- **Health risk reduction** The reservoir operation avoids health risks due to mosquitoes, filaria, schistosomes etc.
- **Maximum environmental value** The new lake is managed to produce the maximum environmental value.

### Integrated water management

- **Integrated operation of multi-component water resource system** The reservoir is operated and maintained in conjunction with all the related components of water resource systems in a comprehensive manner, for multipurpose flood control, water supply, environmental quality control etc.
- **Flexible allocation of water resources** The water allocation rule is flexible enough to react to the real needs of the region whenever necessary, such as during prolonged droughts, or when social needs and preferences may change in the long term.

## 6.2 CONCLUDING REMARKS

Reservoirs are undoubtedly one of the most important means of water resources development and management, and they have been built since earliest historical times. Human beings have been successful in achieving the necessary control of water by reservoirs for agriculture, flood control, hydropower generation, water supply, navigation and recreation. Engineering technology for reservoir construction has saved many lives and made development possible. However, it is also true that many large reservoirs were built, at least in part, without proper account of environmental, social and economic interactions. Critics who claim that many large dams are environmentally destructive, socially tragic and economically unsuccessful should be listened to carefully and their concerns scientifically analysed. New approaches must be taken.

In the 21st century plainly more water will be needed for an increasing world population which aspires to a higher standard of living, and that surface water development through reservoir construction is likely to be the major source. In these circumstances, scientific diagnoses must be subject to a broad public discussion among interested and affected parties. It is no longer acceptable simply to point out the impacts of reservoir construction in terms of some future benefits and disadvantages.

Sustainable reservoir design and management is a new concept in the sense that not only the efficiency of current performance and physical safety should be considered, but also that intra- and inter-generational needs and equity must be taken into account. The general sustainability principle has been widely acknowledged at all levels, yet its concrete implementation in individual

subject matters is not adequately formulated in any field. In this study, the translation of the basic sustainability concept into all aspects of reservoir planning and management has been attempted. During the study, many previous reports were reviewed and considered, and the final outcome is not necessarily new. What is needed is, in many respects, a restatement of integrated water resources management with social consideration, environmental and ecological care, and sediment control combined with democratic decision-making procedures. This has been pointed out for many years in the literature.

This report especially emphasizes the importance of socio-environmental care for the affected people and nature itself. Planners can no longer pay biased attention to the beneficial elements of development and accept adverse effects with a minimum of materialistic compensation. It is no longer acceptable to overlook the intangible negative consequences of a project. The unspoken qualitative, indirect effects should be carefully assessed and included in the overall evaluation process, since they too have an impact on the basic conditions of society, nature and future generations. It is an obligation for engineers and scientists to consider the total system response and provide an objective analysis to enable a rational, democratic and feasible solution.

Human beings change and modify the natural condition of nature. However, human beings also have the ability to protect nature for themselves and for future generations. How much of nature we have to expend in order to sustain our own existence depends on the socio-technical development level of civilization. Even the question of sustainable reservoir development cannot be answered by hydrological and water resource systems sciences alone. Sciences as a whole must work together and solve the problem as an integrated part of the dilemma of contemporary human existence.

In this report a set of new ideas has been explored in order to illustrate possible ways to address the requirements of sustainability in reservoir analysis. One contribution involves the introduction of the least marginal environmental impact rule. It proposes that the size of a reservoir should be limited to the extent that an extra unit increase of dam height has the least negative environmental impact compared to all economically feasible alternative means, reservoir or non-reservoir, which provide the same level of incremental gain in the global objectives as the extra unit increase of dam height.

Among other contributions a new method for designing sustainable reservoirs, based on the De Novo programming approach, is presented as an idea for replacing the optimization of a given reservoir with the design of an optimal reservoir. Reservoir storage reallocation and reassessment of reservoir operational rules are considered to be the two main problems related to existing reservoirs that should be addressed within the framework of sustainability. Another contribution to the report is a method for reassessment of existing reservoirs, which is based on the combined use of simulation and

optimization. The main objective of the approach is to determine: (a) the active reservoir storage requirements based on the current demand; and (b) the best management strategy for the reservoir under consideration.

The report also presents an original cost and benefit allocation methodology for redevelopment of reservoirs. The methodology has been illustrated with two case studies: (a) addition of new water users to an existing water supply system, and (b) addition of new water users to a system with additional reservoirs.

Other ideas emphasize the importance of non-reservoir options, especially demand management, including pricing and other economic incentives to reduce the net consumption and/or pollution of water and institutional mechanisms that promote efficient water allocation and conservation through mobilized water rights and a multi-sectoral approach. This may limit conflicts between different water users and reduce water shortages and the need for new reservoir development, thus becoming the most important contribution from the water resources sector in promoting a sustainable environment.

An important aspect stressed in the report is the necessity of continued scientific research on complex water problems. It has become more and more crucial to conduct research on sediment control, water quality control, ecological impacts and assessments and ecologically conscious release policies. Also, it is necessary to monitor reservoirs in operational use and connected river reaches for a long time after completion. It is essential to utilize advanced hydrometeorological forecasting techniques to improve the performance of reservoirs and to develop procedural mechanisms for conflict resolution which can lead society to a more environmentally efficient allocation of resources. To use a large set of available data requires knowledge of advanced analytical tools, for example, computer-aided decision support systems, artificial intelligent systems, and various operational research techniques such as optimization and simulation, including the application of statistical, stochastic and fuzzy approaches. Many other analytical and synthetic techniques need to be further developed and utilized. They all require interdisciplinary research. The scientific institutional framework, making such an interdisciplinary approach possible, is increasingly important and needs to be encouraged and further developed.

There is an urgent need for implementation of reservoir development and management based on the sustainability principle. The concrete criteria of planning, design, construction, operation and redevelopment of reservoirs depend on local, site-specific conditions of a socio-economic, cultural and environmental nature. However, the basic concept of reservoirs as components of water resource systems that must be sustainable in societal as well as environmental contexts has now become clear. This report, reflecting the views of many critics, has highlighted a number of aspects which all contribute to sustainability, and has provided new methodologies for the improvement of current practice.

Evidently, the 21st century will become the water stress century. Human survival and the Earth environment are largely dependent on the human capability for water management and this, in turn, poses a significant demand on development and use of reservoirs in a sustainable manner. The authors sincerely hope that this report will be a step towards the implementation of sustainable reservoir development and management practices.