

Summary Report

A Subregional Expert Consultation on Spate Irrigation and Wadi Development was organized by FAO from 6 to 10 December 1987 in Aden, PDRY. The consultation, which was sponsored by the United Nations Development Programme (UNDP) and hosted by the Government of the People's Democratic Republic of Yemen, brought together specialists from nine countries to exchange experience on the subject for the first time. The unique experience of the two Yemens in this traditional form of irrigation was highlighted. The other participating countries, Algeria, Egypt, Morocco, Pakistan, Somalia, Sudan and Tunisia, reported substantial areas under traditional spate irrigation.

Although the priorities in most countries have been directed towards the development of perennial irrigation schemes, there is a growing awareness of the importance of improving and modernizing spate irrigation in view of its potential to increase agricultural production and raise social welfare in the traditional areas.

Meeting arrangements

The Consultation was attended by 50 specialists from the nine countries, several international consultancy firms, specialized agencies and financing institutes such as UNDP, the World Bank, Kuwait Fund and Arab Fund. Appendix 2 contains a complete list of participants and observers. A total of 18 technical documents were introduced highlighting the various aspects of wadi development: hydrology, diversion structures, flood protection works, gabion weirs, spate agriculture, socio-economic aspects and the different development concepts in wadi improvement. The country papers from both the Yemen Arab Republic and the People's Democratic Republic of Yemen reviewed overall development aspects, while the seven other participating countries presented information on the extent and development of spate irrigation in each country.

The papers were presented in four technical sessions, followed by group discussions, where participants elaborated on the specific topics and reported on their findings. The group reports were consolidated in the final conclusions and recommendations of the meeting. For further details of the programme of the meeting, the Agenda is given in Appendix 1.

Traditional spate irrigation

Spate irrigation has been practised for millennia in the

alluvial plains along the Yemeni mountain range. This is a unique form of irrigation, predominantly found in arid and semi-arid regions where use is made of occasional heavy floods of very short duration. The floods or spates are diverted into the fields and one, exceptionally two, waterings of 400 to 800 mm are sufficient to sustain a deep-rooting crop. Agricultural yields are, in general, low and may vary greatly from year to year depending on size and frequency of the spates. Devastating floods damage and frequently destroy irrigation structures and agricultural lands, and yearly repair and maintenance are essential elements of the system. Spate water infiltrates into the wadi beds and irrigated fields feeding the aquifers which are tapped by wells for drinking water, stock watering and irrigation. The traditional techniques for construction, operation and maintenance of the irrigation systems have developed into quite sophisticated skills, providing the base for irrigated agriculture in the area and maintaining a sensitive equilibrium of scarce water resources.

Modern developments

The introduction over the past decades of modern techniques and technologies in wadi development has changed traditional irrigation greatly. The construction of tube-wells, pumping water from underground resources, has now ensured the perennial availability of irrigation water, making possible the introduction of new crops, the extension of irrigated areas and an increase in agricultural production. In addition, considerable investments have been made in the development and improvement of the spate irrigation systems in the major wadis of the natural Yemen. A range of new durable diversion weirs has been constructed along the major wadis replacing the traditional structures, while the building of regulating structures and irrigation canals has further developed and improved the distribution of spate waters within the agricultural areas.

Constraints to wadi development

The introduction of new technologies has affected the traditional balance of available water resources and changed the established practice to maintain and operate the irrigation system. The experiences exposed during the conference in a range of technical papers clearly showed the shortcomings and constraints to wadi rehabilitation works and they may be summarized as follows:

- i. lack of sufficient data on spate hydrology to allow detailed analyses;
- ii. serious problems of destructive floods and high sedimentation loads;
- iii. high cost of permanent diversion weirs and flood protection works;
- iv. inadequate development concepts and design criteria applied in wadi improvement studies and frequent ignoring of the specific characteristics of spate irrigation and traditional water rights in work carried out by foreign consultants;
- v. lack of adequate operation and maintenance procedures after completion of wadi rehabilitation works;
- vi. rapid exhaustion of groundwater resources due to over-exploitation of aquifers, thus posing serious threats in many wadis.

