Computer Software for Nodal Network Modelling, Simulation and Optimisation of Water Resources Management

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EXTENDED ABSTRACT

Most water allocation problems are solved using hydrological nodal network framework systems but there is a knowledge gap in linking bio-economic objectives with the optimum use of all water resources under conflicting demands A computer software package was developed to consider the economic and environmental consequences of irrigation water use at the demand node and irrigation system levels. The computer software links a nodal network to GAMS (General Algebraic Modelling System) modelling system to optimise water allocation to different land use options. The model employs multiple-objective water resources decisions that use economic and biophysical constraints to answer questions about the effect of changes in land use on water requirements and whether policy constraints such as minimum rice area (as in Murrumbidgee irrigation area, Australia) can be accommodated. The model can be formulated as a monthly model for a planning year and the decision variables are the nodal water allocation, cropping pattern, flows in the system etc. This paper describes development of a nodal network model for the interaction between economic and bio-physical variables in relation to water allocation through nodal network configurations.

The model integrates multi-criteria decision making algorithms with bio-physical systems. The framework (Figure 1) is a dataflow diagram based on a network of nodes comprising storages, canals, river reaches and irrigation districts under environmental flow constraints. Many decision support systems in agricultural enterprises use conventional linear programming approach to optimize a single objective function such as total gross margin. However, as agricultural systems become more complex, multiple objectives that are in conflict with each other need to be addressed. Due to conflicts between multiple goal requirements and the competing water demands of different sectors, the framework uses a multi-criteria decision-making (MCDM) approach to define the objective equations and constraints. This approach allows the analysis of conflicts that may arise between profitability, variable costs of production and pumping of groundwater.

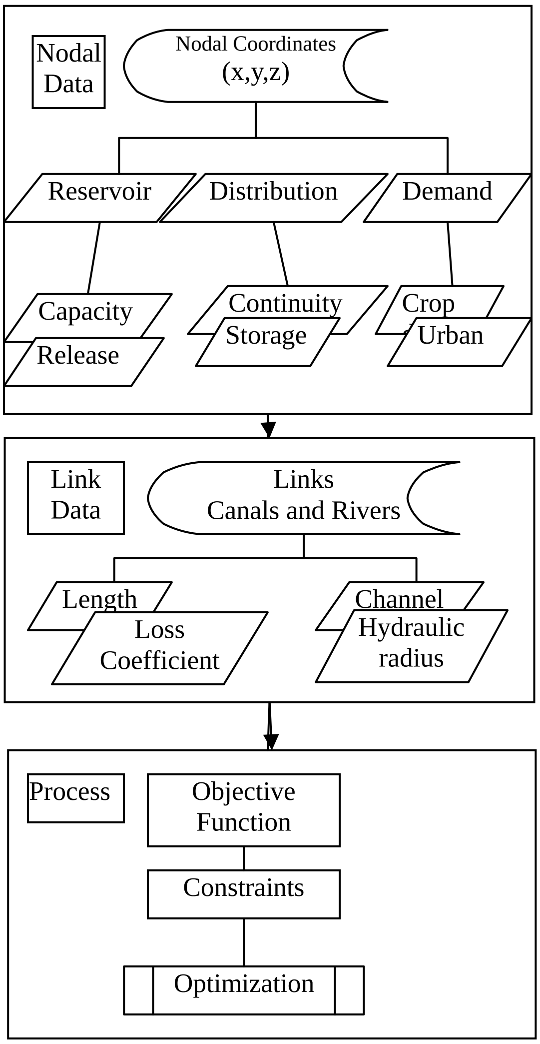


Figure 1. Nodal Network Framework

The paper uses a hypothetical irrigation district to demonstrate the functionality and capabilities of the model.

