

IMPACTS OF WATER STORAGE DEPTH ON COTTON PRODUCTION AND WATER USE

Gordon Simpson¹, Mary Ann Franco-Dixon² and Jeff Clewett¹

Queensland Centre for Climate Applications, Queensland Department of Primary Industries, PO Box 102,
Toowoomba, Qld 4350¹

Policy Analysis and Industry Development, Queensland Department of Primary Industries, GPO Box 46,
Brisbane, Qld 4001²

Introduction

A water management approach commonly used by cotton growers in the Condamine – Lower Balonne catchment area is to divide farm storages into several cells. The strategy aims to reduce evaporative losses by minimising surface area for a given total volume. Cells are nominally 4 m high with a 3 m water depth. Water losses are further reduced by having cells of various sizes, so that water can be stored in the combination of cells that best minimises surface area. Cotton growers face a move towards deeper cells. Current storages can be deepened, but at a cost, or any new storages can be built for a greater depth.

Through the use of computer modelling techniques, we have aimed to quantify the impact of water storage depth on cotton production in the study area. It explores the efficacy of different water management practices on increasing cotton production or decreasing water lost due to evaporation. This study explains some of the factors involved so that better decisions can be made regarding water management.

Methods

A modelling and systems simulation approach was used. Three farms from the Lower Balonne area were chosen for variation in the number and size of the storages and the area of land planted to irrigated cotton. The main parameters of the farms were modelled to estimate the volume of water harvested and lost to evaporation, the area of land sown, the amount of cotton produced and the profit obtained in each year of a 73-year period from 1922 to 1995.

The main assumptions used in the analysis were:

- Each farm used its current water allocation, pumping infrastructure, and on-farm storages as installed at June 2000 (which might be in excess of the licences).
- Cropping area was limited to the area planted to irrigated cotton in 1999/2000.
- Stream flows for the Lower Balonne were estimated for the 73 study years using the IQQM model. This model simulates diversions of water from stream flows to on-farm storages for irrigated farms.

The study used the following site and management factors:

Location: St George in the Condamine – Lower Balonne catchment. The climate data for this site came from the St George Post Office recording station (28° 02'S, 148° 35'E). The site was assumed to be on a grey vertosol soil with 220 mm plant available water capacity. These soils can have high salinity levels below 1 m that inhibit root growth, particularly in the first 5–10 years of irrigated

cropping. We assumed that the soil had been irrigated for a sufficient period such that no restriction to rooting occurred within the top 1.5 m.

Irrigation management strategy: the season's plant area was calculated from the volume of on-farm stored water at the end of August. The strategy used provided for a moderate irrigation risk, by assuming that 4 irrigations (5.3 ML/ha) would be required from October to February and that 609 mm of water would evaporate from the storages during October to February in 50% of the 73 study years. Some rainfall (130 mm), but no river diversion, would be received to assist crop production during the December / February period. Four irrigations were sufficient in about 50 % of years.

Plant area: the area of land available for planting was constrained to the 1999/2000 area planted to irrigated crops for each farm.

Farm development level: the three farms differed in size of storages and plant area, and in the ratio of these parameters. The number of storages for the farms were 4, 9 and 16, respectively. During the simulation, the total volume remained constant. Depth was varied from 1 m to 8 m in steps of 0.5 m. Each storage's surface area was adjusted to maintain a constant total volume. The volume of water on hand at the start of the simulation was $\frac{1}{3}$ of the total storage volume, distributed across the cells in a way that minimised the surface area of water.

A farm production model was developed to calculate the production of irrigated cotton for the three study farms. This model simulated water harvested, water storage, crop area, crop water use, crop yield, and crop production for the period January 1922 to December 1995 (74 calendar years, 73 cropping years) using a monthly time-step.

The key components of the farm production model were:

Water Harvesting Sub-model: the volume of water that each farm could potentially harvest into on-farm storages from the river in each month of the 74-year simulation period and the licensed operating specifications for each pump on each farm as at June 2000 was supplied by Department of Natural Resources and Mines. In each month of simulation, pumping to fill storages was assumed equal to the potential number of days pumping when storages were less than full. Pumping ceased when all storages on a farm were simulated to have reached their maximum storage capacity. Thus the volume of water pumped was equal to or less than the potential and a function of river flow rate, licence conditions, pumping capacity, water storage capacity and water loss from on-farm storages via evaporation, irrigation and seepage.

Water Storage Sub-model: the model assumed an efficient set of methods to manage water in the storages (including water stacking) and the water balance of each storage was determined at the end of each month. The storages of each farm had two water-stacking methods applied in an effort to reduce the total water surface area of the storages. The first method ("Simple") allowed smaller storages to receive the water from a larger storage if the larger storage could be completely emptied. Storages were prioritised in decreasing order of surface area. Only one large storage was emptied at a time with this method. A more comprehensive stacking method ("Perfect") allowed the total on-farm stored water to be allocated to the storages that minimised the total surface area. These methods were compared to no water stacking ("None") being applied.