Conclusions and recommendations

An extensive range of conclusions and recommendations was drawn up during the meeting, providing detailed sug-

gestions on different aspects regarding:

- i. further regional cooperation and exchange of experience in spate improvement and wadi rehabilitation;
- ii. better insight into and study of traditional spate systems;
- iii. importance of better data collection and data analysis of wadi hydrology;
- iv. appropriate development concepts in wadi development;
- v. design criteria for different types of diversion structures, including low-cost structures;
- vi. measures required for better sediment control;
- vii. flood protection and wadi training works;
- viii. distribution and field irrigation systems;
- ix. agricultural aspects in spate irrigation;
- x. importance of monitoring and guiding the exploitation of groundwater resources;
- xi. adequate operation and maintenance after completion of wadi improvement works; and
- xii. importance of adequate training of staff at all levels.

Conclusions and recommendations

The initiative of FAO and the organizing countries in convening the Consultation under the sponsorship of the UNDP was much commended and special thanks were expressed to the Government of the People's Democratic Republic of Yemen for its hospitality in hosting the Consultation and making available its staff and facilities, which greatly contributed to the success of the meeting. Participants expressed their satisfaction and acknowledged for the first time the importance of exchanging experiences in wadi development.

The meeting noted that:

- although spate improvement work may differ in the various countries according to climate, rainfall and geomorphology, the country reports revealed a similarity in spate developments with similar problems and constraints to overcome, such as the irregular and unpredictable character of spate floods, the serious problems arising from destructive floods and high sedimentation in the design and operation of irrigation structures, the search for economically viable structures which can adequately regulate floods and control sedimentation, the specific approach required in the study of spate hydrology, the integration of groundwater and surface water development, the importance of traditional water rights, and the participation of farming communities in operation and maintenance of spate works.
- the solutions applied and the techniques developed in the various countries and wadis to overcome these problems provide important lessons and guidance to further wadi development and spate irrigation improvements for all countries concerned.

The meeting recommended that:

- the exchange of experience in wadi developments between the different countries, in particular the two parts of the natural Yemen, should be actively pursued through the publication and dissemination of studies and documents on wadi development and spate irrigation, the establishment of a bibliography and reference list on wadi development studies and documents, the organization of study tours to appropriate countries, the conduct of joint training courses on specialized subjects, and the organization of re-

gional seminars and conferences.

- thought should be given to the establishment of a regional structure such as a secretariat or institute to promote a regional exchange of wadi development and water resource data particularly between the two parts of the natural Yemen.

1. Traditional spate irrigation

The history of irrigation in the natural Yemen is very ancient. Archeological evidence shows that irrigation was practised in Yemen in 3000 BC and that the cultural and economic prosperity of the area is directly linked with the development of irrigation. The traditional methods based on centuries old experiences of the farming population are elementary but effective; they consist of the construction of deflectors and earthen bunds (ogmas) across the channel of the wadi to divert part or the entire flow of the spate to their fields. Large spates will cause failure of the ogmas and reduce or prevent irrigation of the fields. Though relatively cheap to build, the cost of seasonal maintenance and repair of the bunds is high.

To stabilize agricultural production, better control of spate flows and improved irrigation facilities are needed. Over the past 20 years many different wadi development projects have been designed and implemented. A series of techniques and solutions have been applied to achieve better regulation of the spate flow. The results of the often very capital-intensive improvement works have been variable, revealing the complex nature of spate irrigation structures and the unconventional approach required for their design, which is sometimes underestimated by foreign consultancy firms charged with the study and design of the wadi improvement works.

The meeting noted that:

- insufficient attention was given to understanding the factors that lead to the functioning of the traditional systems;
- little follow-up was given in monitoring the impact of wadi improvement works after their construction.

The meeting recommended that:

- the functioning of the traditional irrigation system should be studied in more detail in all technical, agricultural and socio-economic aspects, particularly

with regard to traditional water rights and equity in water supply, the probability and variability of spate irrigations in the different wadi reaches, the priorities set by the farmers and their wishes in improving their irrigation system, and the economic aspects of the prevalent cropping pattern, including yield and farm inputs and potential for improvement;

- after construction a monitoring system should be established to assess the impact of improved spate regulation on overall water distribution and agricultural production.

