manage and sustain natural resources (especially Netting 1976, and Ostrom, 1990). But it also became clear that the Prisoner's Dilemma logic of "defecting" to take advantage of others applied to rather limited, even artificial circumstances -- once-only interactions, no communication among parties, etc. -- so that it could not serve as a model for all or even most NRM situations.

Second, and more importantly, people came to see and understand the distinction between "common property" and "open access" resources (Anderson and Thampapillai, 1990). One could expect "tragic" consequences with the latter, but they did not need to occur with CPRs, unless the regime of norms, expectations and enforcement mechanisms surrounding common property broke down, e.g., due to in-migration of "strangers" or pressures of over-population.

Certainly "free riding" and "the tragedy of the commons" exist, but these behaviourial patterns are not necessary or universal. There can be a similarly rational basis for more altruistic and cooperative behaviour than these models predict (Uphoff et al., 1990; Uphoff, 1992; White and Runge, 1994). The literature on these issues can be summarised by saying that it is quite evident that the distribution of costs and benefits is a major influence on behaviour; "free riding" is a possible deterrent to collective action even if it is not an inevitable one; people are not motivated only by individual material self-interest; social norms and cultural traditions can make the welfare of others (including particularly future generations) important motivating factors; collective action presents some special problems but also opportunities when CPRs are involved; and institutions are essential for providing "assurance" that encourages collective action (Runge, 1981, 1984; Ostrom, 1990; White, 1992a).

3.3. Profiles of Benefits and Costs

Having indicated that individual and collective behaviour is not simply a function of costs and benefits (net benefits), it is important to take note of these factors since they are important influences on people's willingness to invest in and sustain institutions that manage natural resources effectively. In Uphoff's (1986b) previous work on local institutional development for NRM, among other sectoral activities, he was concerned with the incentives for users to undertake responsibilities for resource management on an individual or collective basis. The alternative would be government control (though possibly by local rather than central government).

Uphoff (1986b) identified four main dimensions along which NRM benefits can vary with respect to the users (or potential users) involved. The same distinctions can be made with regard to costs:

1. Temporal dimension

   (a) Benefits accrue immediately or very soon, or
   (b) Benefits accrue after a long time.

2. Spatial dimension

   (a) Benefits accrue locally, or
   (b) Benefits accrue remotely.

3. Tangibility

   (a) Benefits are quite evident, or
   (b) Benefits are relatively difficult to identify.

4. Distribution

   (a) Benefits accrue to the same persons who incur the costs of management, or
   (b) Benefits accrue to different persons from those who bear the costs of management.

It can be expected that user responsibility will be more feasible where NRM benefits, relative to costs, accrue quickly (1a), locally (2a), visibly (3a), and to those who bear the cost (4a). Conversely, a larger role for government institutions is likely to be needed where benefits are delayed (1b), remote (2b), difficult to identify (3b), and do not accrue to the investor of effort, money or forgone use (4b).

There is thus an important difference between soil conservation as a form of NRM and irrigation water management. Whereas efficient and equitable management of irrigation water produces quick (1a) and visible (3a) benefits to those persons and to the area where management investments are made (4a and 2a), soil conservation's benefits are usually delayed (1b) and often hard to identify (3b). They do occur locally (2a), but the main beneficiaries are likely to be persons downhill or downstream (4b), who are less likely to be flooded out or to suffer dry-season water shortage. Some persons downstream may indeed benefit from the deposition of top soil, even if others bear some costs of deposition, such as need to dredge canals.

Watershed management as a complex activity also has a less favourable net benefit profile than some other forms of NRM: more delayed than quick benefits (1b); and many benefits that are relatively hard to see and measure (3b) -- as well documented in the several studies at the East-West Centre, e.g., Easter et al., (1986) and elsewhere Lee and

Dinar (1995) provide a recent review. From a policy perspective, even greater difficulties arise when conflicts arise over use of the scarce water resource (Dinar and Loehman, 1995). Many of the difficulties in management depend on how the watershed is delimited. Watershed management has often been taken to refer to the upper, forested areas, the catchment area that captures rainfall that flows eventually to the downstream portions. With such a confining definition, it is clear that a considerable share of benefits from "watershed management" occur outside "the watershed" (2b) and go to persons located downstream (4b). But if the whole watershed is taken as a management unit (as is the central proposition in this paper), and if users within it consider their collective benefits and costs as a whole, these two obstacles to effective watershed management are mitigated, if only because there can be mechanisms for compensation and compensatory action within this larger watershed unit. Such compensation is not necessarily easy to arrange to the satisfaction of all concerned, especially if resettlement is required. The experience of the World Bank and others with the Narmada projects in north-west India, for instance, illustrates the imperative need for participatory approaches to project design (OED 1995).

4. Soil and Water Problems - An Analysis of the Present Position

4.1. The Physical Framework

One of the advantages of a watershed approach is that it allows the spatial or geographical linkages to be readily identified. The idealised diagram in Figure 2 suggests that the following broadly defined terrain types can be used; (Sanchez and Nicholaides, 1981; Greenland et al., 1994).

(a) Steep uplands, high rainfall, fast rivers, deeply dissected, naturally forested, initially low population density. Problems: erosion, loss of forest, origin of major floods. Offsite effects: sediment load in rivers, siltation of lower dams, floods. Typically in the Himalayas, Andes, East African Highlands.

(b) (i) Rolling or plateau topography, low rainfall, arid or semiarid vegetation, rangelands or irrigated agriculture. Problems: tendency to desertification, wind erosion, surface crusting, water erosion and flash floods. Off-site effects: dust storms, channel erosion, sediment deposition. Typically Indus valley, Sahel.

(ii) Rolling or plateau topography, moderate to good rainfall, rainfed agriculture and perennial tree crops, originally forest or moist savanna. Problems: acidity, poor structure and nutrient content of soils, poor distribution of rains, erosion under poor management. Typically West Africa,

(c) (i) Flat topography, low rainfall, very small fall on river, naturally arid, irrigated agriculture Problems: siltation of river, unstable channel, floods, salt or sodium contents of soils. Off-site effects: pollution of ground water, saline downstream river. Typically lower Indus valley, Euphrates - Tigris rivers, lower Nile.

(ii) Flat topography, high or moderate rainfall or high watertable, naturally forested. Problems: floods, impoverished and acid soils. Off-site effects: few. Typically lower Niger,

(d) Wetlands, with high watertables, flooded for part of the year. Often used for irrigated agriculture, with high-yielding, deep-water rice, and aquaculture. Problems: rice yields appear to be falling, for unknown reasons, and environmental problems are caused by methane production and potential impacts of sea level rise. Typically SE Asian river deltas.

4.2. Assessment of Problems According to Terrain

There are four possible situations that might require research, but which all merge into each other without sharp distinctions. These need to be kept in mind in considering soils problems.

First, there is the soil under cultivation without immediate serious problems but with mediocre productivity, and which is likely to be degraded over time. The task is to enhance productivity with technologies that together form a sustainable agriculture. The success depends greatly upon the inherent resilience and stability of different soil types; Greenland et al. (1994) suggests that only 10% of tropical soils have the natural fertility to be suitable for continuous cultivation without enhancement. This has been a CGIAR task for many years, and it has developed considerable experience.

Second, there is the soil which has already been seriously damaged or degraded by poor management, and which needs reclamation or rehabilitation before it can become productive. The most common causes are probably excessive shortening of fallow periods in shifting cultivation, and loss of soil by water or wind erosion due to poor cultivation and conservation techniques on slopes. Productivity will have sharply declined (see Table 2).

Third, there is the marginal soil, which should probably not be taken into cultivation at all because of its infertility or susceptibility to damage, but is progressively more likely to be used because of population pressure. This will include very steep slopes, very sandy soils of poor structure, and soils in areas of little or irregular rainfall. Some of their problems will be similar to the degraded soils, but rehabilitation is unlikely to be cost-effective.

Fourth, there is still some potentially good unused land which is gradually being taken into cultivation, and the task is to ensure that this is done in a careful and efficient way so that its productivity is maximised. This would apply to some land in long-term fallow with shifting cultivation, some forest and some savanna land, much being in South America. However, even there, the new land very often has constraints that make it expensive to bring into cultivation, and make intensification of existing farmland more attractive (Couto, private communication).

(a) **Steeplands**. There are many examples of grave problems caused by population increase and movement onto steeplands. The classic case is N-W China, with the heavy erosion of the loess soils. Even more critical cases are now found in Nepal and the Philippines (Garrity and Agustin 1995) and in the Andes and Central America (CIAT 1995; Couto, private communication). Where these steep soils have not been cultivated before, and where the farmers may be incomers, there may be little or no local traditional guidance for farmers. Extension advice is rare, and may be mistaken, again because of lack of experience of these problems. As land pressure increases the fallow period shortens and the cropping period lengthens, so that the net landcover fraction decreases steadily (Table 1). Ultimately good cover does not regenerate. Where systems for mulching with branches from forest trees are in use, the gradual removal of forest makes the system unsustainable.

The standard way to use such land is by terracing or bunding. This may not be used because returns on the investment of labour and materials are perceived to be insufficient or too uncertain, or because of lack of knowledge, lack of organisation or funding, or simply because the speed of the degradative process overwhelms the farmers. In many cases the land is simply not appropriate for arable farming, and should be left in forest, or converted to tree crops (see Report of CGIAR Task Force on Sustainability 1995).

Uplands are typically a major source of river silt if their tree cover is removed, due to logging, harvesting of fuelwood, or for agricultural use. The consequence is that dams are rapidly made useless, and that heavy flooding and silt deposition occur.

(b) (i) **Rolling land, low rainfall.** The low average rainfall, high potential evapotranspiration and high variance of climatic parameters makes agriculture in this zone unavoidably risky without irrigation. The Report on CGIAR commitments to West Africa (McIntire, 1995) considered that the impact of research in this type of area had been weak. However, sustainable agriculture in this situation depends upon maximising the use of all water, and there are techniques for water harvesting or collection of runoff from occasional storms. The prospects of producing cultivars that are still higher yielding in droughts than present ones by breeding or genetic engineering need to be assessed. If the risk of frequent and damaging drought can be reduced, the farmer may find it worthwhile to invest in agronomic inputs. In dryland farming, soil fertility and water supply have to be fully integrated to maximise production.

(ii) **Rolling land, good rainfall.** These areas are core agricultural parts of a watershed. The rainfall can encourage more intensified agronomy to give higher yields, but can also cause higher leaching of nutrients and agrochemicals. Perennial tree crops are an option with advantages for soil protection. The problems are the central ones of overcropping, too little fallow, and too few inputs. The use of pasture as an alternative to bush fallow may be advantageous in some areas where there is livestock. It would be useful to establish: how far the CGIAR System considers it has the biophysical solutions to intensification of agriculture in lands such as these; where application is not occurring for socioeconomic reasons; and, alternatively, where there are still biophysical problems that have to be solved.

(c) (i) **Flat land, low rainfall.** The position of this terrain in the watershed should make irrigation a practical option, as in much of South-east and South Asia. The problems are poor distribution of water, salinity of soils and water, and loss of structure if sodium is a major exchangeable cation. A particular problem arises if there is dependency upon groundwater, and this has become saline. In principle there are biophysical solutions to most of these problems, though much adaptive research is always essential. The cost or the limited managerial capacity may, however, make these solutions impossible to apply. Some of the problems are the off-site result of actions higher up the watershed, in particular the siltation of dams and watercourses. Generally the management of irrigation systems leaves much to be desired, and this is a major cause of low yields. There have been encouraging improvements recently, usually associated with giving a greater role to the farmers themselves. IIMI has been active in this work. The problems are therefore socioeconomic and environmental rather than strictly biophysical (Greenland et al., 1994). Where the Green Revolution has been successful, there are now growing problems of contamination of groundwater with nutrients and pesticides. The solution for nutrients must lie in better control over the use of fertilisers, manure, intensive animal production units and other agricultural sources. For pesticides, much can be done by using only minimum inputs, but more fundamental solutions are to use Integrated Pest Management, with biological control measures.

(ii) **Flat land, good rainfall.** Irrigation is probably not necessary in such areas, but there may be low insolation problems due to the cloud cover. The natural vegetation is probably forest, and tree crops are a valuable method of land use, providing varying degrees of protection to the soil. The heavy rainfall is likely to dilute agricultural pollutants, so that fewer problems are likely than in drier areas.

(d) **Wetlands.** These occur at most levels of a watershed, if the topography is appropriate, but most often in the lower river valleys or deltas. They often are the habitat for important wildlife, and are the subject of the international Ramsar Convention on conservation. Agriculture will again be largely wetland rice cultivation, and problems will be largely off-site ones from higher up in the catchment. This zone is well adapted to aquaculture; if this is intensive, it may itself become a source of nutrient pollution. If much irrigation is practised higher up the river, and the river water becomes saline, it is in this zone that the worst off-site effects are felt (El Ashry, 1980).

4.3. Techniques and Benefits of Management

The above has assessed the problems of an idealised watershed in terms of topographical position. The situation can also be analyzed in terms of the four main outputs from each land use unit of the watershed to the units below, as listed in terms of the four main thrusts, and shown in the four lines emerging from each land use unit in Figure 1. For each line, there are actions that can be taken to improve or ameliorate the situation, and these are now discussed. It is important to remember that most real-life problems are site-specific, and the actions will have to tailored to the local conditions by adaptive research. Further, all these processes are interlinked, and very few of these techniques can be applied without some form of knock-on effect elsewhere.

Production outputs are the first line. These are the main, but only partial, test of the success of agricultural intensification. A main objective of research and extension is to increase yields, or at the very least to prevent declines such as have been recorded in Africa (Table 1). The tools available for this are set out schematically in Figure 3. Different boxes in these schemes will be applicable to different parts of the idealised watershed in Figure 2.

The remaining part of the test of success is to minimise the other three lines. The consequences of water-erosive processes are schematically presented in Figure 4. Prevention of soil loss can be done by a number of well-known techniques, which need selection of the most appropriate, and adaptation to local conditions. The impacts of erosion are felt on-site, both where soil is lost and where it is deposited, and in other land use units where silt is deposited, on fields, in watercourses and in dams.

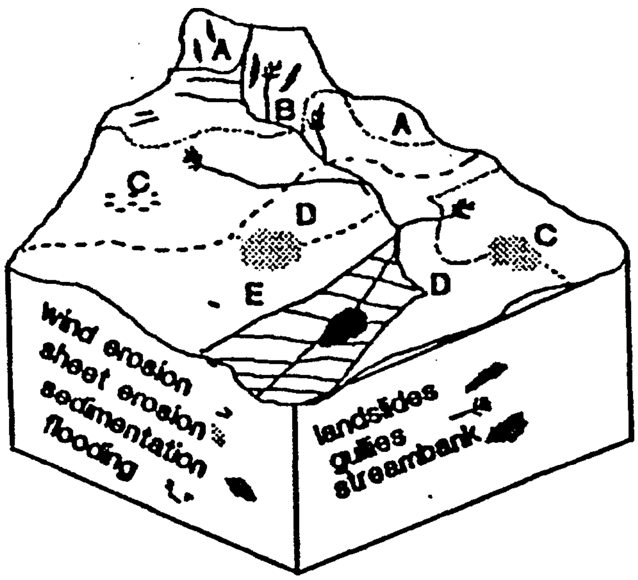
The third line represents water flow rate and flow pattern. Apart from major interventions such as dams and channel alterations, water flow can be modified by altering the rate at which water reaches the river and affects the hydrograph. This can be done by altering land use (for example, from forestry to grassland) or by changing the "first partition point," between infiltration and runoff by altering the soil surface properties with cultivation, mulches, SOM level, water ponding or others. The benefits of this better control are set out in Figure 5.

