Republic of Iraq

Ministry of Water Resources

General Directorate for Water
Resources Management

Strategy for Water and Land Resources in Iraq

Technical Report Series

Possible Water Allocation Model

TR 05

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This document is one of a series of technical reports published by the Ministry of Water Resources addressing issues relevant to strategic planning for the sustainable use of the water and land resources of Iraq.

The technical report provides an overview of a simple water allocation model which is a tool for examining the trade-offs between meeting water needs from scarce water resources.

Report Issue and Revision Record

Rev	Date	Description
P1	August 2006	Preliminary when Phase 1 curtailed

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1 INTRODUCTION

1.1.1 This note outlines the philosophy behind our simple water allocation model, as provided in the simple water allocation model (see Appendix A).

1.1.2 The model is designed to provide a spreadsheet tool for examining the trade-offs between meeting water needs from scarce water resources. The model requires that we put capacities and costs on the various water supply and transport options and that the needs can be specified in terms of absolute quantity (Bcm) requirements.

1.1.3 The model uses a Linear Programme (LP) solver (What's Best) to find the least cost mix of water supply options that meets all the water requirements, subject to not breaching any constraints regarding capacities of water supply options and transport routes. In terms of the spreadsheet, the optimiser finds a set of values in top (water) matrix which produces the minimum value for the sum of products of this matrix and the second (watercost) matrix, and which does not breach any constraints.

Deployment of water resources: Bcm

WATER	power need in area A	power need in area B	power need in area C	irrigation need in area A	irrigation need in area B	irrigation need in area C	industrial water needs	Household water needs	Capacity of supply scheme	Bcm despatched
dam 1	0	10	40	0	10	51	139	0	**250**	250
dam 2	49	40	0	100	0	0	11	0	**200**	200
dam 3	0	0	0	0	20	99	0	0	**145**	119
dam 4	0	0	0	0	30	0	0	0	**75**	30
well 1	51	0	0	0	0	0	0	49	**100**	100
well 2	0	0	0	0	20	0	0	0	**60**	20
well 3	0	0	0	0	20	0	0	0	**90**	20
desal 1	0	0	0	0	0	0	0	71	**100**	71
desal 2	0	0	0	0	0	0	0	0	**85**	0
Total need	**100**	**50**	**40**	**100**	**100**	**150**	**150**	**120**	1105	810
excess supply	0	0	0	0	0	0	0	0		
Shadow price	39	39	39	38	40	41	47	68		

2 WATER ALLOCATION MODEL

2.1 Constraints

2.1.1 The two fundamental sets of constraints are that the amount of water despatched from each source cannot exceed the capacity and that the sum of water despatched towards a specific need equals the need total. It is unlikely to exceed it, as this would imply that a water source was free.

2.1.2 There will typically be many additional constraints and these can be in many forms. The model here for example, provides minimum and maximum despatch constraints, whereby floors and caps are set on water flows from a particular source to a need. A variant of this kind of constraint are percentage diversity constraints on demand and supply. This would reflect the practice of users and suppliers seeking to diversify their portfolios, although this may not be a so important in a country which is trying to meet just basic needs.

2.1.3 There is lots of scope for devising alternative constraints, however, those which link the value of one cell in the water matrix to another can introduce non-linearities, unless this is done through an unconditional formula link, i.e. one with no “if” statements.

2.1.4 It is also possible to fix values in the main water matrix (i.e. exclude certain cells from the optimisation).

2.2 Handling multiple periods

2.2.1 In this example the model is solved for a single period (a year), however, it would be possible run additional periods. This can done either as part of a multi-period solve, whereby the optimisation allows trade-offs between periods, or alternatively run as a series of separate solves covering discrete time periods, in which case results from one solve are fed through to successive periods.

2.2.2 The former is easier to handle and has the advantage of allowing an optimisation over a multiple period time span. This would in principle allow the model to choice optimal capital expansion plans. It does of course assume that investors are blessed with perfect foresight. Solving over an extended period means that any shadow values calculated reflect the changes in value to the system over the whole time horizon. If the problem become very large, (i.e. the main matrices become very large or there are many and complex constraints) then the only solution (within an Excel framework) may be to run the model as a series of solves.