2. Wadi hydrology

Spate run-off is characterized by a great variation in size and frequency of floods which directly influence the availability of water for agriculture. Flood hydrographs typically show a very sharp rise in the peak discharge to be reduced gradually in about 2 to 6 hours.

The sediment load is generally high (3-7 percent by weight) with particle size varying from silt to large boulders. Floating debris is carried along in large quantities causing serious problems for regulators and sluices.

Reference is made to several of the Consultation papers providing details of the wadi hydrology and spate flow characteristics. Project design must take particular account of critical factors such as climate, rainfall and morphological conditions in the catchment, rainfall/run-off analysis, flow frequency and sediment analysis, exceptionally high sediment loads, and quantity and size of floating debris.

The meeting noted that:

- present design and feasibility studies are hampered by lack of adequate data on spate run-off, including hourly discharge data and quantitative measurements of sediment loads;
- the uncertainty in estimating extreme flood return periods greatly increases the cost of diversion structures and the hazard of weir failure;
- although hydrometric stations have been installed by the different wadi projects, little continuity in hydrometric data collection is evident.

The meeting recommended that:

- the systematic collection of basic climatic, hydrological and hydrogeological data on a nationwide basis be given high priority to ensure better planning in future developments;
- the installation of flood warning systems should be given serious consideration in order to anticipate emergency measures, to improve the control and distribution of spate water and to facilitate monitoring of wadi flows;
- adequate budget and qualified/trained staff be committed by government within the framework of a long-term programme of data collection which is essential for the development a national water master plan;
- in view of the scarcity of hydrological data, comparative studies of different wadis may provide more reliable information and thus confidence in the de-

sign of the wade improvement works. Correlations may be established in comparing climate, rainfall, size, geology and shape of the catchment area with annual run-off, hydrograph shape, sediment transport and irrigable area. Also the different elements of the water balance may provide useful criteria for spate diversion capacities, irrigable area, water duties, and allowable groundwater extractions.

3. Development concepts in wadi improvement works

A key issue to be assessed during the feasibility phase is the definition of the appropriate development concept. Should a dam with a storage reservoir be constructed or one or more permanent diversion weirs with wadi training and protection works to replace the 10-20 traditional breachable ogmas. A review of the overall wadi development concepts, together with an in-depth study of the technical, agricultural and socio-economic consequences of the various improvement alternatives, should be made. An overall water balance needs to be set up taking into account options for groundwater and surface water developments, aiming to maximize agricultural production per unit of water and assuring equitable distribution of benefits.

The meeting noted that:

- early development concepts in spate improvement works are often based on conventional irrigation design criteria, developed for perennial schemes and of little relevance to spate schemes;
- spate rehabilitation works are often very capital intensive, while agricultural improvements are difficult to assess accurately;
- although permanent weirs may provide better regulation and more efficient diversion, they can drastically change the traditional water distribution pattern, often at the cost of downstream farmers, deprived of breaching floods.

The meeting recommended that:

- adequate attention should be paid to traditional water rights and any improvement work should ensure as much as possible an equitable distribution of both surface and groundwater between upstream and downstream farmers. Necessary changes in traditional water distribution should be made acceptable;
- a great deal of flexibility be built into the overall scheme design; a phased development would seem most appropriate in this, also in view of the inadequacy of hydrological data;
- investment in diversion structures and irrigation improvement works should be directly linked to the probability of spates and the incremental benefits of irrigation, which may be economic, social or political. Spate systems can thus be subdivided into different probability areas with different investment levels.