1. INTRODUCTION

Competition for scarce resources by different enterprises is a major concern in many agricultural production systems. Competition occurs at the farm level e.g. between different crops as well as at a regional level, where utilization of scarce water resources for agricultural purposes often comes into conflict with the requirement for in stream ecosystem services. Consequently multi-criteria decision making techniques (MCDM) are necessary to adequately address these complexities. A multi-criteria approach has been used extensively to solve diverse decision problems including risk assessment in agricultural systems (Berbel, 1993). Mendoza et. al., (1993) used Fuzzy Multiple Objective Linear Programming (FMOLP) techniques in forest planning where imprecise objective function coefficients are involved. Furthermore, Tecle, (1998) used Compromise Programming (CP) to develop a multi-objective decision support system for analyzing multi-resource forest management problem. The multi-objective problem that this model addresses comprise three objective functions: maximizing net returns (NR), minimizing variable cost (VC) and minimizing total supplementary groundwater pumping requirements to meet crop demand from the irrigated areas. The management options to achieve the above objectives consist of selection of an appropriate mix of crops, optimum level of groundwater pumping and appropriate allocation of water for irrigation and environment. Constraints imposed on the system are:

- continuity
- total farm area
- monthly water allocations
- monthly environmental flow requirements
- monthly groundwater pumping

In addition, water allocation rules and pumping targets for each month are constraints imposed on the system.

Input variables required consist of:

- monthly rainfall
- monthly crop water requirements
- crop growth duration
- crop factors
- yield, price and variable cost of crops

This paper mainly describes the software development that links bio-economic objectives with the optimum use of water resources under conflicting demands Further details about the objective functions and constraints used in the model can be found in Xevi and Khan (2003), Xevi and Khan (2005)

2. THE MODEL INTERFACE

The model interface is written in Delphi for Windows operating systems (NT,2000,XP) and charting uses Steema's TeeChart component. The model interface is composed of four main components: Nodal network topology, Climate data input, Economic and hydrological input and objective function specification The Optimisation software is GAMS (1998).

2.1 Nodal Network Topology.

The model incorporates a graphical interface for defining and entering nodal configurations (x,y coordinates) comprising reservoirs, demand nodes (irrigation areas), distribution nodes and inter-node links representing canals and river reaches. Links are described by providing node numbers for beginning and end nodes of each link. Data consisting of length of canal, seepage rates and total irrigation area for demand nodes can be entered via this component.

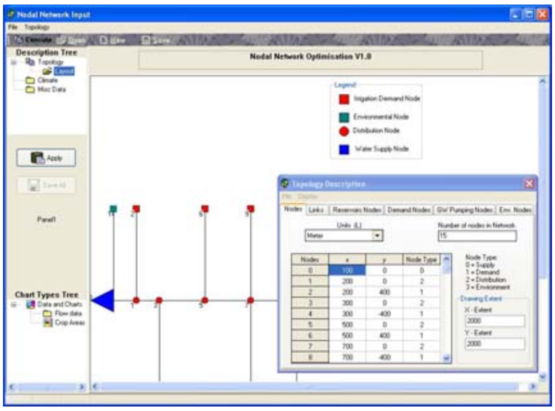


Figure 2: Model Interface showing a table of x,y coordinates and graphical plot of nodal network.

2.2 Climatic Data

Monthly values of reference evapo-transpiration (ET) and rainfall data are specified for three different climatic seasons and are described as dry, medium and wet based on the statistical analysis of data (Tables 1 and 2). Figure 3 shows input tables where monthly rainfall and evapo-transpiration can be specified depending on whether the weather is dry medium or wet.