Water quality is the fourth line. This can be controlled by minimising the use of fertilisers and agrochemicals, controlling feed lots, stopping large inputs of organic material to watercourses, preventing accidental spillages and managing irrigation systems to control saline drainage water. The benefits of successful control for downstream land users are in Figure 6.

In fact, water quality and quantity are closely linked. In a simple case, the concentration peak that travels downstream in a river after a pollution incident will be dispersed at a rate that depends upon the volume of water, its flow pattern and the river's course. All these processes must therefore be seen as a network of interactions. This complexity is the main challenge of integrated watershed work, and any intervention with a single objective raises the danger of unforeseen problems. Sometimes the results are totally unexpected, as with the damage suffered by Mediterranean fisheries when the silt load of the Nile was reduced by the building of the Aswan dam.

The above discussion has focused on the agricultural and forestry land uses. This idealised watershed will almost certainly have cities and towns. These will all have demands for water of acceptable purity, for domestic and industrial use. The waste systems will also produce sewage, which has to be purified, and the effluent fed back into the river -- these are potential point sources of heavy pollution. They are probably even

Figure 2: An Idealised Catchment



Source: Perrens and Trustrum (1984)

more likely than agricultural pollution to cause eutrophication, excessive algal growth and possible anaerobiosis in the rivers and lakes. The management of surface waters in these cases is itself a difficult and professionally challenging task (Ryding and Rast, 1989). Furthermore, the cities will contain soils, and the management and use of urban soils is a growing issue (Bullock and Gregory, 1991).

4.4. Applications and Uses of NRM Research

The value and applications of NRM research on a world scale are incontrovertible. They range from making land agriculturally useful by detecting specific deficiencies, for example copper in Australian soils, to the understanding of hydrology and soil physics that allow irrigation schemes to be designed. In agricultural terms, NRM and production research overlap, and often fuse. This research over decades has built up a considerable knowledge bank on soil management, erosion control, river management and groundwater use, and much applied and adaptive research in the less-developed world has drawn directly on this. In some important cases this adaptation has been extremely successful, as is represented by the Green Revolution, in which improvements in germplasm, plant nutrition, plant protection and water supply all had their part.

It is noted in the main report of this paper that advances in application often do not result immediately from current research, but that all of them draw upon the bank of knowledge that has been stored up by previous research. This is quite appropriate for strategic research, because it is intended, by definition, to produce knowledge of the underpinning or cutting-edge type, rather than immediate solutions. It is more a cause for concern if applied, or especially if adaptive research is not used. However, there do appear to be large areas where NRM research results have simply not been used. It is usual to blame this on the proposition that the proposed solution is socioeconomically difficult to apply, or simply unprofitable, or that conditions in these areas are so different from those elsewhere that the knowledge bank cannot be applied, or that the solutions it provides prove unreliable or partial.

Where the socioeconomic conditions are favourable, so that farmers can get a sufficient cash return for their work, there are successes, such as the well known Machakos work (Tiffin et al., 1993). A number of small-scale pump- or gravity-fed irrigation schemes in Mali and Kenya have also been successful (Muchena, private communication). These depended variously on sound characterisation of the environment, and on participatory approaches with farmers and local authorities. The watershed work in East Africa in the 1950s and 1960s provided essential underpinning information concerning land uses, such as that, in particular locations, indigenous forest could be replaced by softwood or tea plantations without affecting the water yield of the watersheds, or damaging the soil. The level of erosion protection that was necessary for cultivation, and the acceptable level of grazing, was specified. Where these results were applied and followed, they were successful, but elsewhere they were ignored.

A recent update on the situation in Kenya (Pretty et al., 1995) shows how successful the catchment approach has been when consistently applied in a fully participatory way, as is also reported in Section. 4.5 This emphasizes how often major programmes in soil conservation have not been followed through, and have been allowed to deteriorate when the farmers who should benefit are not convinced of the value of the work and of their own role. It is clear that sound technology and biophysical analysis can be successfully applied when the social conditions are right. As an example of this success, the imports of maize to the Machakos district have decreased by more than half on a per capita basis over the period since 1945 during which the population has increased threefold. A somewhat similar report is given by Manu et al., (1994) for a watershed in the Niger. Again simple but well-adapted and basically sound technology worked very well when applied by enthusiastic and convinced farmers, and produced much improved crops. The project did however demonstrate that external nutrient inputs were essential to sustain yields, in line with the discussion in this paper. Similarly, the Parana Rural Project of the World Bank has used tested and adapted technology on 1150 microcatchments, with good results for soil and water conservation (Couto, private communication).

An excellent example of a "catchment" problem at a totally different scale of the whole of Egypt is discussed by Biswas (1995). The uses of land and water resources are inextricable interrelated, and most of the agricultural problems relate to water quantity and quality, and the overall sustainability of the system is dependent on these. Scientific water management is here essential.

There are clearly many situations where existing strategic knowledge can be and has been used for applied and adaptive research, and has produced biophysically successful results. Much of the work in applying this basic information can probably be described as adaptive research. However, it is rarely a question of going into the field and making measurements according to a standard technique and applying solutions from a textbook. Professional scientific understanding, and the ability to modify procedures and technologies according to the properties of a particular area, are essential for this type of work.

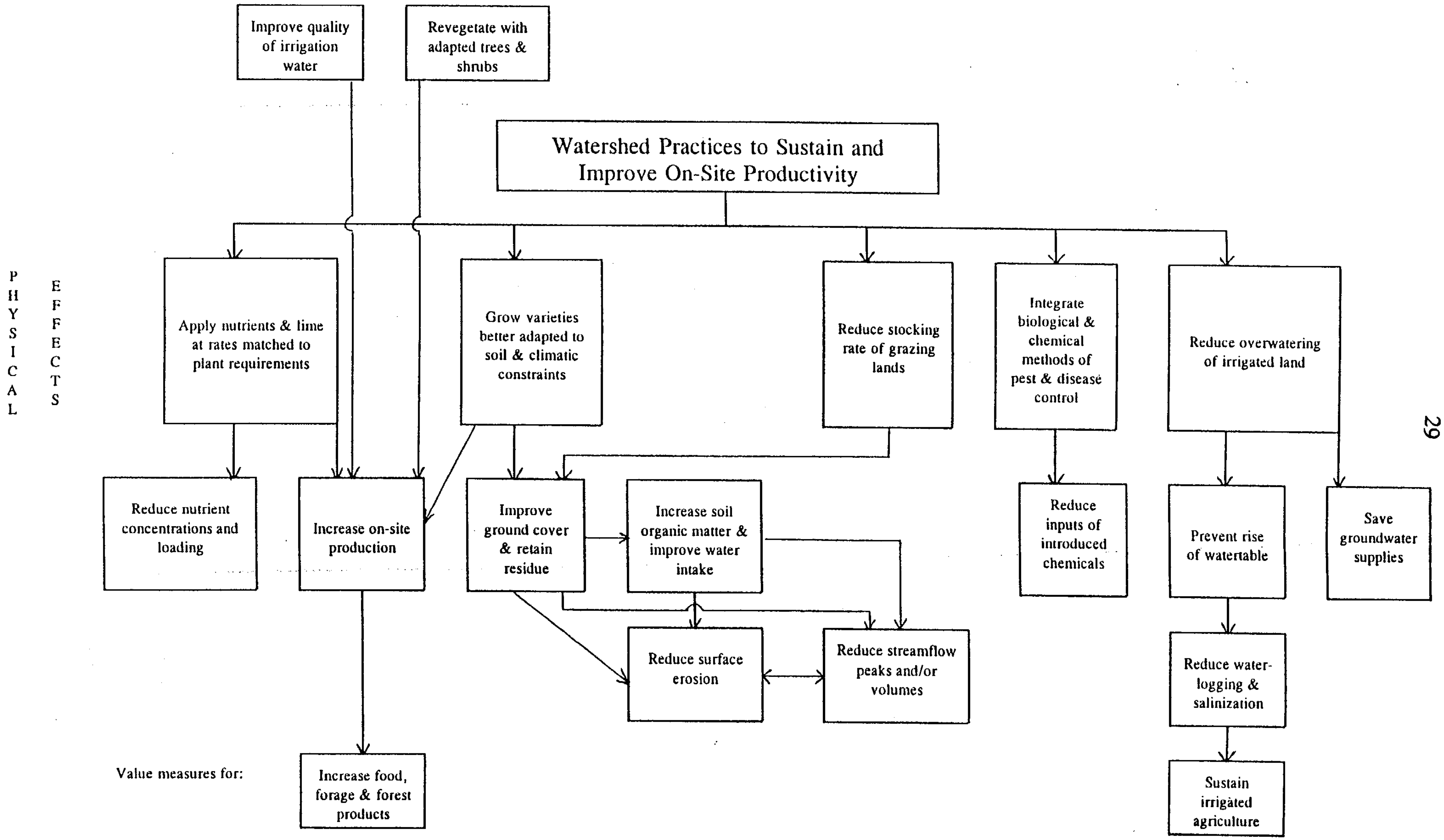


Figure 3: Priorities related to sustaining or increasing on-site productivity

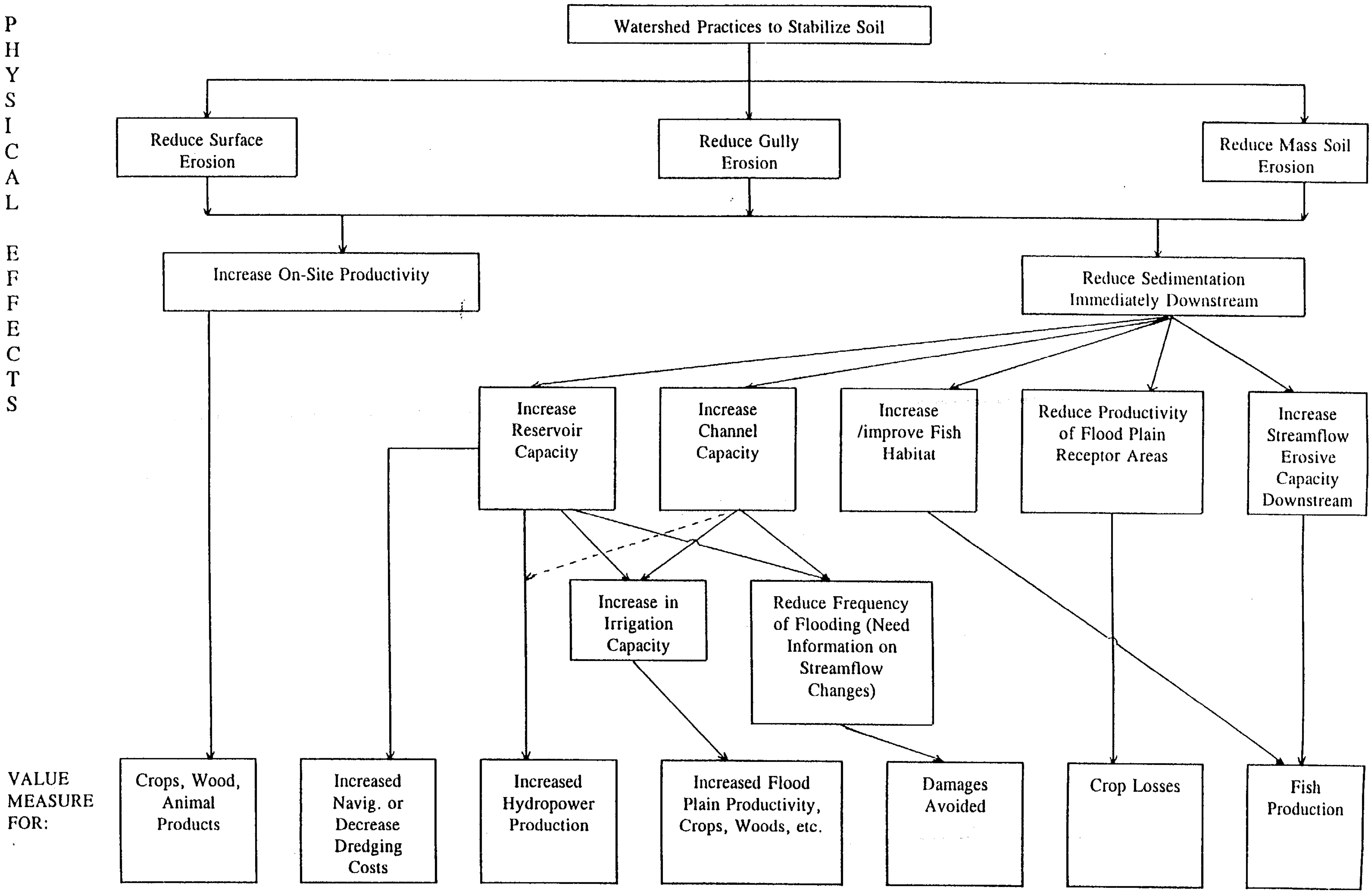


Figure 4: Priorities related to increasing soil stability (from Gregersen *et al.*, 1987).

