REPUBLIC OF YEMEN
MINISTRY OF AGRICULTURE AND IRRIGATION

IRRIGATION IMPROVEMENT PROJECT

(IDA Credit No. 3412 – YEM)

Main Technical Assistance Package for IIP

WORKING PAPER 22

Concept Paper for Spate Management Model

October 2003

ARCADIS EUROCONSULT

IN ASSOCIATION WITH

Halcrow

PAN YEMEN CONSULT

YEMENI ENGINEERING GROUP

CONTENTS

LIST OF APPENDICES

ABBREVIATIONS AND ACRONYMS

CLIMWAT	FAO database of agro-climatic data
CropWat	Software for calculation of crop water requirements (by FAO)
CWR	Crop Water Requirement
FAO	Food and Agricultural Organisation of the UN
feddan	(traditional) unit of agricultural land area (= 4200 m^2 = 0.42 hectare)
GIS	Geographic Information System
IIP	Irrigation Improvement Project
iSIS	Hydro-dynamic modelling software
MIS	Management Information System
obar	(traditional) earthen diversion embankment
ogma	(traditional) earthen diversion embankment
SMM	Spate Management Model
TDA	Tihama Development Authority of MAI
ToR	Terms of Reference
WUA	Water User Association
WUG	Water User Group

WORKING PAPERS

WP 1	Water Management in Wadi Tuban & Wadi Zabid	– Alan Clark
WP 2	Concept Paper Management Information Systems	– Thomas R. E. Chidley
WP 3	Training Report No.1 – Orientation Workshops	– Olaf Verheijen
WP 4	Procedure Manual on Participatory Irrigation Management	– Olaf Verheijen
WP 5	Concept Paper for Flood Warning System	– John Windebank
WP 6	Hydrological Analysis	– David T. Plinston
WP 7	Community Awareness Campaigns	– Darryl Kuhnle
WP 8	Gates Assessment – Interim Report	– David A. R. Wood
WP 9	Initial Roads Study	– Abbas A. Abu Taleb
WP 10	Training Report 2	– Olaf Verheijen
WP 11	Training Report 3	– Olaf Verheijen
WP 12	Issue Paper on PIM	– Wicher Boissevain – Olaf Verheijen
WP 13	Irrigation Management (First Mission Report)	– Wicher Boissevain
WP 14	Hydrological Analysis-Interim Report 2	– David Plinston – Abdul-Aziz Al-Ariki
WP 15	Progress Report MIS-GIS	– Reint-Jan de Blois – Md. Hodish – Abdulrahman Mujahed
WP 16	Training Report 4	– Olaf Verheijen
WP 17	Mission Report Information Analyst	– Tom Chidley
WP 18	Output Communication Specialists	– Christina van Schoot – Abdu Ghalib Alyousufi
WP 19	Construction Supervision	– René van Douveren
WP 20	GIS Manual	– Inga Rasing – Abdulrahman Mujahed – Md. Hodish
WP 21	WUA Contracts - Manual of Procedures	– Wicher Boissevain
WP 22	Concept Paper for Spate Management Model	– Khaled El-Askari

1 EXECUTIVE SUMMARY

A spate management model (SMM) for Wadi Tuban and Wadi Zabid will be prepared for use in the improved operation and management procedures planned for the wadis. The model, in conjunction with the spate warning system, will be used as an aid to decision making. It could also be used to explore the scope for changes to some of the existing water allocation procedures in order to achieve better water management.

The model will simulate the passage and distribution of floodwater starting at the gauging station upstream the irrigated area and down to the WUG command areas. The data required for the SMM includes description of the water distribution network, the water rights and allocation rules, the main crops grown, crop water requirements, cropping patterns, rainfall data, soil characteristics, in addition to the flood (inflow) data.

The SMM will use the lag and rout technique to derive the shape of the flood hydrograph as it progresses down the wadi, after calibrating it using the hydrodynamic simulation model iSIS. Flow distribution at the diversion structures and canal offtakes will be based on defined water rights, canal capacities and the hydraulic properties of the wadi and offtaking canals, and the crop water requirements of the command areas. The losses by infiltration from the wadi and canal beds and the field application losses will be taken into consideration.