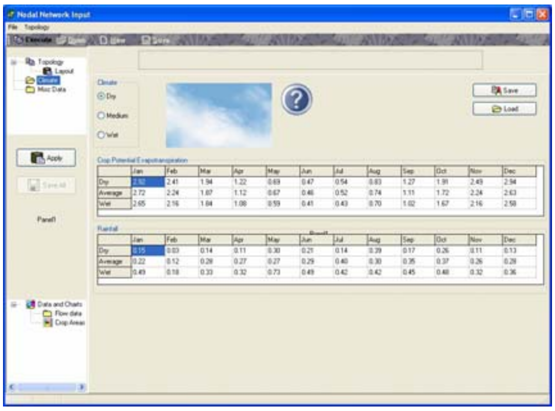


Figure 3: Model interface showing Climatic input

2.3 Economic and hydrological data

Figure 4 shows the input screen for entering economic and hydrological data. Different crops can be selected in the irrigation district and yield, price and variable cost of the selected crops can be modified and saved in a file for later use. This input screen may also be used to specify monthly water release from the reservoir for both irrigation and environmental flows. Furthermore, monthly upper limit for water usage in the irrigation areas and monthly environmental flow requirements may be specified here. In addition, the user may specify monthly maximum groundwater pumping at irrigation nodes.

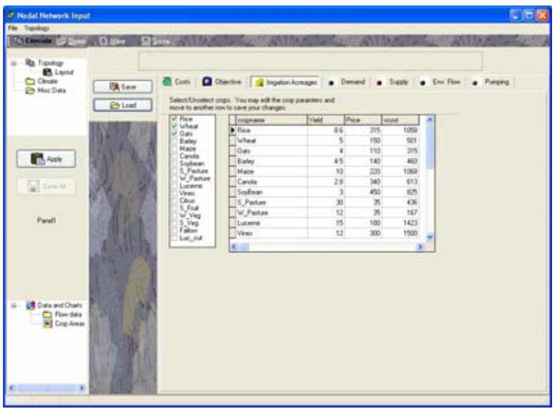


Figure 4: Model interface showing crop and economic data.

2.4 Objective function specification

Figure 5 shows the input screen where multi-objective criteria are specified. Three objectives (Net revenue, variable cost and groundwater pumping) may be used singly or all three may be solved simultaneously using goal programming. Target values and weights may be specified for each of the objectives when all three are being used simultaneously. Goal programming solves multiple objective problems by introducing the objectives into the problem as constraints and setting targets to be achieved. The objectives are included in the problem by adding positive and negative deviation variables to a composite objective function that describe over-achievement and under-achievement of each goal. The model is then defined to minimize only the undesirable deviations from defined targets:

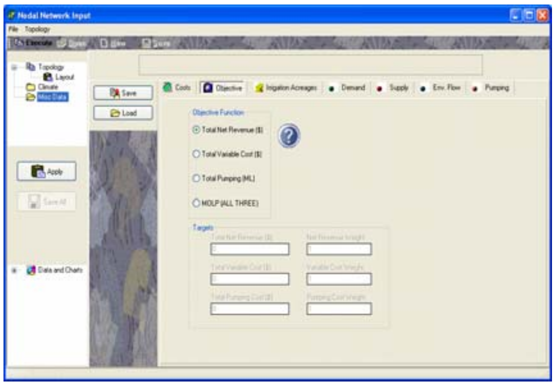


Figure 5: Model interface showing Objective function selection.

3. MODEL APPLICATION

3.1 Model Inputs

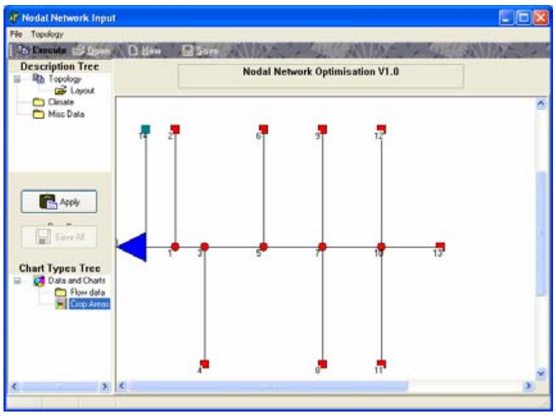


Figure 6: Model interface showing nodal network for example problem.