4. Diversion structures

The design of the diversion weir will play a decisive role in the spate development concept. In evaluating the merits

and constraints of the different diversion structures, the meeting noted that:

- ❑ dams, impounding reservoirs and spate breakers may provide an optional solution in flood regulation, but require thorough study to justify the normally high construction costs and the often short life span due to rapid siltation;
- ❑ permanent diversion weirs will allow a much better regulation of the spate flow. The high cost of construction, in particular where complex sediment excluders and ejectors are included, seems only partly compensated by reduced maintenance costs and better diversion efficiencies. Changes in water distribution need to be carefully taken into account and well-qualified staff and adequate public funds to operate and maintain the structures should be guaranteed;
- ❑ low cost diversion weirs (gabions) may provide an attractive alternative to the traditional ogmas, in particular in the lower reaches of the wadi, where high investment costs are not justified. Earlier designs were tentative and elementary and provided little or no sediment control. New designs have meanwhile been proposed which look promising and may overcome initial problems. Although probably higher in maintenance and repair costs than permanent weirs, they may offer a noticeable improvement over the traditional ogma;
- ❑ traditional ogmas still provide considerable advantages as they can be constructed from locally available materials; because of their number along the wadi they provide a substantial diversion capacity and can easily be repaired after each breaching flood. Their disadvantages include the high maintenance cost (particularly as presently ogmas are mostly constructed by earthmoving plants), the increased risks of flood damage to canals and fields and the unreliable flood regulation.

The meeting recommended that:

- ❑ the experiences presented in several of the Consultation papers in design of the different elements of the permanent weirs should be given serious considerations in future designs;
- ❑ the technique of low-cost diversion structures (gabions) should be further refined in order to find satisfactory solutions, in particular for sediment control and headwork regulation. Reference is made to several of the Consultation papers reporting on low-cost structures;
- ❑ the inclusion of a breachable section (fuse plug) as an extension of the solid weir crest seems a particularly attractive solution to reduce investment costs for weirs and to respond to the uncertainty in predicting extreme floods.

5. Sediment control

The exceptionally high sediment loads of spate flows pose particular problems in the design, operation and maintenance of the spate diversion works.

The meeting noted that:

- ❑ the knowledge and insight in sediment transport through simulation studies and measurements and the experience obtained in the application of different techniques and designs to control sedimentation have increased noticeably. Reference is made to the concerned Consultation papers;
- ❑ the lack of data and measurements on sediment transport during spate flows prevents a quantitative approach to the design of sediment control structures;
- ❑ the costs and operation of the often sophisticated sediment control devices can be substantial.

The meeting recommended that:

- ❑ hydrometric measurements should include the measurement of sediment loads at regular time intervals;
- ❑ further studies should be made to find alternative techniques to improve sediment control in wadi regulation works.

6. Flood protection and wadi training

Flood protection concerns the protection of agricultural lands, towns, roads, structures, etc. against damage from floods. The high flow velocities and flood water levels during spates require strengthening of the embankments at critical places by stones, rip-rap, gabion boxes or mattresses, etc. Wadi training involves the regulation of the streamflow within the wadi bed by the construction of groynes or spurs.

The meeting noted that:

- ❑ good results have been obtained by using gabion boxes and mattresses in both flood protection and wadi training. Examples and design criteria have been presented in several Consultation papers.

The meeting recommended that:

- ❑ in view of the high investment costs in flood protection works, criteria should be set for the design of protection works for agricultural lands, roads, towns and structures, based on careful analysis of the benefits of the flood control works;
- ❑ traditional techniques in flood protection and wadi training should not be neglected. They should where appropriate be encouraged by governments and financing agencies.

7. Distribution and field irrigation systems

The design of spate irrigation canals presents some unusual characteristics owing to the short duration of floods which require large canal capacities, while the heavy sediment load requires steep canal slopes to maintain sufficient carrying velocities.

The meeting noted that:

- ❑ canal capacities of field channels and field inlets tend to be underdesigned in several wadi development projects, as at the design stage insufficient note is taken of the short operational period of the spate flow;

- ❑ improvements to the distribution and field irrigation systems using conventional norms for canal regulating structures and field improvements, such as land levelling, can be very costly.

The meeting recommended that:

- ❑ adequate attention should be paid in the design of the canal system to the flow duration and frequency to determine the capacity and the velocity required to carry the sediment loads;
- ❑ investments in the improvement of the distribution and field systems should be in relation to the probability of spate of the concerned area and the incremental benefit expected;
- ❑ spate irrigation improvement works should take into account the importance of recharge of the aquifer from flood waters. Efforts and investments to reduce irrigation losses seem therefore in general well justified.