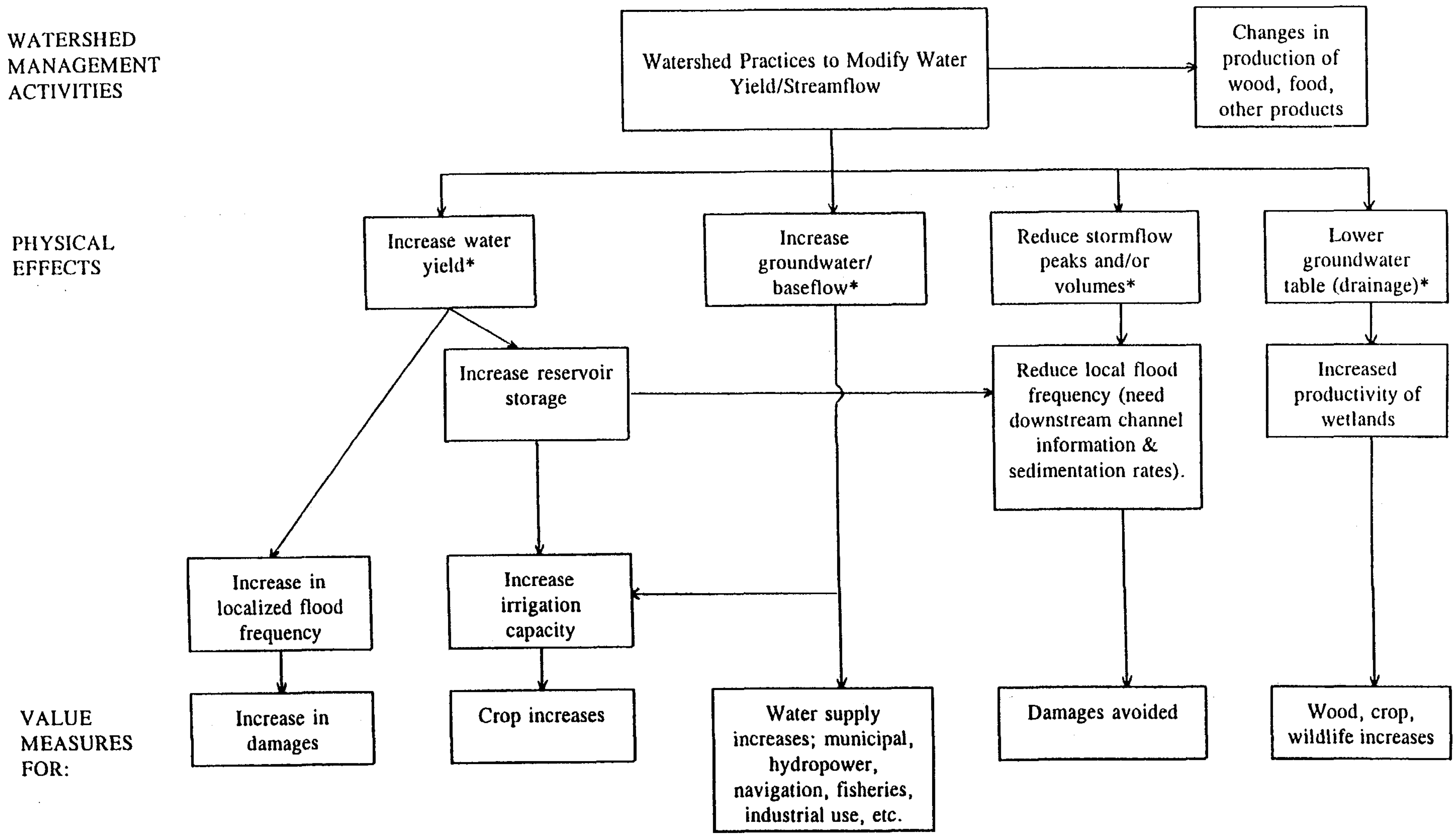


Figure 5: Priorities related to improving streamflow pattern and volume (from Gregersen *et al.*, 1987).

*Note: Some practices can result in the opposite effects resulting in different benefits or costs which must be identified and valued.

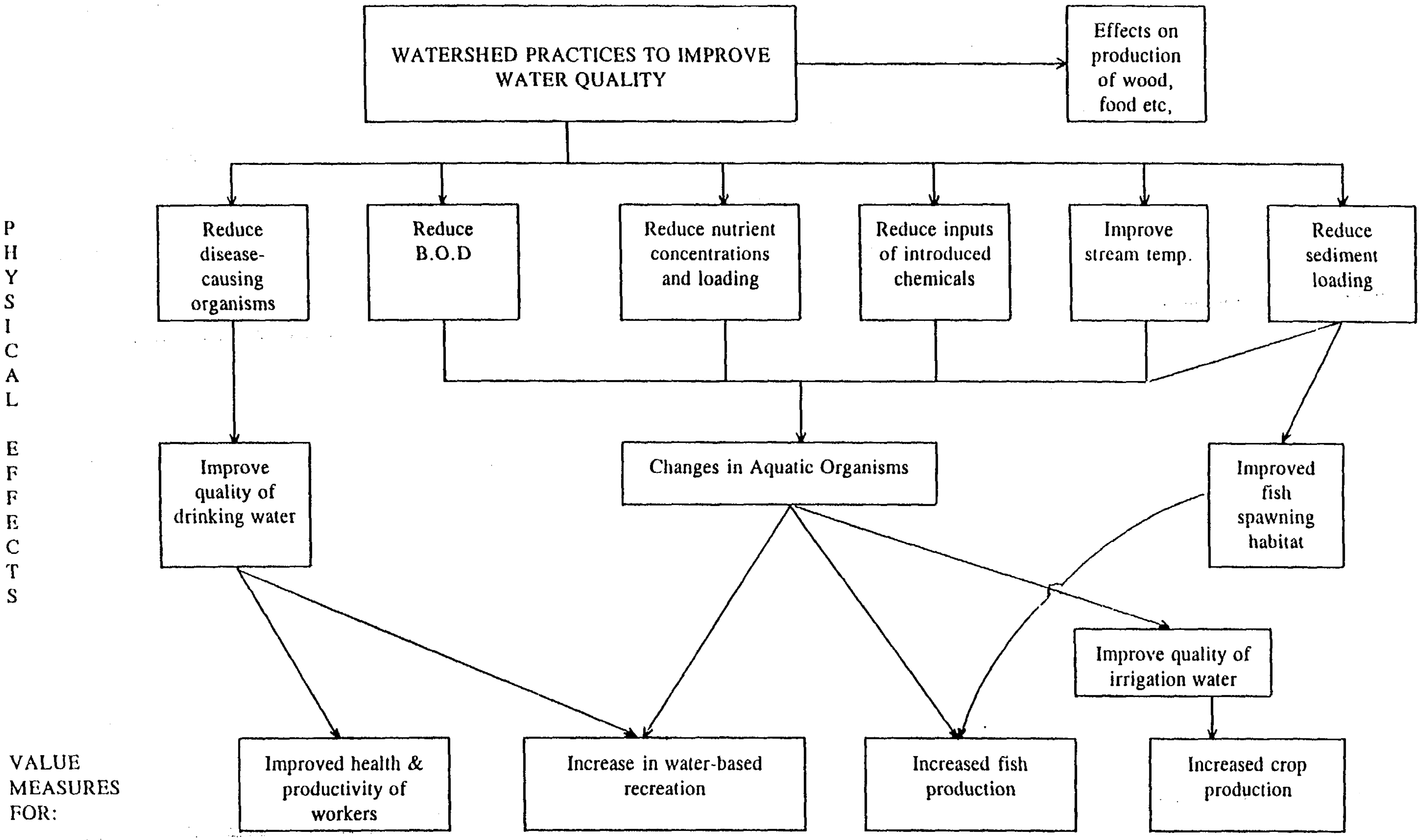


Figure 6: Priorities related to maintaining or improving water quality (from Gregersen *et al.*, 1987).

Where existing methods have not been applied it is logical to call for simpler, cheaper and easier methods, and research should certainly be directed towards discovering these. However, there is a point beyond which it is unreasonable to expect cheaper and easier solutions, if the biophysical situation is in fact technically difficult and complex. If better or cheaper biophysical solutions are not readily provided, it may be possible to use socioeconomic interventions that make the existing lowest-cost biophysical solution acceptable.

If much-superior biophysical solutions are not available, policy interventions that modify the socioeconomic circumstances may still be possible, so that modest low-cost biophysical solutions become more acceptable. It is difficult to assess exactly where research stands at present on these issues, and it is for this reason that this paper suggests that a stock-taking by CGIAR would be useful. As is clear from 4.5, biophysical research alone can rarely solve problems in the real world, but it is very difficult to solve any of them if the biophysical basis is not available and correct.

To close this short review of problems, reference is made to an analysis of relevant World Bank project experience (OED 1989). From recent audits of a set of 335 agriculture and forestry projects, 8% had adverse results involving soil erosion or salinisation. Of the various adverse results, shortfalls in performance were attributed to one or more of *inter alia* **inadequate knowledge** of: physical conditions (42%); techniques (28%) and; social institutions (12%). The stakes for developmental interventions are large indeed, and the returns to improving knowledge of NRM phenomena are likely to be great.

4.5. Three Cogent Questions for NRM Policy and Management Research

The economic, social, policy and public management and administrative dimensions of the topics outlined in section 4.3 are naturally wide-ranging and are in the research agenda of many concerned agencies, governmental and non-governmental. Within the CGIAR System, the broadest programme of work is that of IFPRI on evaluating trends in tropical land degradation and improvement. This work is being given scientific and empirical underpinning through the new collaborative links between IFPRI and other CGIAR Centres active in land research. As IIMI takes on the new directions promised by its Director General designate, its research links to IFPRI on water management will also strengthen. The present status of CGIAR work is taken up in the review of this Study prepared by the TAC Secretariat (Document No: SDR/TAC:IAR/95/10), and is only touched upon in section 5. The present section sets the scene for considering socioeconomic and policy and public management research work by posing and answering three broad questions, which in the event are especially related to management

Question I: *What issues can best be addressed at the international level?*

Natural resource management issues are primarily national and local ones. They can usefully be studied comparatively and cross-nationally, but they are invariably quite political, or have political implications. Thus, solutions need to be developed quite inductively (in a learning process mode, as Korten (1980) has proposed) and in accord with national and local traditions, cultures and values, not to mention their respective and often unique biophysical conditions.

This said, international institutions can play a valuable role in this area, affecting the climate of opinion through their research and publications, and improving analysis through the development of concepts, methods and measures. The first is probably the most important, though it is hardest to plan or to prove.

In the area of irrigation water management, for example, a significant movement has been evident toward new, more participatory, more efficient and more effective management systems over the past 20 years (Meinzen-Dick et al., 1994). This was initiated with Ford Foundation support in the Philippines, India, Nepal and Indonesia; it was supported by donors, first USAID in Sri Lanka, Indonesia and Nepal, and then the World Bank in the Philippines and elsewhere (Korten and Siy, 1988; Uphoff, 1992). This effort is presently being supported by IIMI under the rubric of Turnover. In the course of this period, some successful examples of participatory irrigation management were initiated and documented. Cross-national comparisons were made, supported by FAO, Asian Development Bank and other institutions, in addition to those named above.

Over time, decision-makers and state sector managers in less-developed countries have confronted a growing body of evidence and analysis that pointed the way to more effective and beneficial irrigation management (Uphoff 1986a; Singh 1991; Parlin and Lusk 1991). New assumptions have come to be widely shared about the feasibility and desirability of adopting less bureaucratic approaches.

With regard to watershed management, similar in this respect to forest management, there is a long tradition of technocratic perspectives and control. Indeed, the concept and strategy of bureaucratic reorientation (Korten and Uphoff, 1982) was prompted by experience with forest management agencies that was similar to what was observed with irrigation departments in Asian countries. A similar progression, though slower, has also been apparent in the forestry area, as forest agencies in many places have come to recognise that the resources they are responsible for can be more beneficially and effectively managed in cooperation with persons living in and around forested areas (Cernea, 1989; Arnold and Dewees, 1995). A similar pattern has occurred in terms of rangeland management, recognising that user participation is the key to success, as is increasingly well documented, for instance, in ILCA/ILRI publications and its African pastoral research programmes, and in the ICARDA/IFPRI work in the Middle East steppes.

Watershed management is now receiving similar attention, and lessons from other NRM areas are being brought into this domain *mutatis mutandis* -- and sometimes not in this way, being simply transferred from other domains, which is a prescription for difficulties, since different areas as well as different resources require management systems that are adapted to the particular biophysical and socioeconomic circumstances. There is more interest now in participatory approaches than there was some ten years ago (e.g., Sample 1993; World Bank 1995), and this reflects in part the actions of international institutions and researchers who have raised issues and examined alternatives.

Certain important issues in NRM such as land tenure can be identified as candidates that international institutions should study and provide advice on. But it is hard to say that these can be "best" addressed at the international level unless it is clear that they will not be (adequately) tackled at national and sub-national levels, so the international level only becomes the best by default. In fact, the research community is international, and every encouragement should be given to researchers around the world, in their respective national and local settings, to try to illuminate important issues such as land tenure and its impact on sustainable NRM. But this is not necessarily something done "at the international level." As is discussed in section 5.5, international institutions could well contribute to better NRM by supporting networks of national and local researchers. But this can include research done at and by CGIAR Centres in the "classic" CGIAR mode.

Question II: *What have been the successes in this area, and why?*

Resource management issues naturally differ from country to country but, even where they are similar, performance varies greatly because of significant institutional differences. Attempts to generalise about successes or otherwise are thus fraught with difficulties, but must be addressed to help to define roles for the various potential actors, local, national, and international. Needless to say, there are many actors who have explored their possible roles, although the deliberations are not always documented in the public domain. These include planning documents for concerned NGOs, institutional development documents for governments considering, for instance, how best to set up environmental protection agencies, and so on. One of the players, until recently a somewhat coy one in this area, is the World Bank. It was long and persuasively argued that the Bank had neither the mandate to intervene in matters so deeply rooted in national culture and policies, nor the technical and financial clout to make sufficient a difference. But all this changed radically in the late 1980s as signalled, for instance, by the creation of its Environment Department and counterpart regional environmental operational units. In the process of entering upon these new institutional arrangements, the Bank took various steps to consider its position in resource-management related lending, which has now become strongly oriented to environmental interventions. This included consideration of soil-conservation interventions and policies (Anderson and Thampapillai, 1990; Sfeir-Younis and Dragun, 1993) and it (through its Operations Evaluation Department (OED)) undertook a review of investment experiences pertaining to renewable resource management in agriculture (OED 1989). This report includes a dozen country case studies, as well as syntheses of cogent issues, and the work has guided a proliferation of environmentally oriented lending operations that now occupy a significant part of the Bank's portfolio, in agriculture and other sectors, and (reflecting a persistent theme brought out in the studies) feature strong attention to ensuring participatory approaches, recently enshrined in the World Bank (1995) Participation Sourcebook.

Rather than review this OED review, the question presently posed can be answered indicatively, and still more satisfactorily than could the first question be, by discussing three quite different examples of success in watershed management. These come from India, Sri Lanka and Haiti, and offer useful guidance. None of these cases is as "old" as would be ideal before concluding that they are "successful" but they are still instructive. A number of very short descriptions of innovative watershed management programmes in Africa, Asia and Latin America are available in Hinchcliffe et al. (1995), but they are too cursory to present and analyze here. The common denominator in the cases reported there is **participatory management**. Readers familiar with such case examples might choose to skip to Question III below.

RAJASTHAN, INDIA In 1991, the Government of the Indian state of Rajasthan created a new multidisciplinary department of Watershed Development and Soil Conservation, building on the Soil Conservation wing of the Agriculture Department and drawing in staff then from other departments. The programme had substantial funding available from the central government's National Watershed Development Programme for Rainfed Areas and a World Bank-funded Integrated Watershed Development Project.

Within two years, it was carrying out conservation and development work on over 100,000 ha in over 250 locations (Krishna, 1995). It emphasised local participation through User Committees that were facilitated by department staff. Rules and procedures for sharing costs and benefits among local residents, and between them and the government agency, were worked out consultatively, with different formulas adopted in different locations. In both 1993 and 1994, the programme was awarded a Certificate of Merit from the National Productivity Council of the Government of India for its development of appropriate technology and for its high degree of community participation.