Table 1. Rainfall (ML/Ha or x100 mm) for dry, average and wet seasons.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dry	0.15	0.03	0.14	0.11	0.3	0.21	0.14	0.39	0.17	0.26	0.11	0.13
Average	0.22	0.12	0.28	0.27	0.27	0.29	0.4	0.3	0.35	0.37	0.26	0.28
Wet	0.49	0.18	0.33	0.32	0.73	0.49	0.42	0.42	0.45	0.48	0.32	0.36

Table 2. Reference Evapo-transpiration (ET, ML/Ha) for dry, average and wet seasons.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dry	2.92	2.41	1.94	1.22	0.69	0.47	0.54	0.83	1.27	1.91	2.49	2.94
Average	2.72	2.24	1.87	1.12	0.67	0.46	0.52	0.74	1.11	1.72	2.24	2.63
Wet	2.65	2.16	1.84	1.08	0.59	0.41	0.43	0.7	1.02	1.67	2.16	2.58

Figure 6 shows a schematic of a hypothetical irrigation district that is used to illustrate an application of the model. This nodal network configuration consists of a reservoir, thirteen demand nodes and one environmental node. The network is drawn from a set of x, y coordinates specified in a table shown in Figure 7. The node type describes whether the node is a supply, demand, distribution or environmental node. Table 1 and 2 show rainfall and potential evapo-transpiration for the dry, medium and wet seasons used in the illustration and Table 3 shows the length of growing periods for the different crops used in conjunction with crop factors to calculate the seasonal actual crop evapo-transpiration. Irrigation water supply, demand and environmental requirement used in the model run are shown in Figures 8, 9 and 10.

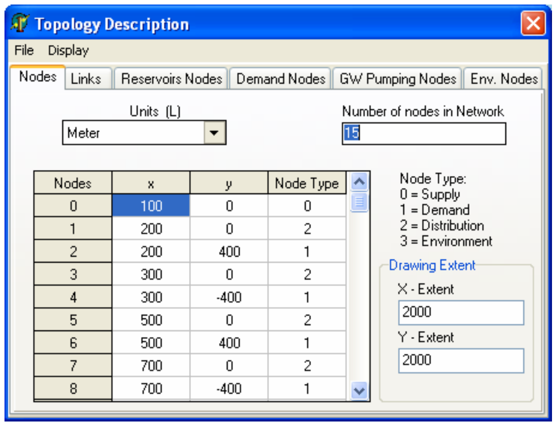
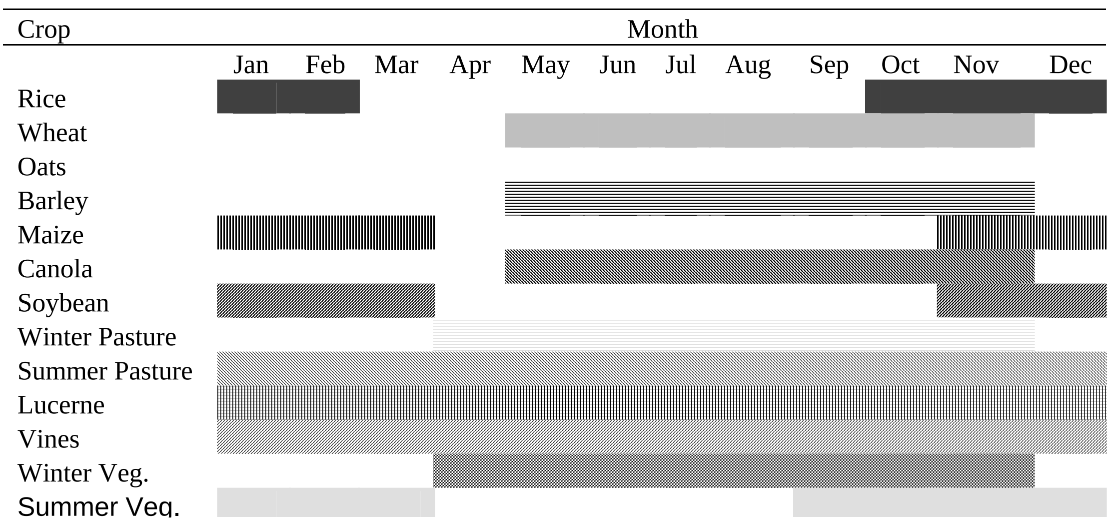


Figure 7: Model interface showing x, y coordinates and node type for example problem.