2.3 Watercost matrix

2.3.1 The watercost matrix here is meant to reflect the annual operating costs in this case built up from a basic cost and a transport cost. It is clearly possible to develop much more sophisticated cost build up and even to have costs altering with level of water despatched – although this can be complicated.

2.4 Slack matrices

2.4.1 There are a number of slack matrices and arrays which show the value of comfort margin between constrained magnitudes of value in the water matrix and the solved values. These values will always be non-negative, assuming that the model has been solved an a feasible solution has been returned.

2.5 Shadow prices

2.5.1 A shadow price is the delta in the total system cost from an incremental relaxing or tightening a constraint. This means that the shadow price will tend to have a positive value only when the constraint is binding, i.e. when the slack variable is zero. Otherwise the shadow price is zero.

2.5.2 The model here shows two sets of shadow prices, one relating to the marginal cost of meeting each water need and one relating to the value of having an additional unit of water from each supply source option.

2.5.3 It is a relatively straightforward task to add shadow price indicators to test the value of relaxing any binding constraint, for example regarding diversity or maximum flow rates on particular routes.

2.6 Key inputs and outputs

2.6.1 The key inputs variable are:

- Water requirements by end-use and region
- Availability and cost of water from each supply source
- Transport costs (loss rates) for getting water from each source to each end-user point
- A volume restriction on flows.

2.6.2 Key output variables are:

- Water flows between each source and end-user point
- Total system costs and average unit cost
- Shadow price of water for each need
- Value of extra capacity for each water supply option
- Shadow price of relaxing constraints on allocation.

2.7 Model Operation

2.7.1 Model users should only change cells highlighted in yellow or beige. The so-called adjustable cells in the Water matrix have a blue font can be changed but the values will be overwritten when the model is re-solved. The model is solved by executing the solve from the drop-down What's Best menu bar (assuming What's Best is installed).

2.7.2 A free trial version of What's Best is available from www.lindosystems.com.

Appendix A Simple Water Allocation Model

Simple water allocation tool

Deployment of water resources: Bcm

WATER	power need in area A	power need in area B	power need in area C	irrigation need in area A	irrigation need in area B	irrigation need in area C	industrial water needs	Household water needs	Capacity of supply scheme	Bcm despatched	Spare capacity	min take	excess over min	Value of extra capacity
dam 1	0	10	40	0	10	51	139	0	**250**	250	0	**100**	150	17
dam 2	49	40	0	100	0	0	11	0	**200**	200	0	**50**	150	12
dam 3	0	0	0	0	20	99	0	0	**145**	119	26	**30**	89	0
dam 4	0	0	0	0	30	0	0	0	**75**	30	45	**30**	0	0
well 1	51	0	0	0	0	0	0	49	**100**	100	0	**20**	80	3
well 2	0	0	0	0	20	0	0	0	**60**	20	40	**20**	0	0
well 3	0	0	0	0	20	0	0	0	**90**	20	70	**20**	0	0
desal 1	0	0	0	0	0	0	0	71	**100**	71	29	**0**	71	0
desal 2	0	0	0	0	0	0	0	0	**85**	0	85	**0**	0	0
Total need	**100**	**50**	**40**	**100**	**100**	**150**	**150**	**120**	1105	810				
excess supply	0	0	0	0	0	0	0	0						
Shadow price	39	39	39	38	40	41	47	68						

Cost of using water resources: £m/bcm

WATERCOST	power need in area A	power need in area B	power need in area C	irrigation need in area A	irrigation need in area B	irrigation need in area C	industrial water needs	Household water needs
dam 1	22	22	22	22	23	24	30	120
dam 2	27	27	28	26	34	30	35	125
dam 3	43	42	41	51	42	41	50	140
dam 4	47	47	48	48	47	51	55	145
well 1	36	40	45	39	39	39	50	55
well 2	45	50	43	43	42	46	56	71
well 3	46	46	46	46	43	45	58	83
desal 1	66	66	65	66	66	66	67	68
desal 2	75	76	76	76	76	76	77	78