8. Agricultural aspects of spate irrigation

The single irrigation (in rare cases a second or even third watering is given) typical for the spate system implies a unique form of irrigated agriculture, very different from standard practices. Deep-rooted and drought resistant crops are best adapted to spate irrigation. Yields are modest and use of fertilizers or imported high-yielding varieties is in general less effective. Land adaptability to spate irrigation is directly linked to the water retention capacities of the soil.

The meeting noted that:

- ❑ interesting results were reported at the Consultation on early research work on spate irrigated crops, but present research seems mainly devoted to crops irrigated with groundwater.

The meeting recommended that:

- ❑ continuous efforts should be devoted to strengthening research in spate irrigated crops to maximize yields per unit of water through the introduction and development of crop varieties adapted to spate irrigation conditions, including short-season and high-yielding varieties; the development of optimum agricultural practices for both soil and plants e.g. fertilizer rate, placement and type, soil cultivation, pest control, etc.; the establishment of optimal cropping density of spate irrigated crops; the assessment of suitability of intercropping; study on the effectiveness of supplementary irrigation; and the assessment of the optimal irrigation depth for spate crops.
- ❑ an information exchange be established among the different countries on results of different crops and varieties grown successfully under spate.

9. Groundwater development

Most wadi development projects have shown a rapid expansion of groundwater exploitation for agriculture. Production of agricultural crops has greatly increased, including diversification into a range of fruit and vegetable crops.

Recharge of the groundwater occurs through infiltration of flood waters in the wadi bed, in the spate canals and spate fields. Groundwater is therefore dependent on spates and forms an effective storage reservoir.

In several cases, though, the uncontrolled installation of tubewells has resulted in serious over-exploitation of the groundwater resources leading to a rapid lowering of the groundwater tables, sometimes combined with increased salinity hazards.

The meeting noted that:

- ❑ the over-exploitation of scarce groundwater resources imposes a serious threat to wadi development;
- ❑ spate irrigation plays an important role in the recharge of groundwater.

The meeting recommended that:

- ❑ an adequate government policy be formulated to monitor and guide the exploitation of groundwater resources and the possible enforcement of groundwater legislation;
- ❑ the integration of surface and groundwater developments to optimize crop production per unit of water take into account the different components of the water balance;
- ❑ the conjunctive use of ground and spate waters should be seriously considered wherever feasible;
- ❑ more efficient use be made of groundwater resources by adopting more efficient irrigation methods such as localized irrigation and pipe distribution systems.

10. Operation and maintenance

An essential element in each spate irrigation system is the establishment of adequate operation and maintenance (O&M) procedures. In traditional systems the seasonal repair and maintenance of the ogmas was the exclusive responsibility of the farming community. With the implementation of new spate improvement works, part of these O&M activities has to be taken over by the government.

The meeting noted that:

- ❑ the increased responsibility of government in operation and maintenance after completion of spate improvement works requires that adequate funds and qualified personnel be made available.

The meeting recommended that:

- ❑ participation of farmers in the O&M activities be strongly encouraged;
- ❑ to increase farmers' responsibility and participation in O&M work, serious efforts should be made to involve farming communities in the planning and construction of spate improvement works;
- ❑ adequate training in operation and maintenance of the increasingly sophisticated diversion structures should be provided to national staff;
- ❑ adequate facilities, equipment and machinery should be provided after project completion to ensure the necessary repair and maintenance works.

11. Training

The meeting noted with concern that:

- the lack of qualified staff at all levels is seriously affecting essential government services in carrying out operation and maintenance, the continuation of necessary data collection and monitoring of ground and surface water resources, and the national capability in planning and design of wadi development work.

The meeting recommended that:

- training of staff at all levels be intensified by in-service training programmes to be established as integrated packages in the development programmes, establishment and strengthening of local training courses and institutes, and short specialized courses for senior staff abroad;
- regional cooperation in joint training activities be promoted through the organization of study tours to the relevant countries, and the conduct of joint training courses on specialized subjects.