A very decentralised approach was taken, with the delimitation of 250 watersheds averaging about 4,000 ha each. A multi-disciplinary (multi-departmental) team was assigned to each watershed, to work with the villagers residing therein. Great encouragement was given to be experimental and to innovate, with the result that a visiting GOI official spoke of "a widespread unleashing of the creative talent of field staff." (Krishna, 1995). The programme expanded rapidly, to cover ten times the area previously served by soil conservation schemes, and this was possible with staff reorientation and enthusiasm, and with village response.

Krishna considers as the main factors in the rapid success: (a) the experimental and adaptive approach taken to technological innovation, (b) the rapidly and strongly enforced administrative coordination, and social organisation among government agencies, and (c) the attention and support given to social organisation, i.e., to user and community participation. Whether the programme will retain its operational and philosophic thrust without his leadership is something yet to be assessed. But this case has shown what even a bureaucracy known to be rather lethargic and a set of communities known to be quite traditional and isolated can achieve in short order.

SCOR PROJECT, SRI LANKA In 1990, the International Irrigation Management Institute was contracted by USAID to design a new kind of NRM project. USAID's previous support of a water management project focused on the Gal Oya irrigation system (1979-85) had shown good results by engaging water users in a multi-tiered structure of organisation, starting at the field channel level and extending upwards. The largest and one of the most run-down irrigation systems in the country had become one of the best managed within a few years, doubling the efficiency of water use (Uphoff, 1992).

After extending this participatory irrigation approach to four more major irrigation schemes (in Polonnaruwa district) through a follow-on project (1986-91), USAID and IIMI were interested in tackling the resource management problems of whole watersheds in a participatory manner, to see how far the methods developed inductively, i.e., in a learning process mode, in Gal Oya could be extended beyond irrigation.

Two whole watersheds were chosen as pilots for the Shared Control of Natural Resources, known as SCOR: Huruluwewa in the North Central Province, and Nilwala in the Southern Province. Each had a major irrigation system downstream that would be jeopardised in the long run if shifting cultivation continued in the upper catchment area and accelerated the deforestation and erosion already evident there. Sub-watersheds in the range of 75 to 600 ha were identified (similar in scale to those in Rajasthan). The project was not implemented by a single department as in Rajasthan. Rather, IIMI recruited interdisciplinary teams of professionals with a variety of skills and backgrounds, but all committed to a participatory approach (SCOR 1995).

SCOR combined participatory assessments of present land and water use patterns, capabilities of resource user groups and support services, socioeconomic status, status of resource degradation, and potential for development, with more sophisticated geographic information system (GIS) technology. Persons were recruited, trained and deployed in the field as "catalysts" (as in Gal Oya) to work with communities to promote social organisation. Here they worked not just with irrigation water users but also with upstream resource users.

To assess progress and success, the project is monitoring sediment concentration and sediment load in the streams and rivers of the respective watersheds, changes in soil fertility and soil loss, biomass, water quality, and rainfall runoff and infiltration; water use efficiency in agricultural activities, factor productivity and profitability, cropping intensity, and cost reduction/value added; and effects of land (including common property) covered by group activities in terms of production and protection, value of investments made by user groups, number and type of commercial activities undertaken by groups, number of policy and procedure changes associated with project and user activities, and returns to shared control of land and water resources. The strategy is characterised as seeking an effective balance and blend of technologies, organisations and resources.

This is quite a dramatic step forward toward integrated management of soil and water resources. While it is operating on a smaller scale than the Rajasthan case, it is similarly interesting because of its promotion of commercial enterprises that are intended to give **greater value to natural resources** in a way that should create incentives for their conservation, and because it is linking upstream and downstream resource users into a common forum to assess and decide on all forms of NRM. Implementation is involving all relevant government agencies and the several levels of local government that have jurisdiction within the watersheds, so that the new people's organisations will have understanding and support from public-sector agencies.

MAISSADE WATERSHEDS, HAITI Beginning in 1989, staff of Save the Children, an international NGO, began meeting with landowners in 22 small, multi-owner watersheds (averaging 9 ha in area) in the central plateau of this impoverished country. The region was quite hilly (average 12 percent slope), and soil erosion was contributing to steadily declining agricultural yields.

Although Haiti is not known for collective action, a majority of the landowners were members of informal, self-organised and self-governing farmer co-operatives known as groupman (with 8 members on average). The average size of holding was 2.5 ha, spread in usually three separate parcels. A survey showed that the average watershed in the area had 9 agricultural parcels with 9 different landowners (White and Runge 1995).

Transboundary erosion was common in these watersheds and could hardly be avoided where the soil infiltration rate was low and there were few if any soil conservation structures. All but the topmost farmers both lost and received soil through erosion, creating a perverse kind of interdependence. Downhill farmers in principle could benefit, but the rapid runoff itself caused problems, and the spread of gully erosion as well as sheet erosion was a threat to most farmers on these hillsides. (See also White, 1992b; and White and Quinn, 1992, on the watershed programme.)

State efforts to curb erosion had proved ineffective, according to Murray (1979). Yet this NGO programme proved quite successful in mobilising local voluntary labour to construct checkdams, working with rural residents on the basis of informal cooperative action that they were familiar with (groupman). Within two years, 10 of the principal ravines had been treated, with partial treatment of another seven, while five remained without much soil conservation accomplished.

A total of 590 checkdams were constructed by the groups, averaging 27 dams per watershed, which were estimated to retain an average of 39 t/ha/y of soil (White and Jickling 1992). The amount of labour mobilised on a voluntary basis for soil conservation was impressive: 32 person-days per year from landowners. Perhaps more impressive was the voluntary contribution of 18 person-days per year from persons who did not own land in the watershed. Building on traditions of cooperation and mutual self-help, there was a substantial community effort to counter the effects of erosion that were visibly eating up future production possibilities.

White and Runge (1994) report that project support of the watershed activity ceased after two years "due to political instability and government repression of peasant groups." Yet despite this adverse climate, when White carried out a survey two years after the halt in support he found that groups remained active in 12 of the 22 watersheds (White and Runge, 1995).

The Haiti case is considered a success not because of the large scale of operation as in Rajasthan, or the innovative institutional development as in Sri Lanka, but because (a) it operated under very adverse sociopolitical conditions and in a physical environment where soil conservation and watershed protection was so urgently needed, and (b) it showed possibilities for collective action that had hardly been considered possible by most social scientists and most policy-makers. Extremely poor and isolated rural people were willing to invest labour and organisational effort to preserve as best they could their agricultural possibilities for the future.

Question III: What are the ingredients for success?

Discussion of this question could be long indeed, mirroring such 200-odd page treatments such as that of OED (1989) but, for brevity, the ingredients are simply listed here with only minimal discussion.

- All three of the above case examples built upon the foundation of **participatory local organisation.** These were formally recognised in two cases and left quite informal in the third, partly because rural organisations were at some risk under Haitian conditions in the late 1980s. In all three cases, rural people when approached with respect and a spirit of cooperation, rather than of technocratic management and control, responded positively.

- How rural communities were approached was important in all three cases. Specially trained **catalysts** were used in Sri Lanka, building on some years of experience with this approach there, whereas NGO staff with a non-bureaucratic orientation were used in Haiti. It is impressive that, in the Rajasthan case, government personnel were somehow persuaded to adopt unofficious manners and to engage rural communities in a fairly collegial manner.

- The outside agencies took a firmly **interdisciplinary approach** and also stressed **inter-departmental coordination and cooperation.**

- All three programmes worked in a **learning process** mode, with some advance plans but a willingness to adapt and change plans as experience provided new insights and presented new challenges. It is unlikely that a "blueprint" approach can devise a successful strategy for watershed management/soil conservation under many conditions (cf. Critchley et al., 1992).

- The programmes gave attention to **appropriate technologies**, being very experimental and taking local people's advice and ideas into account. Especially when dealing with soil and water, as well as trees and grasses, one cannot violate technical requirements and limitations. But it was particularly important to devise an appropriate "fit" between the technologies being promoted and the organisational channels developed for management.

- The method of **diffusion of innovation** was more horizontal than vertical, with provision made for farmers and communities to visit each other and exchange experience. While it true that "seeing is believing," it is also very persuasive to learn about success from people "like yourself." Observation tours were important in all three programmes.

- It was helpful that in Haiti, the programme could build on **indigenous 4institutions**, and this seems generally a successful approach. However, in the other two cases, it was possible to establish new bodies, user committees, groups or organisations.

- Such successes are not achieved with average or typical persons in top roles. The proof of outstanding **leadership** is that other persons within the programme perform at levels above and beyond what they would do with others in top roles.

- A further element going along with this preceding point is **bureaucratic reorientation** that redirects the thinking and efforts of the implementing organisation (Korten and Uphoff, 1982; Uphoff, 1992). This is most important where a government agency is responsible for carrying out the watershed management programme.

Other comparisons and observations could be made, but these points sketch a picture of the kind of strategy that is most likely to promote effective public management and to **help develop institutional capacities** at various levels to achieve better utilisation and protection of soil and water resources.

International agencies can attempt to support processes of bureaucratic reorientation, for example, or can lobby for the right of free association where this is denied or constrained, and its lack inhibits effective user groups. But such issues are intrinsically political and thus do not sit readily in the portfolio of activities of centres so studiously and jealously apolitical as those of the CGIAR. A more effective approach is the indirect one of **building up a broadly-shared consensus** that supports the kind of watershed management strategies that effectively involve resource users in decision making and implementation.

5. Present Position of CGIAR Work

5.1. Soils and Plants Research

The Centres have a long record of soil research, in IITA, IRRI, CIAT and ICRISAT. IITA has made valuable contributions on the structural behaviour of West African soils. IRRI's work on the chemistry of anaerobic soils and the production of methane is internationally known, and IIMI has a programme on salinisation and waterlogging of irrigated soils in Pakistan. Apart from this, most soils work has been of a fairly traditional nature, and has basically supported agronomic nutritional and cultivation work. Recently ICRAF has brought in new studies on soil-plant relations and roots systems using innovative techniques, and the CIAT results on the deposition of soil carbon at depth by deep-rooted tropical grasses has gained much attention (Fischer et al., 1994). In total there is a fair amount of soil and water research in progress within the CGIAR system, of which much will be directed at focused on-site productivity questions, but some is certainly relevant to NRM in a more general sense.

A wide-ranging proposal for a Soil-Water-Nutrient-Management (SWNM) programme has been developed by a group of organisations both within and outside the CGIAR

(DSE/IBSRAM, 1995). It has been commented upon by TAC, and is highly relevant to this study. In its latest form, it contains four Themes. The first Theme "Combating Nutrient Depletion" is generic and crosscutting - it is a necessary aspect of almost any soils or agronomy programme. Theme 2, "Optimising soil water use" fits naturally into a watershed water allocation and use project; as TAC commented, standing alone the proposal deals with processes that are largely well understood, but given a broader hydrological and water resource orientation it would be very appropriate. Theme 3 "Managing acid soils" is localised with regard to soil type, and would apply in some watersheds; it is however directed straight at a major aspect of the value of the soil resource, and involves the activity of soil organic matter. The 4th Theme on "Managing soil erosion" is seems to be focused on the on-field issues, whereas it would be better to see it as an aspect of watershed research, including off-site effects. All these themes will to a greater or lesser extent involve the study of soil organic matter.

In this study a set of specific research topics needing more attention in relation to NRM are identified (section 6.2), and it will be noted that these in fact agree with the Zschortau Plan in many respects. It is likely that any careful examination of the NRM needs in the CGIAR System at the present time will reach a similar agreement, because the needs are urgent and pressing.

5.2. Hydrology and Water Use

In general the CGIAR Centres are not strong in landscape hydrology, and have little tradition of such studies, with the exception of IIMI and IRRI, which are both concerned with water management for greater efficiency of irrigation. In contrast, a considerable amount of research has been done on plant use of water and on-field water management. Thus ICARDA and ICRISAT are working on supplementary irrigation and water harvesting techniques. ICLARM has an Inland Aquatic Resource programme, which is intended to include studies on aquaculture in relation to other land uses. In some agricultural systems fishfarming in ponds can be seen as an integral part of the farming system. Both IFPRI and IIMI have interests in the management of, and the rights to, the water resource. Work by IIMI has for obvious reasons dealt mainly with irrigation sources, slow-flowing and canalised rivers, and the control of complex systems. IRRI's and WARDA's interests are similar, so there is a fair amount of work in and experience of this situation.

There are also relevant Systemwide CGIAR programmes that are just coming into being. IIMI has the responsibility for the Systemwide programme on Water Management Research. This is intended to deal broadly with water-use efficiency for production, environmental and conservation impacts, including climate change, and relevant policy and institutional questions. The Rice-Wheat programme on the Indo-Gangetic Plains is addressing apparent sustainability problems in this cropping system, and while not specifically targeted towards water, this is an irrigated farming system, so water supply, quality and use must be an issue. ICLARM's proposal for a Coastal Environment Initiative will demand study of the lower reaches of rivers, with a watershed approach. IFPRI's Initiative on Property Rights and Collective Action is addressing socioeconomic issues in natural resources. It seems that much of this work proceeds largely in isolation, and some mechanism seems necessary to review it in order to identify generalizations and principles that can be applied more widely.

5.3. Ecoregional Programmes

The CGIAR Ecoregional concept has developed strongly, and any new Natural Resource programme must have a clearly defined relationship to it. Four characteristics have been defined as essential for the "ecoregional approach": research on the technical and human aspects of the sustainable improvement of productivity; dealing with a priority ecoregion; partnerships with NARS and other research agencies in the region; linkages with CGIAR global research activities (Report of the CGIAR Task Force on Ecoregional Approaches to Research, 1995). This paper places stress on the watershed as an organizing framework for research, but it is evident that the definition of a watershed as a unit of the landscape is not congruent with that for an ecoregion. The latter is for an "agroecological zone, regionally defined," i.e., that part of a particular agroecological zone which lies within a defined region, usually chosen to produce greater homogeneity in the final unit. This definition means that a large watershed might well contain parts of two or even more ecoregions, just as an ecoregion may contain many small watersheds. On the watershed concept, each of these ecoregions may then be emitting or receiving impacts from upstream or downstream ecoregions. This is evidently true of any of the major river basins.

Most of the research in an ecoregional programme will not be organised on a watershed basis, but this discussion suggests that ecoregional programmes should consider whether distant impacts of this type need to be included in their work. Where a watershed is smaller, and wholly within one ecoregion, then it is simply an excellent landscape unit for researching many of the processes occurring in the use of natural resources, either by using the watershed concept for interpreting results, or as the basis for an actual field experiment. As suggested earlier, it is likely that a watershed will contain soils and land forms which are replicated across the ecoregion.