The direct output from the SMM will be in tabular and report formats. In addition, the model will export selected output data into the ArcView GIS for graphical presentation. The outputs from the SMM will include the volumes of water diverted to each command area, the quantities of water still due to each crop in each command area, the quantity of water that has been used to meet crop water requirements and that that has been lost, and the volume of spate water that has not been diverted to command areas.

Data exchange between the MIS, SMM and GIS will be facilitated by ensuring that the common data is stored in the same structure in the three databases.

The SMM will run on standard PCs with a user-friendly interface. A detailed manual will be provided complete with sample data and a worked example.

2 INTRODUCTION

2.1 OBJECTIVES OF THE SPATE MANAGEMENT MODEL

A spate management model (SMM) for Wadi Tuban and Wadi Zabid will be prepared for use in the improved operation and management procedures planned for the wadis. The model, in conjunction with the spate warning systems, will be used as an aid to decision making. The ToR envisages the SMM to allow decisions to be made promptly regarding:

(i) *Which command areas should be irrigated, as the model keeps a record of the depth of water application a particular command area has received, allowing the outstanding requirements to be estimated.*

(ii) *How much water to divert to each ogma/weir on the wadi as, based on the calculated requirements, the model works out how far the forthcoming spate will supply needs, given canal capacities and restrictions, etc, and determines the quantity to be diverted and for how long.*

(iii) *The spate waters to be diverted from the Wadi and in what quantity, as the model determines the peak spate discharge threshold at which the last ogma will be breached, and water will flow to the sea.*

(iv) *For any required improvement works, it is possible to use the model to simulate the passage of floods down the wadi, using hydrographs developed for the wadi. This allows decisions to be made regarding the size of the supply canals to the traditional areas and possible improvement works in other areas.*

(v) *The probability of irrigation of the areas commanded by each diversion weir will assist in deciding on the type and value of any improvements that are required.*

In summary, there are two basic uses for the model:

1. As a planning tool: in which case the SMM will be used to advise on the most appropriate operation and water distribution in the wadi over a future period of time, typically one year or more.
2. As an in-season operation tool: in which case the SMM could be given the quantities of water the command areas have received, allowing the outstanding requirements to be estimated, perhaps on flood by flood basis.

The Spate Management Model will need to be easy to use by irrigation staff from the Agriculture and Irrigation Department for Wadi Tuban and from the TDA in Wadi Zabid, the immediate target users of the model.

2.2 PREVIOUS SPATE MANAGEMENT MODEL

A Spate Management Model was developed in about 1986 under the FAO-funded Abyan Delta Project. The consultants have obtained a copy of the model and some details have been obtained from the developer, Mr D M McNamara:

- The program was specifically designed for the Abyan Delta Project (Wadi Bana and Wadi Hassan), South Yemen. Based on the estimated flood volume the flood peak and hydrograph shape was computed. At a sluice/ogma the program calculated the volume of irrigation water required by all the blocks/fields on the canal offtake. After distributing the water to the blocks any surplus water was returned to the wadi. The actual volume of water passed down a canal was then deducted from the hydrograph volume and the flood was routed down the wadi, taking account of wadi bed losses. The process was then repeated.

- The program allocated water to the fields according to the water requirements of different crops. Once the full water requirements allocation of an upstream crop had been satisfied, no more water was given to that crop.
- The programs output gave, for each canal, a summary of each crops required volume, actual volume to date, command area and irrigated area. The output included a summary of each crops total area and its area irrigated to date. Cumulative flood, irrigation, bed losses and surplus volumes were also given.