Table 3: Growing periods for different crops.



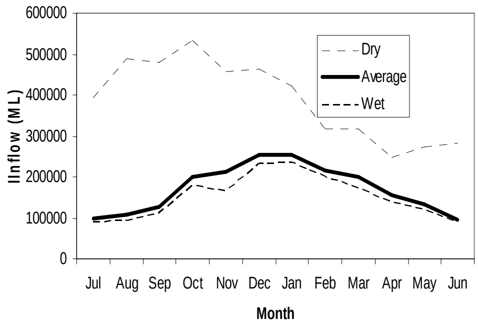


Figure 8: Monthly inflow hydrograph at weir for dry, average and wet seasons

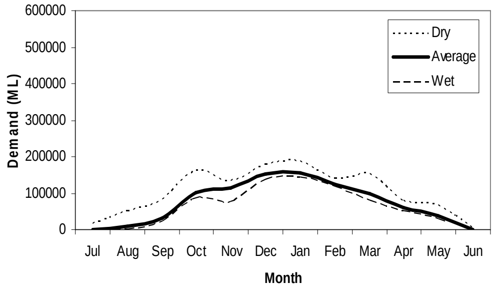


Figure 9: Monthly demand curves in irrigation areas

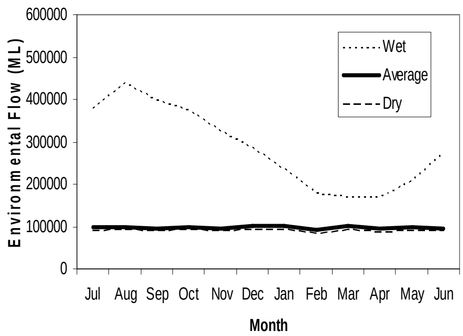
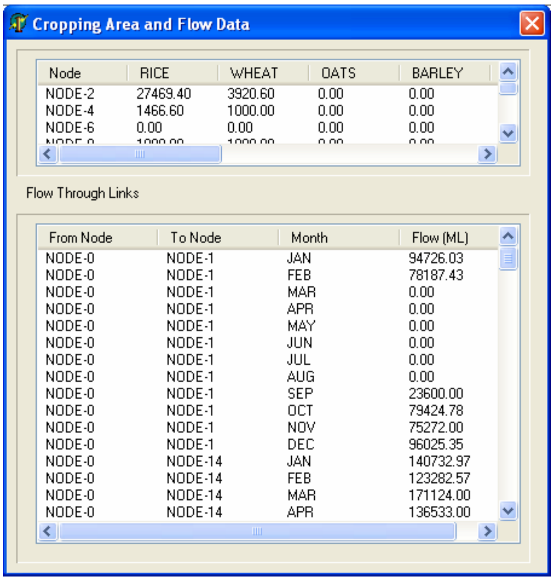


Figure 10. Monthly environmental flow curves

3.2 Model Outputs

The model output is presented in the form of tables that list the flows in each link by month and also graphically showing the optimum areas cultivated with each crop in each demand node (Figures 11, 12 and 13). When each of the objective functions is optimized individually a pay-off matrix can be constructed (see Xevi and Khan (2003 and 2005)). The pay-off matrix is obtained by optimizing each of the functions individually and then calculating the values of the remaining objectives using the solution vector of the decision variables (Table 4.) This matrix contains valuable information pertaining to the existence or otherwise of conflicts between the objectives. The existence of conflicts enables us to use multiple decision criteria methods that combine all the objectives into a compromised model. The diagonal elements of the pay-off matrix are the optimum values for each individual goal and the corresponding off-diagonal elements are the values of the other objectives evaluated using the basic elements of the optimized solution vector.