Of the five Ecoregional Programmes already in being, four have a very strong orientation towards land degradation and the use of natural resources; in the Lowland Rainfed Rice consortium led by IRRI the natural resources aspect is present, but less prominent. All are targeting the overriding problems of nutrient deficiencies, shortage of water, or soil physical damage. However, there is as yet less emphasis on water as a resource other than for agriculture, or on the on-site/off-site impacts comparison. A further proposal for an ecoregional Initiative for the West Asia/North Africa region has been submitted by ICARDA, mainly aimed at increasing water-use efficiency, which is somewhat similar to the existing Desert Margins Initiative put forward by ICRISAT.

The relevance of NRM to land use as a general topic is discussed above. The only ecoregional programme that includes a mention of land use (systems) in its objectives is the Alternatives to Slash and Burn programme. This is, of course, logical, as the whole thrust is towards changing farming systems. On the other hand, CIAT has developed as part of its core programme a growing capability in land use study, including GIS and the technology for using remotely sensed imagery for land characterisation. It is assumed that this will be used in the Hillsides Ecoregional programme, as well as in others.

5.4. Socioeconomic, Policy and Public-Management Research

Notwithstanding the work of IFPRI and other Centres noted in the introduction to section 4.5, only a modest portion of the research presently undertaken within CGIAR Centres addresses the kinds of management and institutional issues discussed above. As noted above, the wide-ranging Centre work on socioeconomics, policy and public-management research is considerable, and is the subject of the companion Strategic Review. What follows are a few remarks pertaining to CGIAR research specifically related to soil and water. This has focused on:

- Improving nutrient-related fertility enhancement practices;
- Improving soil moisture-related fertility enhancement practices;
- Reducing vulnerability on agricultural lands; and
- Improving on-site aspects of irrigated resource systems.

The subjects discussed concerning the Three Questions in section 4.5 are related very much to the last-mentioned focus of research, on irrigation water management. The SCOR project grew out of efforts to improve management of irrigation water as a scarce natural resource, and the lessons to be drawn from the other two cases are consonant with what has been learned from work in the irrigation sector.

As noted in discussion of the Rajasthan case, a good part of the soil conservation and watershed rehabilitation strategy involved soil-moisture retention measures, including surface management and water harvesting, as well as measures to reduce the vulnerability of agricultural lands through vegetative coverage, channelling of runoff, contour bunding and terracing, etc. The Sri Lanka and Haiti cases also implemented such interventions. While there may be somewhat different incentives at work for watershed management and soil conservation, as distinguished from the agricultural practices that have been the traditional focus of CGIAR research, it does appear that substantially similar public-management issues arise for state, community or NGO institutions, and thus the scope for potential Centre research is wide.

A common problem when trying to improve NRM regimes is the fact that naturally-occurring resource units or systems, such as watersheds, rarely correspond to political or administrative boundaries. This has been a particular problem for improving irrigation management when, for example, such boundaries put head-enders under one political jurisdiction and tail-enders under another. The same situation is common for watersheds, with upstream portions in one region or district (or in several) and downstream areas lie in a different one (two, or three, or more).

It is quite clear that improving planning and implementation of natural resource use requires having resource users within a common political or administrative unit, so that decisions can be made with the knowledge and consent of all concerned. (If there are dissenters, at least they have had their say and have been part of the process producing management decisions.)

Some of the hardest things to change in the world are existing boundaries, as there are surprisingly many (and powerful) vested interests in the *status quo*. Yet one obstacle to more rational and consensual improvements in the policies and practices governing resource use is the patchwork quilt of politico-administrative jurisdictions that seldom match "the lay of the land." Without any illusions that research will produce a new willingness to alter boundaries, this is a worthy subject for many researchers, even though it is outside the traditional domain of the CGIAR System itself, to bring together knowledge: (a) on the obstacles and irrationalities arising from present mismatches between natural and man-made boundaries, and (b) on the consequences of any efforts to improve NRM by adjusting boundaries. To maintain its strong traditions of independence from political sensitivities in its partner countries, it is appropriate for the System to continue to rely on others to "make the running" in these fields that, nevertheless, remain vital to achievement of many agreed and high-priority resource-management research themes.

Resource tenure is another subject of major significance for NRM. This includes "tree tenure" (Fortmann 1988) along with land tenure. It is generally agreed that security of control over natural resources, whether land (soil) or forest (trees), is a major influence on whether people will manage these in ways that conserve productivity over time, rather than extract value from them quickly. This has been used to argue for private ownership and for secure formal-legal titles.

In fact, there is no consistent evidence on this, as common-property ownership has under a variety of circumstances (but not all) produced resource-conserving stewardship. And sometimes, formal title provides no real assurance, if the government is disorganised or predatory, while common-law, *de facto* title fully supported by community knowledge and sanctions may be quite secure as has been documented in recent World Bank research studies in Africa (Crosson and Anderson (1995) provide a synthesis).

The body of research that has put "common property resources" on the policy agenda has been a good example of useful social science research. Distinguishing this from private and public (state) ownership, and contrasting it with open-access situations, has clarified the range of tenure options. Such typological analysis needs to be elaborated with regard to specific resources since, especially in "traditional" systems, great complexity can attend people's access to and responsibility for natural resources.

6. Research Gaps and Needs

6.1. Operational needs

The detailed implementation of these multidisciplinary programmes is not a subject for this paper. It is evident that the many participants in such NRM programmes must form consortia to work towards a common aim, as is now being done. Any scientist who has worked in such consortia is well aware of the effort, time and money needed to ensure proper planning, coordination and execution, and this aspect must not be dismissed lightly. The managerial and organizational aspects can easily ruin a large programme if they are not well designed for efficient running, careful planning, proper evaluation and final accountability (Tinker, 1994a). It is argued in the main report of this paper that another layer of management is not wanted, and this is certainly correct. However, control and coordination responsibilities must be located in one of the existing levels for each consortium, and this must be known to all participants. Some mechanism is also needed to ensure overall contact and coordination because of the extent of interconnection in the different parts of NRM work.

There is a strong consensus of opinion in the CGIAR Centres and in their many collaborating organisations that progress in NRM research is only possible if there is a close working relationship between the many disciplines involved. In particular the biophysical scientists and the socioeconomists engaged in research must collaborate at all stages of the research process, including problem identification, research design and execution, and evaluation of the results. The exchange of views must be a two-way process, in which the understanding and evaluation of the problem is fully shared. Biophysical solutions that are not economically and socially viable must be regarded as incomplete or inadequate solutions. Where biophysical solutions can only become viable in practice if policy changes are made, these results must be fed into the design of policy research. Thus biophysical and socioeconomic scientists must participate fully as members of the multidisciplinary INRM research consortia being developed to improve the use and conservation of natural resources.

A broader approach to sustainable agriculture and NRM research, including attention to all environmental factors, must be multi-faceted as well as multidisciplinary, and several different modes of research organisation will have to be used. It is not possible to be prescriptive, because of the variety of problems, and their location-specific and country-specific nature. There are, however, some general points that can be made. The first is that work must be truly multidisciplinary, as is argued at greater length above.

It is vital that the work is done in a fully participatory way with the farming communities. This has been well argued by Greenland et al., (1994) and others, and only needs endorsement here. Contact with farmers is needed to ensure that their real problems are well understood and that proposed solutions are relevant to their purposes. Secondly, the detailed operations of farmers must be analyzed to ensure that all possible ideas and opportunities are exploited in the research.

The linkage with local organisations, particularly NARSs, NGOs and universities is equally essential. It is simply impossible for CGIAR Centres to do all the necessary work themselves. Local organisations can contribute vital local knowledge, contacts with farmers, and on-the-ground presence to the research, as well as their professional skills.

It is envisaged that work on NRM will be organised in various ways. Firstly there will be projects in the core and complementary programmes of Centres, linked with particular issues, and probably often with an adaptive or applied aspect. Secondly, there will be work in Systemwide programmes, such as have been developing over the past few years within the CGIAR. Existing ecoregional programmes contain much NRM research, and the various elements of the Zschortau plan for Soils, Water and Nutrient Management research are being developed in a similar way (DSE/IBSRAM 1995). Thirdly, we are suggesting that integrated multidisciplinary experiments on watersheds should be used as the basis for a more specific approach to sustainable agriculture, on a small number of major sites. This triple level of experimentation should provide a solid and flexible system to meet all the significant problems of NRM in relation to soils and water.

Soil and water problems will continue to appear in the mainstream research of the Centres, and will be dealt with as part of these programmes. The specific ecoregional programmes that are now developing must often contain SWNM elements, as described above, and will need targeted soil and water programmes. It is recommended that, wherever possible, these projects should be classified or organised in relation to the watershed model discussed here, thus using it as a framework. That includes identifying the work by terrain type, by main processes and by outputs and impacts (in the sense of Figure 1). This will allow research efforts with a similar conceptual base to be grouped and reviewed together, so that general results and principles, successful and unsuccessful technologies can be identified and compared, despite the many site-specific differences that will certainly appear.

However, an underlying weakness in this use of the watershed approach, despite its advantages, is that sets of watershed data will be combined from different times and places, and are unlikely to be compatible. It is important that in a few sites a full watershed experiment should be set up, so that a coherent data set is available for a full analysis, and possibly a watershed model. Ideally, any agronomic or other intervention aimed at improved production in a particular land use unit can be tested for impacts on soil movement, river flow and water quality within the same watershed, in different terrain types and land use units. The environmental impacts and hence the sustainability of the agronomic changes can therefore be proven in this new type of experimentation.

It is important that all this work should be done for clearly identified reasons, and with the best available concepts and techniques. Several soils and water research topics are listed below, which have present priority because of their potential for poverty alleviation, or for reducing impacts on the environment and enhancing sustainability, or because scientific developments suggest that these areas will become essential research subjects before long. This last may imply the strengthening of subjects in which CGIAR Centres may have no special comparative advantage now, but where it will be needed in the future.

A further rationale for addressing such needed research comes from World Bank experience. The Bank's evaluation unit (OED 1989, p.xix) in assessing required effort for increasing the relevance of economic and sector work in countries where resource degradation is judged to be a matter of critical importance (such as Nepal, Niger, Pakistan, Philippines, Sudan and Uzbekistan, to mention a few) concluded as follows: "it would be necessary to: (a) examine the national and, in some cases, the international dimensions of resource issues, the intersectoral linkages, tradeoffs and conflicts, and the interrelationship with macro policies; (b) assess what the government, non-government organisation and external aid agencies are doing to address the issues; (c) identify and evaluate a set of policy options to build on what is already being done; (d) discuss the institutional constraints frankly; and (e) suggest how **the information base necessary to improve policies for resource management** on a broad scale can be strengthened." (emphasis added). The CGIAR System can thus provide a direct contribution to bettering NRM globally by being a key provider of, and facilitator of the provision of, this information.

6.2. Specific Research Topics

There are many aspects of soils and water research in which CGIAR Centres are well equipped and staffed, and which will be used to the full in the future escalation of SWNM research. In others it may be advisable for the System to take stock. If our suggestions for a stronger stress on watersheds and hydrology are taken up, skills in these subjects will be needed. It would be best to obtain these largely from existing centres of expertise in the first instance, until the need for in-house skills in the Centres can be judged. The topics listed here are traditional, in the sense that research on them has been continuing for many years. They are therefore all of central importance to the use of soils, and in all there are new developments that need to be taken up by all CGIAR Centres with appropriate interests.

(a) **Soil organic matter** (SOM) levels and properties are crucial to soil structure and fertility. These include the rate at which mineral nutrients are formed by SOM breakdown, the retention of some nutrient ions, and the improvement of soil structure and resilience. The faunal and microbiological processes that lead to stabilised SOM, the ways in which the properties of this may vary, its interaction with the mineral parts of the soil, and its rate of breakdown need more work, particularly in the tropical environment. This is essential for sustainability of soil use. The use of models to predict the behaviour of organic matter in different conditions and depths in the soil is developing rapidly. A world-wide network on soil organic matter studies and models (SOMNET) (Gregory and Ingram, 1996) has just been launched with CGIAR staff involvement. Socioeconomic work on the costs and opportunities of possible sources of organic matter that could be added to the soil, including gender aspects and alternative uses, adds to the research agenda.

(b) **Soil biological relations** also include the microbial and faunal relationships around roots, including plant growth promoting bacteria, soil-borne diseases, symbiotic and non-symbiotic N fixation, and mycorrhizal function (Tinker and Barraclough, 1988; Lynch, 1990). Research on these subjects is important for plant nutrition, soil-borne diseases and the possibility of biological disease control. The activities of soil fauna such as earthworms and termites are also important, and need more detailed study in terms of their function in the soil. Soil biology is undergoing a general resurgence of interest at present, and good collaborators in centres of excellence in the developed world should be available. It is a specialised, but extremely important, part of the general study of biodiversity.

(c) More cost-effective and socially acceptable **methods of combating and predicting erosion** are highly desirable, because of direct impacts upon the productivity of eroding fields, and the environmental damage caused downslope and down stream. The chance of finding genuinely new methods of control may not be high, but it is important that methods of predicting erosion in particular conditions are improved, so that the consequences of other changes in farming systems or technologies can be estimated at an early stage. Further understanding of rainfall erosivity is also needed. This is essential for sustainability of soil use, as erosion is generally a particularly irreversible process. Knowledge of the correct economic and policy circumstances in which technical interventions should be used are however vital for their success.

(d) New and improved ways of **managing water** for greater efficiency are essential, especially for rainfed agriculture in the semi-arid tropics, where it is often found that only a small proportion of the rainfall is actually transpired by the crop, for reasons explained earlier in this paper. This requires research on better management of crop and soil for maximum infiltration and water storage, and elimination of other constraints to rapid growth. Combined nutrient and water deficits need particular study to determine efficient ways of detecting and dealing with both. There is now a better understanding of how stomata function, and that they are influenced by chemical signals from the root, so that understanding of transpiration rate is improved.

(e) **Better models** of the movement of water, salt and other solutes such as plant nutrients are needed. These are used for controlling waterlogging and salinity in irrigated areas, and also for predicting water-borne disease risks. The models for nutrient movement is mainly to understand the losses by leaching under high-rainfall conditions, but are also relevant to eutrophication of watercourses. It is likely that most of this modelling work can be done by universities and other centres in the more-developed world, but adaptive research on their effective use would be necessary by local organisations.

More acceptable use of water also depends upon a better understanding of the decisions and incentives faced by water users, especially in public irrigation schemes and in the private exploitation of aquifers. Research on water pricing and allocation, water users associations and other socioeconomic aspects is therefore required.

(f) Better methods of **managing soil nutrient fertility** are essential for sustained productivity increases, because of nutrient export in produce and the continued shortening of the fallowing component of shifting cultivation cycles. This calls for the maximising of nutrient recycling, and the use of additional organic manures and inorganic fertilisers in controlled amounts tailored to the circumstances of the individual farmer and the different field situations. The decisions of the farmer will be strongly influenced by fertiliser/farm product price ratios, which depend on many market and policy-related issues. Where soils are already intensely depleted, the use of "one-off" heavy applications of nutrients may be deserving of careful economic assessment and could turn out to be cost-effective in some circumstances (Sanchez and Izac, 1995)

(g) The improved and more efficient use of nutrients that is required needs applied studies on the rate of **movement and reaction of nutrients** in soils and of the dynamics of development of crop root systems, to determine how long applied nutrients remain potentially available for crop growth. It also calls for continued research on nutrient turnover in the soil through the microbial biomass.