After evaluating the model, it was concluded that it should not be used for Wadi Zabid and Wadi Tuban for the following reasons:

- The relationship between the hydrograph volume and its flood peak and shape was obtained from previous hydrological studies for Wadi Bana and Wadi Hassan. The model only takes food volumes and computes flood peaks and hydrograph shapes according to that relationship. It is very unlikely that the same food volume-peak-hydrograph shape relationship will be applicable to the other main wadis in Yemen too.
- The model allows for a maximum of six crops only. The crop water requirements for each crop are given to the model as the total application depth per growing season. Crop planting dates are not given to the model; hence it is possible to make runs that cover one growing season only (summer and winter crops cannot be given to the model in the same run since it will assume that they are grown at the same time).
- The model uses rather simple water rights and allocation rules for setting the priorities of water allocation to the fields. It assumes that water is allocated to the offtakes in turn from upstream to downstream. If two offtakes exist at the same location, they are given relative priorities defining which one should be irrigated first. It is not possible to define water allocation rules based on calendar dates, as is the case in Wadi Zabid for example.
- The model does not take account of rainfall or soil characteristics.
- The model runs under DOS and is, by current standards, not user friendly. It requires a lengthy pre-prepared data file and produces an output file which takes time to interpret.

3 DATA REQUIREMENTS AND MANAGEMENT

3.1 DATA REQUIREMENTS

The data requirements for the SMM as listed in the ToR are:

- Land and water resources
- Water rights and the establishment of priorities for water use at the wadi level
- Water right contradiction with existing irrigation canals or offtakes
- Water retention capacity of the soils
- Cropping pattern and crop water requirements
- Root zone parameters
- Water application depth
- The irrigation distribution system and the operational protocols
- Irrigation efficiencies
- Social implications of alternative strategies

In addition, it is envisaged that the following data items will also be required for the model:

- Rainfall data

The following sections give detailed descriptions of the data required for the SMM.

3.1.1 WATER DISTRIBUTION NETWORK

The SMM will need to "know" the type of water distribution network it is dealing with in any run, i.e. the configuration of the wadi and irrigation network of the project[1]. It is envisaged that the water network simulated in the SMM starts at the gauging station upstream of the irrigated area and includes the wadi sections and irrigation canals down to the command areas. Accordingly, the components of the simulated water distribution networks for Wadi Tuban and Wadi Zabid can be classified as:

- The main wadi and its sub-branches (e.g. Wadi Zabid splits into Wadi Nasery and Wadi Ain).
- Link canals connecting the wadi to irrigation canals.
- Main and secondary irrigation canals serving the command areas.
- Direct offtakes from the wadis (ogmas/obars).
- Command areas.

[1] Throughout the text, "project" refers to a wadi delta with its irrigation network and irrigated command area.

The data attributes required for each of these components can be outlined as follows:

Component	**Data Requirements**
Wadi reaches	▪ Reach length. ▪ Average cross section width of the reach. ▪ Average bed slope of the reach. ▪ Average Manning's roughness coefficient.
Link and irrigation canals	Same as for the wadi reaches, in addition to: ▪ The maximum capacity of the canal head works. ▪ Water rights and allocation rules.
Direct offtakes from the wadis (ogmas/obars)	▪ The average width of the canal fed by the offtake. ▪ The average canal bed slope. ▪ Average Manning's roughness coefficient for the canal.
Command areas	▪ (Refer to Section 3.1.5)

The current GIS work under the Project includes the development of layout maps for the two main wadis of Phase I. The maps include the wadis, the link canals, the irrigation canals starting from the main down to the tertiary level, the direct offtakes from the wadis (ogmas/obars) and the offtakes from the irrigation canals. The maps are created with the SMM in mind; as such the SMM will use the information in those GIS maps to "understand" the configuration of the water network. This way, the user can take full advantage of the facilities offered by the GIS when building the network, however, any changes in the layout will have to be made in the GIS first before the SMM can take them into consideration.

3.1.2 CROPS

The data required for each crop will be:

- Typical planting months (it is understood that some farmers will plant the crops to be irrigated by spate water only when the first spate arrives and irrigates their lands. A provision for simulating this behaviour will be included in the model).
- Length of growing period.
- Length of harvesting period (this is the period at the end of the growing season when the crop does not need any water).
- Rooting depth.
- Typical water application depth (for spate irrigation).
- Monthly crop coefficients (Kc).
- Approximate relationship between the total water consumption per growing season and potential yield (Ky).