Node	RICE	WHEAT	OATS	BARLEY
NODE-2	27469.40	3920.60	0.00	0.00
NODE-4	1466.60	1000.00	0.00	0.00
NODE-6	0.00	0.00	0.00	0.00

From Node	To Node	Month	Flow (ML)
NODE-0	NODE-1	JAN	94726.03
NODE-0	NODE-1	FEB	78187.43
NODE-0	NODE-1	MAR	0.00
NODE-0	NODE-1	APR	0.00
NODE-0	NODE-1	MAY	0.00
NODE-0	NODE-1	JUN	0.00
NODE-0	NODE-1	JUL	0.00
NODE-0	NODE-1	AUG	0.00
NODE-0	NODE-1	SEP	23600.00
NODE-0	NODE-1	OCT	79424.78
NODE-0	NODE-1	NOV	75272.00
NODE-0	NODE-1	DEC	96025.35
NODE-0	NODE-14	JAN	140732.97
NODE-0	NODE-14	FEB	123282.57
NODE-0	NODE-14	MAR	171124.00
NODE-0	NODE-14	APR	136533.00

Figure 11. Model Output with crop areas and flows through links.

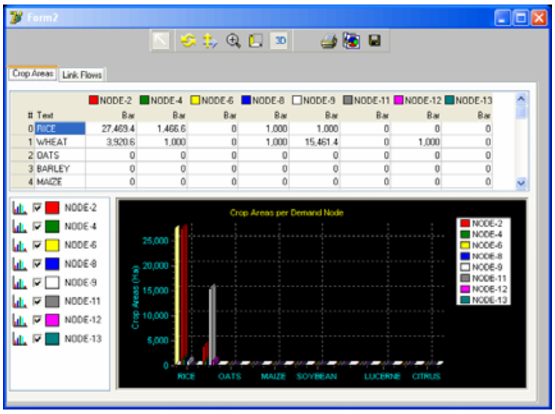


Figure 12: Model output showing tables charts of crop areas.

Table 4: Pay-off matrix and crop mix for dry season

Pay-off Matrix				Crop-Mix (Ha)											
Optimization Goal	Net Revenue ($)	Total Cost ($)	Total Pumping (Ml)	Rice	Wheat	Canola	Vines	Citrus	Stone Fruit	Summer Veg	Winter Veg	Oats	Barley	Maize	Soybean
Net Revenue	152.3	100.5	482605	48819	22382	13594	5012	16000	8000	8000					
Total Cost	98.5	67.04	279169	30936	22382		6000					52090			
Total Pumping	122.5	137.3	124372	30936	22382		6000				46530			15959	

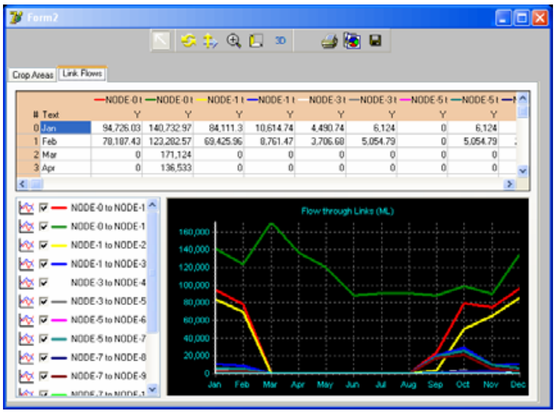


Figure 13: Model output showing tables and charts of flows through links.

4. CONCLUSIONS

This model provides a simple tool to define and optimize water allocation within a nodal network of supply and demand nodes in the irrigation district. The nodal network can be specified using a set of x, y coordinates in a table. It does not however provide a graphical means of specifying the nodal network. Optimization of the network is achieved using the components available in the GAMS optimization framework. The availability of the GAMS modeling framework to the user of this model can be a drawback since it is expensive to acquire a user license. The model combines bio-physical and economic variables to determine optimal crop mix for an irrigation area in addition to determining the optimal flow of water from a reservoir to the irrigation areas. Further work is required to incorporate market constraints that take into account price and demand fluctuations for different crops.

5. REFERENCES

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