(h) **Acid soils** cover large areas of the humid and subhumid tropics. The traditional method of curing this, by the application of liming materials, is often not practicable due to the absence of local sources of lime, and the consequently prohibitive costs. Thus savanna soils in Latin America can be used for pastures, but their productivity could be greatly increased if the acidity effect could be removed. This can be partly achieved by maintaining high soil organic matter levels, which sequesters the soil aluminium ions in acid soils, and partly by introducing pasture, crop and treecrop varieties that are tolerant to acidity and economically feasible. More research on both aspects is needed.

(i) The general subject of **modelling** is continuing to grow rapidly in importance, as computers become ever more powerful and simulation modelling is applied to a steadily growing list of topics. It may be that some CGIAR Centres are less well advanced than they should be in these applications, despite excellent work in particular Centres. This is, of course, essential for hydrological work, as has been emphasised in this paper, but it is also becoming standard procedure for the study of most soil and agricultural processes. This includes models for soil chemical and microbiological reactions, crop growth, transport in the soil profile and many others, including farm/household and community decisions and processes. Models can be misused, but ultimately they are the only way to determine how our understanding of component processes can predict the behaviour of complex systems.

(j) One area where there is most clearly a role for international centres and researchers is in developing better **measurement of the status and trends of natural resources** being managed under different regimes, to be better able to document trends and extents of change. This is being addressed in at least one initiative, namely that on Land Quality Indicators, underway between the World Bank, CIAT, and others. One of the areas where our knowledge is most deficient is in this domain of measurement concerning NRM and environmental consequences. A particular measurement theme still yet under-emphasised (notwithstanding such IFPRI Environment and Production Technology Division work as by Rosegrant and Evenson (1995)) is the careful assessment of changes in total factor productivity (TFP) at various levels of agricultural systems. Crosson and Anderson (1993) have argued strongly that TFP trends must serve as the main guideposts to policy work in NRM in general and NRM research in particular.

The NARS, which are to be assisted by the CGIAR System to become more effective in natural resource management, are likely to face particular difficulties in operationalizing such measures. There is little consensus within academic and practitioner circles on such measurements, which should themselves be linked in some systematic way to models of causation, so that the measures are not arbitrary but rather can contribute to an improved theoretical understanding of the complex dynamics within natural resource domains. One way of improving this linkage is by setting up a monitoring programme as an integral part of long-term field experiments, so that the change in soil or other parameters can be linked to performance and output. Environmental monitoring at all scales is a rapidly growing activity that is essential in maintaining environmental quality (Tinker, 1994b).

(k) One theme on which further socioeconomic research should be done concerns **local government and decentralisation** issues affecting NRM. There are strong advocates pro and con with regard to devolution of responsibility for soil, water and forest resources to local government bodies and/or user groups. Some consider this the only salvation, while others fear it will accelerate the degradation of ecosystems. Examples can be cited to support either view. What is not known are the frequencies of alternative outcomes or, more important, what conditions or objectives make either approach more likely to produce desirable (or undesirable) outcomes for NRM. A major research initiative on decentralisation launched at the World Bank (by H.P Binswanger and others) should also help shed light on these questions, several aspects of which are also already being addressed in IFPRI's research programme on "Property Rights and Communal Action."

(l) Some different suggestions concern how useful research might be done for the purposes of promoting better, more sustainable natural resource use. The International Association for the Study of Common Property (IASCP) is an exemplary organisation for bringing together people from a variety of disciplines and with different national and institutional backgrounds (including the CGIAR Centres).

In particular there appears to be a need to bring together socioeconomists working on soil degradation issues to identify priorities more sharply, in close coordination with biophysical scientists. The Zschortau Plan (DSE/IBSRAM, 1995) has set up a potential programme that is strongly focused on soil degradation mechanisms. The socioeconomic aspects of soil degradation are of comparable importance to the biophysical aspects, and it is important that socioeconomists get together to formulate their plans. There appears to be a need for a structure such as a Network for the Economics of Soil Degradation for socioeconomists, but working in close linkage with the biophysical groupings, to produce a coordinated approach to these multidisciplinary problems.

(m) A large amount of biophysical research has been done, in various contexts, with the aim of **increasing crop and other enterprise productivity** in a sustainable way. This is particularly relevant to the need to move from shifting cultivation systems to permanent cropping. It is desirable to further review this body of work, and to determine in which conditions it is believed that the problem has been solved in a biophysical sense. If the solution has not been adopted, the question should be asked whether farmers find it unattractive and it is not taken up for socioeconomic reasons. If so, the further question should be asked whether other and more attractive biophysical solutions have been sought, or whether socioeconomic interventions have been considered. This study, which requires no further field work in the first instance, will help to extract maximum value from work already done.

6.3. The Watershed Experiments

The watershed approach can be an organising principle for research prioritization and management on land use, soil or water; it can be used to organise large integrated experiments; it can be a planning tool for the development of watersheds; it can be an ongoing system for long-term management of a watershed. The present study is engaged only with research, but the subsequent use of the watershed approach for development or management would increase the value of research done in this way. This will allow a large-scale linkage of research results with policy and management, if the latter are also seen in a watershed context.

To summarise, the benefits of the approach are:

(a) A complete oversight over the whole water resource in a defined area, with the possibility of planning water allocations between different uses.

(b) Clear information on externalities, in the sense of off-site effects, so that cause and effect, costs and benefits of possible interventions can be compared.

(c) The definition of relatively uniform land units, so that agricultural, or other land use advice can be precisely targeted, and applied in other watersheds.

(d) Present land allocations and uses can be tested to determine if they are technically and economically acceptable and sustainable.

(e) A rational framework for research planning is provided, that can follow effects back to their spatial origins.

(f) An ability to see the socioeconomic conditions, the infrastructural situation and the flows of inputs and outputs across the whole watershed.

(g) A better structure for dealing with biodiversity and other environmental questions.

A watershed programme needs an international level approach. The complexity of a fully integrated study, the variety of disciplines involved, and the difficult technical issues that will almost inevitably be raised by the many interdisciplinary contact points, will demand staff of high calibre and with good backup. It will be essential to have good contacts and collaboration with universities and other centres of excellence from the more-developed world. The development of the necessary models for expressing the interactions and functions of a watershed do likewise. The organisation of all the adaptive and applied work in such a programme is itself a considerable challenge and an important research task. There may also be scope for manipulative experiments in these ecosystem-scale projects (Rasmussen et al., 1993).

A full watershed experiment will be a considerable investment, and which will need to be continued for a number of years to give full value - for example, it would be optimistic to believe that **sustainability** can be proven in a period of five years. The work done in Kenya over the past 50 years shows what can be done, but it also emphasises the importance of consistent long-term support for the work.

An experiment of this type would require a powerful consortium of Centres, NARSs and other national or regional organisations, and centres of excellence in more-developed countries. Consequently only a small number of them can be set up, and they would have the status of CGIAR flagship sites. Their size, high cost and visibility demand that site-selection, planning and organisation should be fully thought through and meticulous, and that the assignment of responsibilities should be absolutely clear. Similar comments apply, of course, to all SWNM work in the Ecoregional and Systemwide programmes.

Within a watershed there may be several land uses or agricultural systems. It may not be necessary to do research on all of them, but there will be a need to have basic expertise about each one to allow it to be included in the overall approach. There will be a need for hydrologists, agronomists, soil scientists, economists, social scientists, livestock scientists and foresters. This disciplinary complexity does, of course, carry dangers of fragmentation, because researchers will tend to see their problems through disciplinary lenses, and may drift away from the main objectives. There has to be frequent and repeated contact between the various types of scientist, and the responsibility for overall management has to be clearly identified and enforced. The managing of a full watershed experiment is not to be undertaken lightly, but the added value from successful single-site collaboration could be great.

Equally, close linkage with the farmer is essential in soil/water natural resources work. For example, the detailed treatment of the land may be of great importance for water relations, and the exact cropping regime is vital for soil protection, in addition to the many socioeconomic issues that arise. It is possible that, over a large spatial extent, this participatory link to the working farmers, knowledgeable as they are about the management of their natural resources, may best be made through NGOs (Malena, 1995). The need for strong local involvement of scientists and farmers is essential to ensure appropriate solutions to real problems, and to ensure that all off-site problems are detected and quantified (Rasmussen and Meinzen-Dick, 1995).

Watersheds are of many sizes, and it is impractical to mount a concentrated research effort on more than a moderate spatial scale. The best approach is probably to select a very few typical sub-watersheds for intensive experimentation, and then ensure that essential data such as streamflows and pollutant concentrations are measured across the whole of the selected watershed. Socioeconomic data will almost certainly also have to be measured widely. The ultimate aim is to have sufficient data to model the watershed as a whole. A programme at this level is a sound base for extrapolation of results, and for assessing off-site costs of any proposed improvement. More complex programmes, such as those described above, could be approached as experience grew.

It may be asked if this is practicable in less-developed countries, and how it will benefit the farmer. It will not produce immediate benefit in the short term, but the approach is undoubtedly the way forward for improved land-use management. It is necessary to develop forward looking strategic research, from which the next generation of applied and adaptive research will draw its inspiration. The alternative is constant ad hoc experimentation addressing now this single issue, now that, but without coherence.

The logical user-level product from modelling is a Decision Support System, which could be considered as part of a watershed programme. CIAT (1994) considers that such systems will be useful in reconciling divergent interests amongst stakeholders, and is already working on one.

7. Concluding Remarks

"Natural resource management" is an excellent rallying cry, but it has little meaning unless the question is asked: "management for what?" Conservation of the status quo is clearly not the answer. Within the CGIAR the only purpose must be management for higher productivity, to meet the demands of an increasing and hopefully better fed population. Within this, equity must be improved by an appropriate share of the benefits going to the poorest farmers and their families. Finally, this must be done whilst preventing or decreasing damage to the resources, so that preservation of resources is linked directly to their use. However, this is not sufficient now that we understand how far the effects and impacts of this use may spread: to neighbours in diseases and weeds, downstream in silting and pollution, to the globe in greenhouse gases and biodiversity effects. If all these levels of damage can be kept within acceptable limits, then we have some of the key conditions for sustainable use, which is the objective of natural resource management.

This interdependence of enhanced productivity and better management of resources means that there is very little "natural resource management research" per se, because the great majority of the CGIAR projects dealing with soils and water will have both aims, though some will focus most on productivity and others on resource management. In this paper we set out the various types of research that we believe are necessary for the CGIAR System to deal effectively with these interwoven thrusts, though the paper focuses on soil and water resource management in the first instance. The most innovative proposal is that the CGIAR should develop a small number of watershed experiments, dedicated to showing how productivity can be increased in what can be proven to be a sustainable way, in addition to the large body of research in Ecoregional Programmes and elsewhere that must now focus more clearly on these issues. CGIAR Centres, as part of their movement away from their earlier focus on commodity research, can truly embrace an agroecosystem perspective, and should be able to contribute importantly in this conceptual and theoretical realm.

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SDR/TAC:IAR/96/10

CONSULTATIVE GROUP ON INTERNATIONAL AGRICULTURAL RESEARCH

TECHNICAL ADVISORY COMMITTEE

A SYNTHESIS OF CURRENT ACTIVITIES IN SOIL AND WATER RESEARCH IN THE CGIAR

TAC SECRETARIAT

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

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1. Background and Objectives

At TAC 65 the Committee considered a proposal for a Strategic Study on natural resources management research in the CGIAR. The identification and assessment of major suppliers to that field of research was among the terms of reference endorsed by the Committee, including an analysis of the current and planned work of the CGIAR Centres. Convenors of the Study requested then TAC Secretariat a first "in-house" attempt at such an assessment.

Initially the information was compiled exclusively from what was available in the Medium Term Plans (MTP) and the Program and Budget (P&B) proposals for 1996, and the useful compilation done by CIAT on current research in Soils, Water and Nutrient Management[1]. Not having had the time to consult the Centres on the interpretation given to the information contained in these documents, the preliminary report was limited to proposing an analytical framework and to make a tentative identification of the current Soils and Water (S&W) research at the Centres.

Following discussions at TAC 67, it was decided to take this part of the study a step further by:

i) focusing on S&W-related activities, with emphasis on those having a resource-conserving perspective; and
ii) consulting Centres on the validity of the information compiled;
iii) analyzing the information required for TAC's priority-setting exercise.

In this context, this desk-study attempts to answer three questions concerned with the current S&W-related research at the CGIAR Centres:

1. **Which types of agricultural lands** are the main targets of CGIAR research?;

2. **Where in the systems scale** are Centres concentrating their research efforts?;

3. **What research strategy** are the Centres pursuing?

2. An Analytical Framework

Most of the programmatic and financial information available from Centres follows the five categories identified in the CGIAR's classification of research activities. It is recognized, however, that in processes related to the management of natural resources for agricultural production many of such activities are interrelated. Consequently, it would not be appropriate to include only a few of the CGIAR activities as S&W-related in a resource-conserving context (e.g., 2.3, Land resources conservation and management, or 2.5 on Processes and mechanisms of sustainable resource systems). There was a need to design a conceptual framework to characterize current CGIAR Centre activities so that the particular objectives of this study could be addressed.

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[1] CIAT-SWNM Secretariat, 1995. Intercenters SWNM Initiative.

The analysis necessary to deal with the above questions requires a three-dimensional framework, that addresses the *demands* for international research derived from prevailing systems in the most relevant agricultural land types; the *scope* of S&W research in the hierarchy of agricultural systems, and the applied or strategic nature of the *approach* Centres are following in their S&W research. These three dimensions are briefly discussed in the following sections.

2.1. Agricultural Land Types

Identified land types are derived from the basic criteria followed by TAC in its latest review of priorities and strategies, by Greenland et. al.[2], and the TAC document SDR/TAC:IAR/96.9; but an effort was made to link them with the operational approach pursued in the Centre's MTPs. One of the difficulties in the application of S&W-related research is its location-specificity. Management practices thus respond to variations in soils, climates, land forms and human behaviour with the result that S&W management problems differ considerably in significance and extent in different parts of the globe. To assess their relative significance, it is therefore necessary to categorize them in relation to major land and land-use characteristics. The following land types were selected for having some internal consistency in S&W issues, and linked to TAC-defined agroecozones:

Warm arid and semi-arid tropics and sub-tropics	* semi-arid lands
Warm sub-humid tropics and sub-tropics	* savannas * hillsides
Warm humid tropics and sub-tropics	* rainfed lowlands * forest margins
Cool tropics and sub-tropics	* highlands
Cool sub-tropics, winter rainfall	* semi-arid lands, winter rainfall
Cross agroecozones	* irrigated

The dominant farming systems in the desert margins are animal-based, ranging from nomadism to improved pastures in mixed farms. Shifting systems prevail in the wetter savannas and humid forests, with grazed fallows in the savannas and tree-fallows in the forests. Rice predominates in the lowlands, while sedentary agriculture and livestock are the main systems of land use in the heterogeneous steeplands. In general, methods to keep soil nutrient levels as cultivation pressures increase are critical. Manure or fallow organic matter becomes critical to nutrient cycling and water retention, as well as to erosion control and biological activity. Water shortage dominates drier areas, while

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[2] Greenland ,D.J., G. Bowen, H. Eswaran, R. Rhoades, C. Valentin, 1994. Soil, Water and Nutrient Management Research - A New Agenda. IBSRAM Position Paper

excesses are a major concern in the wetter lands, exacerbated on a landscape scale by sedimentation.