Most of this data is available in the crop data files supplied with CropWat and CLIMWAT.

3.1.3 CLIMATE DATA AND CROP WATER REQUIREMENTS

Because crop-planting times may vary according to water availability, it will be difficult to enter crop water requirements data directly into the SMM. Alternatively, the model can calculate the crop water requirements from climate data and the crop coefficients. For this purpose, monthly reference evapotranspiration data will be required.

3.1.4 RAINFALL DATA

The rainfall data over the project area will be required since rainwater can contribute to the crop water requirements and to groundwater recharge. The model will require daily rainfall data. The rainfall intensity will be considered constant over the whole wadi delta.

3.1.5 COMMAND AREAS

It is envisaged that a command area in the SMM will be the area managed by a WUG. However, the actual definition of command areas will be up to the model user to decide. For example, the user may wish to simulate more than one WUG as just one command area in the SMM. This will be possible provided that the WUGs in any command area take water from the same canal and have the same water allocation rights.

The following pieces of information will be required for each command area:

- Total net cultivable area.
- Cropping pattern: the crops grown in the command area (selected out of the crops defined for the whole project) and the percentages of their areas. A maximum of four crops will be allowed for in each command area.
- Soil type: water retention capacity of the soil.
- Average irrigation efficiency for the whole command area.
- Maximum water diversion capacity.
- Irrigation priority.

3.2 DATA CLASSIFICATION

The data required for the SMM may be classified as:

- Project-wide data: this is the data that can be reasonably considered constant across the whole project area; and,
- Command-area-specific data: this is the data that varies from one command area to another within the project.

In fact, the description of the data required for the SMM in Section 3.1 followed this method of data classification. All the data items that are envisaged to be command-area-specific are included under **Command Areas**, e.g. the cropping pattern data and the soil data. All other data items are envisaged as project-wide; e.g. the crops, the rainfall data, etc.

3.3 DATA STORAGE AND MANAGEMENT

Most of the data required for the SMM will be stored in two main sources: the MIS database and the GIS. Close integration between the MIS-SMM-GIS is therefore very important in order to ensure the integrity of the data and to facilitate data entry and maintenance.

4 MODEL CONCEPT AND CALCULATION METHODS

4.1 MODEL RUNS

4.1.1 FLOOD ROUTING

A run of the SMM is likely to simulate the occurrence of a flood or a series of floods at the top of the wadi (at the gauging station). The hydrograph shapes of the floods to be simulated will be entered (or imported) into the model as date & time-discharge relationships. The user will define the time period of the simulation run (start and end dates).

The SMM will simulate the passage of the given hydrographs down the wadi using the lag and rout technique, deducting seepage losses from the hydrograph as it proceeds (other losses such as evaporation losses from water surface will be ignored). As yet, no accurate estimates of the seepage losses from the wadi beds have been made and it is envisaged that they will be taken as percentages of the flow. Nonetheless, those losses will be considered as recharge to the groundwater.

At the location of each diversion structure or direct offtake (ogma/obar) in the wadi, some flow will be diverted into the supply canal(s). The remaining flow will then be routed down the wadi until the location of the next structure/offtake is reached, and so on.

During the development stage of the SMM, the lag and rout technique implemented in the model will be calibrated by comparing the results of simulating selected hydrographs in the SMM and in the hydrodynamic simulation model iSIS.