Add-on delivery/processing costs

COSTBUILDUP	power need in area A	power need in area B	power need in area C	irrigation need in area A	irrigation need in area B	irrigation need in area C	industrial water needs	Household water needs	**Basic production cost**
dam 1	2	2	2	2	3	4	10	100	**20**
dam 2	2	2	3	1	9	5	10	100	**25**
dam 3	3	2	1	11	2	1	10	100	**40**
dam 4	2	2	3	3	2	6	10	100	**45**
well 1	1	5	10	4	4	4	15	20	**35**
well 2	4	9	2	2	1	5	15	30	**41**
well 3	3	3	3	3	0	2	15	40	**43**
desal 1	1	1	0	1	1	1	2	3	**65**
desal 2	0	1	1	1	1	1	2	3	**75**

Total cost being minimised	Average cost per unit
29480	36.40

Delivered cost of water despatched

DELCOST	power need in area A	power need in area B	power need in area C	irrigation need in area A	irrigation need in area B	irrigation need in area C	industrial water needs	Household water needs
dam 1	0	22	22	0	23	24	30	0
dam 2	27	27	0	26	0	0	35	0
dam 3	0	0	0	0	42	41	0	0
dam 4	0	0	0	0	47	0	0	0
well 1	36	0	0	0	0	0	0	55
well 2	0	0	0	0	42	0	0	0
well 3	0	0	0	0	43	0	0	0
desal 1	0	0	0	0	0	0	0	68
desal 2	0	0	0	0	0	0	0	0
max	36	27	22	26	47	41	35	68

Minimum despatchs

MINDESPATCH	power need in area A	power need in area B	power need in area C	irrigation need in area A	irrigation need in area B	irrigation need in area C	industrial water needs	Household water needs
dam 1	0	0	0	0	0	0	0	0
dam 2	0	0	0	0	0	0	0	0
dam 3	0	0	0	0	20	0	0	0
dam 4	0	0	0	0	0	0	0	0
well 1	25	0	0	0	0	0	0	0
well 2	0	0	0	0	0	0	0	0
well 3	0	0	0	0	0	0	0	0
desal 1	0	0	0	0	0	0	0	0
desal 2	0	0	0	0	0	0	0	0

Slacks

	power need in area A	power need in area B	power need in area C	irrigation need in area A	irrigation need in area B	irrigation need in area C	industrial water needs	Household water needs
dam 1	0	10	40	0	10	51	139	0
dam 2	49	40	0	100	0	0	11	0
dam 3	0	0	0	0	0	99	0	0
dam 4	0	0	0	0	30	0	0	0
well 1	26	0	0	0	0	0	0	49
well 2	0	0	0	0	20	0	0	0
well 3	0	0	0	0	20	0	0	0
desal 1	0	0	0	0	0	0	0	71
desal 2	0	0	0	0	0	0	0	0

Maximum despatchs

MAXDESPATCH	power need in area A	power need in area B	power need in area C	irrigation need in area A	irrigation need in area B	irrigation need in area C	industrial water needs	Household water needs
dam 1	55	999	999	999	999	999	999	999
dam 2	999	999	999	999	999	999	999	999
dam 3	999	999	999	999	999	999	999	999
dam 4	999	999	999	999	999	999	999	999
well 1	999	999	999	999	999	999	999	49
well 2	999	999	999	999	999	999	999	999
well 3	999	999	999	999	999	999	999	999
desal 1	999	999	999	999	999	999	999	999
desal 2	999	999	999	999	999	999	999	999

Slacks

	power need in area A	power need in area B	power need in area C	irrigation need in area A	irrigation need in area B	irrigation need in area C	industrial water needs	Household water needs
dam 1	55	989	959	999	989	948	860	999
dam 2	950	959	999	899	999	999	988	999
dam 3	999	999	999	999	979	900	999	999
dam 4	999	999	999	999	969	999	999	999
well 1	948	999	999	999	999	999	999	0
well 2	999	999	999	999	979	999	999	999
well 3	999	999	999	999	979	999	999	999
desal 1	999	999	999	999	999	999	999	928
desal 2	999	999	999	999	999	999	999	999

Diversity constraints
on demand
on supply