Semi-arid Lands. Most of the soils are sandy or gravelly and shallow, but there are also large areas of potentially productive and difficult to manage vertisols. Water scarcity is the major resource problem, compounded with loss of organic matter, erosion and crust formation in soils. In warmer areas during the short wet seasons soils are susceptible to waterlogging or erosion, while winds are a threat to erosion in sandy soils during the long dry season.

Savannas. In the higher rainfall areas soils are severely leached, acid and of a low inherent fertility, showing signs of soil chemical and physical degradation with increasing pressures. Farming systems are in the transition from grazed fallows to improved pastures and crop-livestock systems. In zones with moderate rainfall soils are less acid, but still have problems of poor structure and low nutrient content. Increasing pressure on the prevailing subsistence-oriented agriculture is shortening fallow periods, exposing soils to compaction and erosion. The *Inland Valleys* are an important land form that cuts across this agroecological zone and that of the Rainfed Lowlands. They offer considerable potential for increasing productivity because of higher soil fertility and opportunities for dry-season cash cropping.

Hillsides. Soil erosion is the main problem in this land type, not only because it undermines agricultural productivity, but also because it can cause downstream problems for hydroelectric generation, irrigation and urban water supplies. As fallows shorten, cropping intensifies, and more marginal lands are brought into cultivation, soil erosion compounds nutrient depletion problems.

Rainfed Lowlands. Soils vary across the different regions, but rainfed ecosystems share one major characteristic: uncertain moisture supply. Fields may have too much water, too little water, or both, within the same cropping season. The concern for sustainability in this land type is not about raising very low yields, but maintaining and increasing existing high levels. Yields are stagnating or showing a downward trend. In the uplands soil erosion and degradation could be a special problem following logging. As mentioned for the Savannas, the Inland Valleys offer considerable potential for increasing productivity because of higher soil fertility and opportunities for dry-season cash cropping.

Forest Margins. Soils are mostly of low inherent fertility with low activity clays. Those in the drier part are very easily eroded. Farming systems are tree-based shifting cultivation. When the vegetative cover is removed, heavy rainfalls induce the collapse of the structure of the surface soil. Lower organic matter replenishment leads to soil compaction and heavier leaching causes nutrient depletion.

Highlands. The characteristics of the soils and the climate differ widely, but the slopes result in a common problem of water erosion. Farming systems are based on mixed crop/animal/tree systems. Unsustainability in these steeplands can have an impact at different spatial scales. As in the case of the hillsides, problems are compounded by increasing rates of deforestation.

Semi-arid Lands, winter rainfall. Agriculture is based on soils that are calcareous, and low in clay and organic matter. The resource base shows signs of deterioration, with expansion of cultivation into marginal zones leading to serious erosion on rainfed lands, while overgrazing causes the rangelands to deteriorate. Shorter fallows reduce their capacity to conserve soil moisture and improve fertility, and the potential of integrated crop-livestock systems is not fully exploited.

Irrigated. The threat to this land type arises mainly from waterlogging and salinization, reservoir siltation, and decreasing capacity of soils to release nutrients. Inadequate drainage of the irrigated area, leads to waterlogging or a rising in the water table. If the latter contains saline water, as it often does in arid and semi-arid areas, the soil will be salinized and productivity severely reduced. An additional problem is that of reservoir sedimentation, caused by the increased intensity of deforestation in catchment areas. In the intensive rice systems of Asia, soils are showing an increasingly lower capacity to release nutrients, indicated by divergent trends of higher soil organic matter and lower N supply to the crop.

2.2. The Scope of S&W Research

There is an increasing awareness about the socioecological nature of agricultural land use systems, which is shaped by interdependencies among agricultural, environmental and socioeconomic factors. This multidimensional and interactive nature of agricultural systems emphasizes the need to incorporate a spatial dimension in the understanding of the structure and function of such systems. Agricultural, environmental and socioeconomic factors have an impact on the sustainable management of S&W resources. But their relative importance and the nature of the impact tends to differ according to levels in the hierarchy of production systems (e.g., water erosion affects crop production in the upstream fields, and power-generating capacity in the downstream dam).

The main part of this TAC study advocates an integrated approach to NRM research in the CGIAR, as an "organizing framework within which to consider a number of critical linkages and subjects in the natural resources area". It is further argued that research should be prioritized within the context of four sets of linkages: the linkages between productivity-enhancing and resource-conserving research; between spatial levels in the landscape (e.g., upstream-downstream); between research and adoption; and between present and future users. From the point of view of the actual management of natural resources, these linkages represent interactions across different levels of decision-making in the systems hierarchy. In this context the proposed linkages could be organized as:

- links between productivity enhancement and resource-conserving research in developing S&W management alternatives (field level);
- links between research on resource management options and that on farmer's decision about production systems (farm level);

- links between "on-" and "off-site" research to estimate private/social benefits/costs of resource management options, often dealt at community levels of decision-making (watershed/landscape level); and
- links between farmer/community level(s) of decision-making and policy issues (normally at country/regional levels of decision-making).

Against this background, we believe that the scope dimension of the analytical framework should take into account scales in the systems hierarchy at which research activities are carried out by CGIAR Centres. Here four scale levels are proposed for the categorization of the S&W research in the CGIAR. Each one of the scales includes a set of research activities which are identifiable, to a certain extent, with those included in CGIAR's existing research categories. The adopted scales and corresponding research activities are presented in Table 1:

Table 1: S&W-related Activities in a Hierarchical System context

System Level		Research Activities
Field	1.2.3/5.a)	soil nutrient dynamics
	2.3	maintenance and improvement of the resource base
	2.5	processes and mechanisms
Farm	1.2.1	production systems studies
	1.2.2	farming systems, technology evaluation
	4.1	microeconomic analysis, technology implications
Watershed/ Landscape	2.1	characterize ecosystems
	2.4	management of aquatic resources
	2.6	modelling landscape and watershed phenomena
Country/ Region	4.2	policy analysis
	4.3	public systems management

2.3. The Research Approach

The research approach adopted for this study is already followed by some of the CGIAR Centres in their research on natural resource management. It derives from a macro perspective at the agroecosystem level and focuses on biophysical and socioeconomic processes and mechanisms regulating S&W management. This "systems-and-processes paradigm" (Scholes, M.C. et. al.)[3] recognizes the limitations of empirical

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[3] Scholes, M.C., M.J. Swift, O.W. Heal, P.A. Sanchez, J.S.I. Ingram and R. Dalal, 1995. Soil Fertility Research in Response to the Demand for Sustainability. *In* The Biological Management of Soil Fertility, Ed. by P.L. Woomer and M.J. Swift. John Wiley & Sons.

research for the development of information-based management technologies. These require a deeper understanding of agroecosystem functions at the process level.

As mentioned, the sustainable management of agricultural systems is influenced by the interrelationships between different factors of an agroecological and socioeconomic nature, as well as by constraints and opportunities surrounding the systems at the particular hierarchical level being addressed. Given the multifactor and interactive nature of agricultural systems, their sustainable management could best be implemented if based on an understanding of mechanisms governing their functioning. In the hierarchical context this means understanding the processes operating at the scale below the level being managed. That is, if the scale to be predicted is that of the farm, a degree of process-level understanding at the field level is required.

In this context, relevant CGIAR activities were categorized according to their expected contributions to two main research approaches: *applied*, concerned principally with the development of technologies and practices; and *strategic*, aimed at the understanding of processes and mechanisms to predict the system's behaviour under alternative managements. Table 2 presents CGIAR activities according to their expected contribution to either applied or strategic research at the four scale levels.

Table 2: CGIAR activities by research approach and system scale

System Level	Research Activities: applied-oriented (technologies and practices)	Research Activities: strategic-oriented (processes and principles)
Field	2.3 maintenance and improvement of the resource base	1.2.3/5.a) soil nutrient dynamics 2.5 processes and mechanisms
Farm	1.2.2 farming systems (+ baseline) 4.1 microeconomic analysis	1.2.1 production systems trends
Watershed/ Landscape	2.1 characterize ecosystems 2.4 management of aquatic resources	2.6 modelling landscape 4.3 community-based organizations
Country/ Region	4.2 policy analysis	4.3 public systems management

3. Gathering and Analyzing the Information

The second stage of the study was carried out in two steps: validation of compiled information by Centres, and analysis of incoming data.

In mid-July a note was sent by the TAC Secretariat to the 14 Centres currently involved in S&W research, requesting their cooperation in the critical evaluation of our compilation of activities in soils and water-related research from MTPs and P&Bs of their respective Centres; as well as to estimate the proportion of project funds allocated to such fields of research. They were also asked to identify both partner institutions that collaborate with them in carrying out the S&W research agenda and possible trends in soils expertise at their Centres since 1985.

All Centres responded to our request. As expected, the main point of misunderstanding regarded the selection of S&W activities specifically aimed at the maintenance and improvement of the resource base (vis-à-vis those of a productivity-enhancing nature). For example, many Centres proposed germplasm adaptation to soil conditions as a relevant activity for that purpose. However, it was finally decided not to incorporate it, on the grounds that research focused on plant mechanisms and not on those of the soils and water complex. There was a need then to discuss these issues with the majority of Centres, which were willing to review their information and correct estimated allocations, when appropriate. This desk study would have not been possible without their cooperation, which is indeed most appreciated.

In all cases, the total budget figures used in the analysis are those supplied by Centres for activities considered in the study. Their figures are the result of our heuristic judgments on which activities corresponded with the study focus, and how much of the funding was specifically related to S&W research.

Although total project figures were taken as given, the proportion of funds allocated to activities within "mega" projects (e.g., in allocating funds of transnational projects to land types) had to be "guesstimated". For lack of a more rational criterion, in most of the cases we used simple arithmetics (i.e., dividing the total budget by number of activities in the mega project). We do realize that this can lead to over- and under-estimates, and hope that they compensate across Centres.

Other "analytical liberties" we had to take concern the allocation of CGIAR research activities to both scales in the systems hierarchy and research approaches, i.e., applied and strategic (see Table 2). We believe allocations on the scale dimension to be straightforward. The debatable point could be the placing of 2.3, about maintenance and improvement of the resource base, at the "field" level. Although it is recognized that it could also be placed at higher levels in the hierarchy, the main reason for putting it there was that cropping systems prevail as a focus for such activities in the Centres.

Two points should be made about the approach dimension. First, in slotting 1.2.1 under the strategic approach, emphasis was given to its more dynamic component in the CGIAR description, that of "monitoring sustainability developments". As a consequence of this emphasis, projects focusing on the more descriptive part of characterization studies were shifted to 1.2.2, farming systems. The second point refers to placing 4.3, public management systems, under strategic research. It is based on the role of such institutions in understanding technology adoption processes, a central issue in the "management" of natural resources. Policies certainly influence such processes, but they are not seen as contributing as much to research on the prediction of behaviourial patterns as local institutions do.

Finally, a note on the land types. As it was not possible to accommodate all the types used by the different Centres, land types sharing relevant characteristics were combined within one of the eight selected. Relevant cases are those of the savannas and the rainfed lowlands. The former type includes both the less-acid savannas of western and central Africa, and the acid savannas of Latin America. It also includes half of the resources allocated by Centres to inland valley projects. The rainfed lowlands include all three types of "lowlands" (flood prone, lowlands and uplands), as well as the other half of the inland valleys.

4. Allocation of Resources by CGIAR Centres to Soils and Water Research

As S&W-related activities are an essential part of research on natural resources management (NRM), an attempt was made to characterize them in terms of the strategic context in which resource-conserving research is carried out in the respective Centres. It was considered as a useful background to allot activities to the scale of the system at which they are focussed, and to the research approach followed. In most of the MTPs the natural resources dimension of the research strategy is not explicitly stated. That component of the characterization was then derived from reading different chapters of the MTPs and P&Bs, and included in the tables sent to the Centres. Based on the few comments made we believe they correctly interpret the Centre's approach to research on the management of natural resources. Table 3 purports our interpretation of how IARCs approach S&W-related research in their respective mandate areas. CIFOR and IPGRI were not considered at this stage, as they are not undertaking any S&W-related research at the moment.

Table 3: Centres Approach to S&W Research

Concentrated around	Centres	Focusing on
CROPPING SYSTEMS	IRRI	Soil Nutrient Dynamics
	ICRISAT	Legume-based Rotations
	CIMMYT	Green Manure and Input Efficiency
	CIP	Ecological Characterization and Collaboration
FARMING SYSTEMS	ICARDA	Legume-based Rotations
	ILRI	Crop-Livestock Interactions
	ICLARM	Ecological Sustainability
LAND RESOURCES	ICRAF	Soil Processes
	WARDA	Cropping Systems
	CIAT	Production Systems
	IITA	Production Systems
INSTITUTIONS	IFPRI	Decisions of Poor Farmers
	IIMI	Management
	ISNAR	Research Organization

Against this background, the information supplied by Centres was analyzed in response to the three issues posed as questions for the study: target land types, scope of research on the systems' scale, and research approach. But before discussing the results for each of the three dimensions it is useful to examine the overall picture of Centres' allocation of resources to S&W research.

4.1. Overall Resource Allocation to S&W Research

Table 4 shows the 1996 budgeted allocations of each of the 14 Centres.

Table 4: Resources Allocated to S & W Research

Centre	in US$ '000	as % of Centre's Total
CIAT	3,538	9.4
CIMMYT	1,299	4.1
CIP	1,140	5.4
ICARDA	1,903	8.2
ICLARM	1,130	12.1
ICRAF	7,139	40.4
ICRISAT	4,923	16.2
IFPRI	2,499	15.1
IIMI	8,860	92.8
IITA	5,587	17.5
ILRI	938	3.7
IRRI	7,336	16.8
ISNAR	838	8.0
WARDA	2,246	26.0
TOTAL:	**49,376**	

Allocation by the Centres to S&W research represents 17 percent of the total CGIAR funding for 1996 (estimated at 300 million USD). This is equivalent to two large "resources" centres of the size of IITA, fully dedicated to S&W research. Some Centres intimated that the study was following a "conservative" approach in its selection of activities under S&W research. Should the total figure indeed represent a conservative estimate, this would suggest that a substantive proportion of the total CGIAR funding is, in relative terms, allocated to S&W research. It should be noted that the share of efforts in water research, as represented by the ICLARM and IIMI budgets, accounts for 20 percent of the total S&W budget. It was not possible, however, to calculate the proportion corresponding to water-related research in soils studies.