4.1.2 FLOW DISTRIBUTION AT OFFTAKES

Flow distribution at the offtakes will be worked out as follows:

- Free direct offtakes (ogmas/obars): the flow division between the offtake and the wadi will be proportional to their widths and limited by the hydraulic characteristics of the outlet canal (inlet cross-section, bed slope, roughness, etc.). The direct offtakes take spate water from the wadi whenever water is available and are not restricted by water rights.
- Canal offtakes: the water diverted into any irrigation canal will be governed by its water rights, allocation rules and priorities, the capacity of the canal head works, and the crop water requirements of the served command areas. When it is the turn of the canal to take water, the model will assume that the gates of the canal headworks are fully open and accordingly the canal takes its maximum capacity. Nevertheless, the model will also allow the simulation of user-defined canal operations, i.e. without water rights, such that the simulation of different management plans can be possible. In these cases, the user will be able to instruct the model to allow certain percentages of the canals' maximum capacities to pass through their headworks. No simulation of the actual gate settings and flow through offtake gates will be made by the SMM in order to simplify data entry and model use.

4.1.3 COMMAND AREA WATER ALLOCATION

The volume of water to be allocated to any command area, and hence the duration of water diversion, will be worked out using one of two methods (the user will select the method to be used in the simulation):

1. Fixed target depth of application per growing season: the volume of water required by the command area will be calculated as the net area irrigated from spate only times the target

application depth for spate irrigation plus the net area irrigated from well and spate times the respective target application depth. Additionally, the following rules will be applied to this calculation method:

- When possible, the model will apply the total target depth in the first spate irrigation that reaches the command area. If no sufficient water is available in the first irrigation, additional applications will be allocated to the command area until the target depth has been applied (depending on water availability and water rights).
- Rainfall, if any, will be deducted from the required application depth on the assumption that even if the farmers apply fixed water depths, they are likely to reduce the depth of application when it rains.
- The target depth of application will be applied irrespective to soil moisture conditions on the day(s) of application. In fact, the calculation procedure in this case is reversed such that the actual application efficiency is calculated as the ratio of the soil moisture deficit on the day of application to the actual depth of application.

2. Actual crop water requirements: the depth of water to be applied in any irrigation is calculated based on the soil moisture deficit on the day of application after deducting the rainfall, if any, and allowing for the average irrigation efficiency. The area irrigated from wells will not be allocated any spate water since it will not be possible for the SMM to keep track of the soil moisture conditions in those areas.

The following notes apply to both allocation methods:

- The model will keep track of the change in the soil moisture conditions in the command areas based on the given cropping patterns and crop water requirements.
- Rainwater takes precedence over spate water in replenishing soil moisture deficit. Accordingly, rainwater is assumed to be fully stored in the soil profile until the soil moisture deficit is replenished, i.e. no rainfall run-off is assumed to take place until the soil profile has been filled with water. The volume of rainwater that exceeds the soil moisture deficit will be considered as losses, but will be added to groundwater recharge.
- The field efficiency of spate irrigation will be calculated as the ratio of the volume of spate water stored in the root zone to replenish soil moisture deficit to the total volume applied. Lost spate water at the field level will be added to groundwater recharge.

4.2 OUTPUT

The direct output from the SMM will be mainly in tabular and report formats. In addition, the SMM will export selected output data to the ArcView GIS for graphical presentation. The outputs from the SMM will include:

- the incremental and cumulative volumes of water diverted to each command area,
- the quantities of water still due to each crop in each command area,
- the quantity of water that has been used to meet crop water requirements and the quantity that has not and is therefore not accounted for (this water may partly be lost by evaporation, stored in the soil profile for future use by subsequent crops, or deep percolated into the soil recharging the groundwater),
- the potential yield of each crop (at the end of the growing season only), and
- the volume of spate water that has not been diverted to command areas (either lost by seepage from the wadi bed or was lost to the sea).

5 MISCELLANEOUS ISSUES

5.1 MODEL USERS

The target users of the SMM are typically engineers, system operators and managers. The first immediate users will typically be irrigation staff from the Agriculture and Irrigation Department for Wadi Tuban and from the TDA in Wadi Zabid. The users must have clear understanding of the system being modelled. The model will be constructed with a user-friendly interface and a detailed manual will be provided complete with sample data and a worked example.

5.2 HARDWARE AND SOFTWARE REQUIREMENTS

The SMM will be developed as a Microsoft Access 2000 database application that can run on standard PCs running 32-bit Microsoft Windows and Access 2000 or later. However, other pieces of software, such as ArcView 3.x with DCWater Design extension, will be required for data entry, editing and presentation.