Cropping Area Sub-model: farm size was defined as the maximum area of land that could be irrigated. For each farm this was assumed equal to the area of land planted to irrigated cotton as at June 2000. In simulation, farm size was set equal to the crop area planted on each farm in 1999/2000 (a year with few restrictions on irrigation water). In each year of simulation, the area of crop sown was set equal to the minimum of the farm size or the area of land that could be irrigated from the stored water available at the beginning of the season. The following parameters were also accounted for in estimating crop area: expected evaporation and seepage losses from stored water; expected inflows from pumping and rainfall; transmission losses in irrigation (assumed to be 30%); the volume of water required per hectare of crop.

Crop Yield Sub-model: yields of irrigated cotton for the period 1923 to 1995 were obtained from a set of data derived from simulations using the CSIRO-developed OZCOT model. Irrigation efficiency for the OZCOT model was 100%.

Cotton Production Model: farm production in each year was estimated as the area of crop sown multiplied by yield/ha. The OZCOT model assumes production is equivalent to that obtained by the top 20 percent of growers. District average yield estimates for the last 10 years published in The Australian Cottongrower showed they were 86% of OZCOT yield estimates. This factor was applied to all yields to provide a better estimate of the true farm yield.

Economic Model: industry benchmark economic data were applied to generate the profit per bale of growing cotton under each of the water-stacking methods for each storage depth. The whole-farm budget for each of the study farms was used to simulate the impacts of the different depths for each year. The impact of the options on the profitability and viability of the farms were expressed as profit per bale.

The assumptions used for the economic modelling were:

Cotton price was \$450 per bale;

Total variable costs were \$1758 /ha excluding pumping costs and water charges;

Total fixed costs of \$1020 /ha; and

Pumping costs were \$15 /ML.

Results

Results are shown for Farm 1; results for the other farms were similar and are discussed in the text. Evaporation (Figure 1) was reduced in deeper storages for all farms, reducing by 56% at 8 m compared to 3 m. Evaporation was 70% greater at 1 m. Evaporation was lower with "Perfect" stacking than "Simple" or no stacking, with the differences between stacking methods reducing with increasing depth. The differences between stacking methods at shallow depths increased with storage area.

Less water had to be pumped from the river with deeper storages (Figure 2). This varied by farm, with Farm 1 reducing its relative volume of water pumped by about 30% at 8 m compared to 3 m, while Farm 2 and Farm 3 had smaller relative reductions of 9% and 12% respectively. The differences between stacking methods were minor.

The volume of unused water (Figure 3) increased as storage depth increased, with the relative volume decreasing with storage volume (Farm 3: 44%; Farm 1: 63%). The volume of unused water increased with stacking method efficiency, although the methods approached a common value with increasing depth. Although Farm 3 had a smaller relative increase than the other farms, any changes to the proportion of water unused impacts greatly on the stream flow due to its total storage volume.

Production increased with storage depth (Figure 4), but farm parameters had a major effect on the influence of depth. Farm 1 was constrained by its plant area, and its production approached an asymptote with depths greater than 5 m. All farms had lower production at the shallowest depth, being 58% ("None") to 83% ("Perfect") of that possible from 3 m storages. Relative differences in production reduced with depth, with production increasing by smaller amounts.

Profit per bale increased with depth (Table 1). It was negative for all farms at the shallowest depths, and quickly approached an asymptote of about \$46 per bale (Farm 1) or \$50 per bale (Farm 2 and Farm 3) at the greater depths. The relative increase from 3 m to 8 m depended on farm, with Farm 1 having the lowest increase and Farm 2 the greatest. Profit per bale increased with water-stacking efficiency. However, the relative differences between the methods declined with efficiency for each farm as better use of available water was made at 3 m with "Perfect" stacking compared to no stacking.

Discussion

Shallow storages with a large surface area wasted much of the water diverted into them from stream flow. This loss of water directly impacted on the current season's yield, and hence crop economics, but also to some extent on future yields as the total on-hand water at the end of August determined that season's plant area. Deepening storages reduced the water lost to evaporation and increased crop yields marginally. However, production approached an asymptote with reduced changes in benefits being realized.

Stacking water showed that further reductions in water losses were possible, although the value of this practice reduced with the deeper storages. Less water was being lost to evaporation with deeper storages, resulting in less being able to be saved by stacking. Farm parameters played a role in this study, as Farm 1 approached its maximum plant area more often with deeper storages or with water stacking being practiced. This study suggested that a better match of plant area to storage volume would become more important with deeper storages and with the reduction in water lost to evaporation following from this strategy.