As it can be seen, there are large differences among Centres on the proportion of budget allocated to S&W research, indicated by a Coefficient of Variation (CV) of 118 % on a mean of 19.7 percent. Even if IIMI is excluded, as the only "resources" Centre, the CV is still as high as 72.2 % on a mean of 14.1 percent. The proportion allocated by Centres ranges from minimums of 3.7 percent for ILRI and 4.1 for CIMMYT, to maximums of 40.4 for ICRAF and 26.0 for WARDA.

4.2. Agricultural Land Types

Table 5 indicates what are the main agricultural lands targeted by the CGIAR Centres. As expected, irrigated lands are the receptors of the largest investments, including almost all of IIMI's budget. If rainfed lowlands were considered as relatively high-potential lands and added to irrigated lands, *35 to 40 percent of total CGIAR investments in the field of S&W research would be allocated to research on well-endowed lands.*

Table 5: Investments by Land Types

Agroecological Zone	Land Types	Investments (in US$ '000)	Investments (% of CGIAR Total)
Warm arid and semi-arid tropics and subtropics	**Semi-arid**	6,581	13.5
Warm subhumid tropics and subtropics	**Savannas**	7,712	15.8
	Hillsides	2,577	5.3
Warm humid tropics and subtropics	**Rainfed Lowlands**	5,696	11.7
	Forest Margins	6,590	13.5
Cool tropics and subtropics	**Highlands**	4,306	8.8
Cool subtropics, winter rainfall	**Semi-arid**	2,084	4.3
Cross agroecozones	**Irrigated**	13,303	27.2

Note: In the case of ISNAR only those resources specifically allocated to the Highlands were included

Two investment-level groups can be distinguished among the other six land types, the so-called marginal or fragile lands. Highlands, hillsides and semi-arid lands (cool sub-tropics) are getting an average of 6 percent of the total S&W budget. The savannas, forest margins and semi-arid lands (warm tropics) get an average of 14 percent. This level of investments group could be joined by the highlands and hillsides, if these were to be grouped under a steeplands banner.

S&W investments across land types could also be seen from the point of view of Centres' funding commitments to research on their sustainable development. That perspective is represented in Table 6, where CGIAR investments are seen as a percentage of the total amount committed by each centre to that particular land type.

In many of the land types it is quite evident that particular Centres have a clear quantitative lead in efforts on S&W research. Thus, as expected, S&W research by ICRISAT and ICARDA in the warm and cool semi-arid lands respectively, IRRI in the rainfed lowlands and IIMI in the irrigated lands account for close to 70 percent or more of all CGIAR activities in those land types. In the highlands ICRAF and CIP account for almost 80 percent of such efforts, a similar figure to that accounted for by CIAT and IFPRI
in the hillsides and IITA and ICRAF in the forest margins. It is only in the savannas where more than two Centres have a substantive share of the total CGIAR efforts in S&W research. There IITA holds close to 40 percent of the total "shares", followed by WARDA, ICRAF and CIAT with around 15 percent each.

Should TAC consider a landtype-based coordination of Systemwide S&W research efforts, Centres' current share of total commitments could provide a good rationale for the allocation of responsibilities.

4.3. Research Scope

As reflected by the discussion in Section 2.2 on the Scope of S&W Research, it was initially understood that the analytical framework should include four levels in the hierarchy of agricultural systems: field, farm, watershed and country/region. An analysis of available information indicated, however, that these four levels could be combined into two, to characterize on-site and off-site research. Table 7 presents the estimates of resources allocated by each centre to on-site and off-site research activities. The former brings together research focused on the field and farm levels, considering the farm as the basic unit for managing natural resources in agricultural production. Off-site constitutes research at the watershed/community levels, and relates to the effect of on-site practices (at farm levels) on off-site processes (i.e., reservoir sedimentation). We realize that in this case boundaries are not so clearly recognizable as at the farm level, but in it we include research on both other sub-systems affected by decisions made at the farm level, or viceversa, and institutional areas whose deliberations influence farmers' decision-making.

Table 6: Centres' Resource Allocation to S & W Research by Land Type
(as % of the total amount invested in each land type)

	CIAT	CIMMYT	CIP	ICARDA	ICLARM	ICRAF	ICRISAT	IFPRI	IIMI	IITA	ILRI	IRRI	ISNAR	WARDA
Warm Semi-arid	2.6					**18.2**	**74.8**				4.4			
Savannas	**16.4**	2.7			7.3	**15.1**				**38.3**	2.9			**17.2**
Hillsides	**52.0**	11.9						**36.1**						
Lowlands		3.3			9.9							**79.0**		7.8
Forest Margins	11.6					**38.1**	10.3			**39.9**				
Highlands		3.9	**26.5**			**52.5**					9.8		7.3	
Cool Semi-arid				**91.0**				9.0						
Irrigated		3.2						5.3	**66.6**			**21.3**		3.6

Table 7: Scale Focus of Research Efforts

Centre	On-site	Off-site
	(as % of the Centre's S & W Budgets)	
CIAT	76.6	23.4
CIMMYT	100.0	-
CIP	74.0	26.0
ICARDA	71.5	28.5
ICLARM	100.0	-
ICRAF	73.5	26.5
ICRISAT	90.7	9.3
IFPRI	40.0	60.0
IIMI	28.5	71.5
IITA	88.0	12.0
ILRI	49.7	50.3
IRRI	86.9	13.1
ISNAR	3.0	97.0
WARDA	73.8	26.2

In this case variation among Centres is not as large as that for resources allocated to S&W research. *For all 14 Centres the average proportion of on-site research is 69 percent, with a CV of 41.9 %. When ISNAR is not included in the analysis, given the special nature of its activities, the average increases to 74 percent and the CV decreases to 30.6 %.* Estimates range from minimums of 28.5 percent for IIMI and 40 for IFPRI to maximums of 90.7 percent for ICRISAT and 100 percent for CIMMYT. But even those figures would be misleading, given the social nature of the policy and management research carried out by both institutes (and therefore, off-site by definition). It would be more meaningful to examine those of ILRI (49.7 percent) or ICARDA (71.5).

Figures indicating the low proportion of total S&W resources being allocated to off-site research are of special concern, as off-site environmental costs of on-site unsustainable management practices are considered to be higher than their impact on productivity. It is precisely this type of information that led TAC to recommend activities on spatial or landscape level linkages as an essential component of the integrated approach to natural resources management research. In principle this would require that a higher proportion of funds are allocated to off-site studies, including interactions between land types in the watershed and property rights.

A positive finding is that agroecological characterization accounts for a significant proportion of current off-site activities (27 %), a necessary base to develop off-site research. But, although such activities are certainly essential to plan and implement research to predict off-site impacts of on-site management systems, they could also be used mainly for descriptive purposes instead.

Linkages between productivity-enhancing and resource-conserving research constitute another set of concerns that figures prominently in TAC's framework for the recommended integrated approach to natural resources management research. Questions posed to the Centres, unfortunately, were not specifically aimed at estimating that relationship. However, resources allocated to activities included in the field and farm scales could be used as proxies to estimate such a linkage in current research. Proportions of resources allocated to field and farm levels are presented in Table 8, as percentages of total on-site activities.

Table 8: Resources Allocated to Field and Farm Levels of Research

Centre	Field	Farm
	(as % of total on-site resources)	
CIAT	55.7	44.3
CIMMYT	55.2	44.8
CIP	22.3	77.7
ICARDA	56.5	43.5
ICLARM	26.5	73.5
ICRAF	77.9	22.1
ICRISAT	52.0	48.0
IFPRI	25.0	75.0
IIMI	88.1	11.9
IITA	71.2	28.8
ILRI	40.0	60.0
IRRI	57.7	42.3
WARDA	61.1	38.9
Mean	**53.0**	**47.0**

The assumption is that field activities focus essentially on resource-conserving research (see list in Table 2), while those at the farm level are mainly of a productivity-enhancing nature. It follows then that an even proportion of resources allocated to the two levels would indicate the existence of a linkage between the two research focuses. Average figures for percentages allocated to field and farm levels of research would indicate this to be the case, although the high CVs (38% and 43% for field and farm levels respectively) indicate large variation among Centres.

It is recognized that the information gathered from Centres does not specifically indicate linkages between the two levels of activities. But it seems fair to assume that Centres are focusing on the same problem when working at two scales along the systems hierarchy. Should these assumptions be correct, *it could be said that the link between productivity-enhancing and resource-conserving activities is already part of the Centres operational framework, albeit with large variation among them.*

Another important linkage in TAC's integrated framework is that between research and adoption. There are no proxies in this case that would allow us to estimate such a link. It could only be said that, judging by described activities, the majority of Centres appear to have incorporated a participatory approach in the design and evaluation of management practices.

4.4. Research Approach

As discussed above, this component of the study refers to the classification of research activities according to their applied or strategic nature, in relation to the system-and-process paradigm. Information was analyzed according to the framework presented in Table 2, with the qualifications discussed in Section 3. Table 9 presents the percentage of resources allocated by each Centre to the two research approaches.

Table 9: Centre Approaches to S & W Research

Centre	Research Approach	
	Applied	Strategic
	(% of total S & W Research Budget)	
CIAT	42.8	57.2
CIMMYT	66.0	34.0
CIP	64.9	35.1
ICARDA	74.1	25.9
ICLARM	100.0	-
ICRAF	61.1	38.9
ICRISAT	87.7	12.3
IFPRI	70.0	30.0
IIMI	60.0	40.0
IITA	52.4	47.6
ILRI	91.9	8.1
IRRI	56.7	43.3
ISNAR	27.0	73.0
WARDA	73.5	26.5

On the average Centres allocate two-thirds of the total S&W budget to applied activities, with a CV of 29.1 %. If, for the reasons already stated we do not include ISNAR, the average increases to 69 percent. In this case proportions of budgets range from minimums of 42.8 percent for CIAT and 52.4 for IITA to maximums of 91.9 percent for ILRI and 100 for ICLARM.

Location-specificity is a main characteristic of research on the management of natural resources, but the CGIAR has given renewed emphasis to focusing its activities on issues of an international public goods nature. In this context, knowledge of mechanisms and processes governing the sustainable management of S&W resources appears as the approach Centres should follow. The high proportion of funds allocated to applied research is then an issue that may require further deliberation by the Committee.

To contribute to such a deliberation it was decided to take the analysis a step further. We examined the approach followed by Centres according to both the system scale at which research is conducted and the land types on which such research focuses. Table 10 presents the percentages of the S&W budgets being allocated by Centres to applied and strategic research in their on-site and off-site focused activities.

Table 10: Research Approach by System-Scale Focus

Centre	On-Site		Off-Site	
	Applied	Strategic	Applied	Strategic
	(as % of total on-site activities)		(as % of total off-site activities)	
CIAT	48.9	51.1	22.5	77.5
CIMMYT	66.2	33.8	-	-
CIP	56.2	43.8	89.6	13.4
ICARDA	75.1	24.9	71.6	28.4
ICLARM	100.0	-	-	-
ICRAF	62.3	37.7	57.6	42.4
ICRISAT	86.4	13.6	100.0	-
IFPRI	100.0	-	50.3	49.7
IIMI	100.0	-	43.6	56.4
IITA	45.9	54.1	100.0	-
ILRI	100.0	-	83.9	6.1
IRRI	54.2	45.8	73.1	16.9
ISNAR	100.0	-	24.7	75.3
WARDA	66.9	33.1	92.2	7.8

It should be noted that in this case the analysis examines each of the sites as independent sets of data, i.e. percentages allocated to applied and strategic research within each on-site and off-site activities add up to 100.

For on-site activities the average proportion of funds allocated to applied research is as high as 76 percent (CV 21%). And even within the off-site category applied research accounts for 67 percent (CV 28%). Proportions between applied and strategic within on- and off-site activities are then consistent with the unbalanced picture seen for all S&W data.

When the analysis is taken to the *allocation of funds within land types* (see Table 11), *percentages allocated to applied research within on-site activities also fall within the proportions for all S&W data* (68 and 32 percent respectively, with CV of 17% and 37%). Within off-site activities percentages are slightly more balanced between applied and strategic research (63 and 37 percent respectively, with CV of 32% and 55%). This is influenced by considerably higher than average allocations to strategic research in the hillsides and irrigated lands. A closer look shows that such allocations correspond to heavier work on public systems management, a fundamental "tool" in the management of natural resources in both types of lands.

Table 11: System Scale and Research Approach by Land Types

Land Type	On-Site		Off-Site	
	Applied	Strategic	Applied	Strategic
	(as % of total CGIAR resources allocated to the land type within on- and off-site activities)			
Warm Semi-arid	85.6	14.4	52.1	47.9
Savannas	61.9	38.1	77.7	22.3
Hillsides	77.8	22.2	26.6	73.4
Lowlands	61.6	38.4	86.7	13.3
Forest Margins	49.0	51.0	82.2	17.8
Highlands	62.0	38.0	66.8	33.2
Cool Semi-arid	76.2	23.8	67.6	32.4
Irrigated	73.5	26.5	45.9	54.1

5. Conclusions

Taken with the caution suggested by the possible differences in the interpretation of the information by us and the Centres, by the variations among the number of institutions involved in supplying the information, and by the assumptions that had to be made in analyzing it, the results of the desk study would indicate that:

1. *The CGIAR System is allocating a substantive proportion of its total resources to soils and water research (17 percent, or 49 million USD),* which is equivalent to funding two large Centres the size of IITA.

2. *The average proportion of funds allocated by Centres to S&W research is around 14 percent of their budgets,* but differences among them range from 5 to 40 percent.

3. *Thirty five to forty percent (35-40 %) of the total CGIAR investments in S&W research are directed towards irrigated lands and rainfed lowlands,* which could be seen as *proxies for well-endowed lands.* Among the so-called "fragile" or "marginal" lands, the warm semi-arid, savannas and forest margins each account for around 15 percent of the resources, while the cool semi-arid, highlands and hillsides each account for 5 percent.

4. *On average Centres focus about 75 percent of their S&W efforts to research on-site, ranging from 30 to 90 percent.* This may be seen as an expression of weak attention to the spatial or landscape linkages, an important component of the framework for integrated natural resource management research advocated by TAC.

5. *Judging from the share of resources allocated to activities at the field and farm scales, there appear to be good linkages between productivity-enhancing and resource-conserving perspectives,* a major set of linkages mentioned in TAC's framework for integrated research.

6. *On average Centres allocate some two-thirds of their S&W budget to research of an applied nature, ranging from 50 to 90 percent.* This allocation, taken together with that of three-quarters to on-site research, suggests a strong concentration of research efforts on location-specific activities, rather than on the strategic research required to focus on issues of an international public good nature.

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