LIST OF APPENDICES

A. APPENDIX A

TOR DESCRIPTION OF THE SPATE MANAGEMENT MODEL

A1 SPATE MANAGEMENT MODELS

A water management study needs to be carried out in order to be able to make recommendations regarding all improvement works in the traditional irrigation areas, and to present a spate flow management plan for the irrigation system in the Wadis Zabid and Tuban.

A good water management plan will need to take account of components in optimizing the crop returns on a delta-wide basis. These components include:

- Land and water resources
- Water rights and the establishment of priorities for water use at the wadi level.
- Water right contradiction with existing irrigation canals or offtakes.
- Water retention capacity of the soils
- Cropping pattern and crop water requirements
- Root zone parameters
- Water application depth
- The irrigation distribution system and the operational protocols
- Irrigation efficiencies
- Social implications of alternative strategies

To combine the different variables and parameters in a spate managements plan that takes into account the uncertainty and sporadic nature of spate irrigation, a mathematical model is required to simulate spate flows through the Wadis and the irrigation systems in wadi Tuban and wadi Zabid.

A spate management model is now proposed for use in the improved O&M procedures planned for Wadis Zabid and Tuban. The computer model, suitable for implementation on a standard PC computer system, would in conjunction with the spate warning system proposed for Wadi Tuban and Wadi Zabid allow decisions to be made promptly regarding:

Which command areas should be irrigated, as the model keeps a record of the depth of water application a particular command area has received, allowing the outstanding requirements to be estimated.

How much water to divert to each ogma/weir on the wadi as, based on the calculated requirements, the model works out how far the forthcoming spate will supply needs, given canal capacities and restrictions, etc, and determines the quantity to be diverted and for how long.

The spate waters to be diverted to the Wadi and in what quantity, as the model determines the peak spate discharge threshold at which the last ogma will be breached, and water will flow to the sea. The determination of this threshold will allow an operating limit to be developed for the weirs so that water in excess of this threshold may be usefully diverted.

For any required improvement works, it is possible to use the model to simulate the passage of floods down the wadi, using hydrographs developed for the wadi. This allows decisions to be made regarding the size of the supply canals to the traditional areas and possible improvement works in other areas.

The probability of irrigation of the areas commanded by each diversion weir, will assist in deciding on the type and value of any improvements that are required.

The program simulates the passage of spates of varying size as provided by actual spate records. At each weir or ogma, water is diverted into the supply canal for the duration of each spate. The remaining spate water is passed down the wadi and bed losses and flood attenuation for the wadi reach are deducted. The spate hydrograph is then reformed at the next diversion point, taking into account the bed losses and spate attenuation. The model should also allow alternative scenarios of traditional water rights and allocation plans to be investigated.

It is envisaged that a 4.5 months input by a modeling specialist would be required to develop a working model for the two wadis systems, assuming that the original model can be located. In addition to the hydrological data collection requirement, other information to be collected by an irrigation engineer would include:

- Layout plans for all canal distributaries and minor canals and control structures.
- Listing of each canal in the wadi system giving its command area, design discharge capacity and length between control structures. This would lead to the preparation of detailed schematic maps for all the systems (which is required for detailed design and is likely to form part of the requirements for implementation for improved operation of the system).
- Listings of each structure giving its design discharge capacity and basic dimensions – such as width and height of outlet.

Accordingly, a significant amount of fieldwork would be required to obtain the details of the irrigation system networks to allow meaningful and practical application of the model.

It is envisaged that the model would be sufficiently developed for it to be used as an aid to decision making in the detailed design stage where alternative development options for some of the traditional irrigation schemes is being considered. It would also be used to explore the scope for changes to some of the existing water allocation procedures to perhaps introduce more equitable water distribution plans. Over the time this operational tool will assist the eventual SMU with water management activities. The estimated TA input for this sub-component is 4.5 m/m of international consultants and 23 m/m of national consultants.