These simulations suggest that the main benefit from deeper storages is to reduce the volume of water lost to evaporation, with the additional steam flow then available for other purposes. These may be on- or off-farm. Production and profit increased with deeper storages. While improved crop production will result due to the farm's plant area being planted more often, the main benefit of deepening storages is to reduce water losses. Economic benefits will consequently flow from these two factors. The study suggests that any new storages should be at depths greater than the current limit of 3 m. Whether existing storages should be deepened was not examined in this study,

although the results from this study do suggest that water losses would be reduced by this practice. The economic benefits of reworking existing storages would need to be examined separately.

This study assumed the storages were built to the specified depth from new. It also assumed the same number of storages as currently exist were built, each being reduced in surface area as depth increased. Our additional, unpublished, studies have identified the water losses associated with storing water in one or in many storages. They suggest that the water losses from storing water in 1 storage as against the current farm number would be so great as to question the farm's economic viability.

Acknowledgements

We thank Paul Harding (Queensland Department of Natural Resources and Mines) for providing the IQQM simulated stream flow data for the simulation, and Dr Mike Bange for the cotton yield data for given irrigation volumes.

Table 1. Profit per bale (\$) for each farm for storage depths of 1 m to 8 m for 3 water-stacking methods.

Depth	Farm 1			Farm 2			Farm 3		
	Water stacking method			Water stacking method			Water stacking method		
	None	Simple	Perfect	None	Simple	Perfect	None	Simple	Perfect
M	\$	\$	\$	\$	\$	\$	\$	\$	\$
1.0	-139	-83	-51	-142	-94	-76	-138	-92	-73
1.5	-38	-26	-4	-20	-13	-6	-28	-14	-7
2.0	-9	3	14	7	9	15	10	13	20
2.5	14	19	30	17	19	23	20	24	28
3.0	28	32	36	24	28	30	28	30	34
3.5	35	36	37	30	32	34	34	37	38
4.0	37	37	39	34	36	38	38	40	41
4.5	38	38	40	39	39	41	40	42	44
5.0	39	40	41	40	41	44	43	44	45
5.5	40	42	43	43	43	46	44	45	46
6.0	41	43	44	45	46	47	46	47	48
6.5	43	43	44	46	47	49	46	48	48
7.0	44	44	45	47	48	51	48	48	49
7.5	45	45	46	48	50	51	48	49	50
8.0	45	46	46	50	51	52	49	50	50

Note: the price per bale was assumed to be \$450.

Figure 1. Average evaporation (relative to 3 m) for 73 years at Farm 1 for 3 water-stacking methods

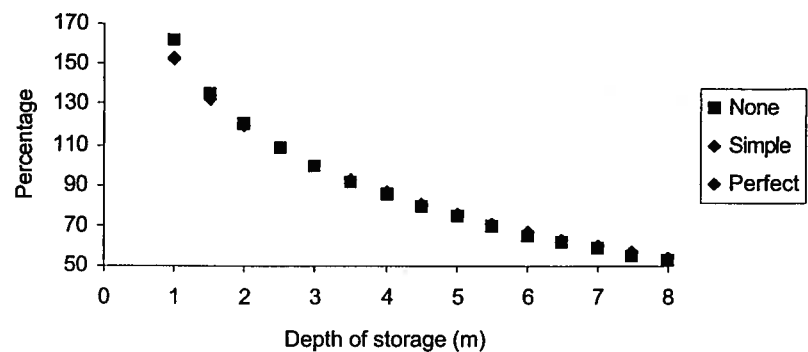


Figure 2. Average water pumped (relative to 3 m) for 73 years at Farm 1 for 3 water-stacking methods

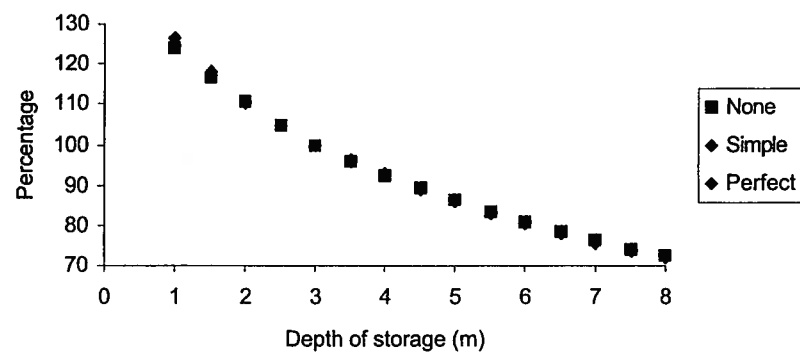


Figure 3. Average water unused (relative to 3 m) for 73 years at Farm 1 for 3 water-stacking methods

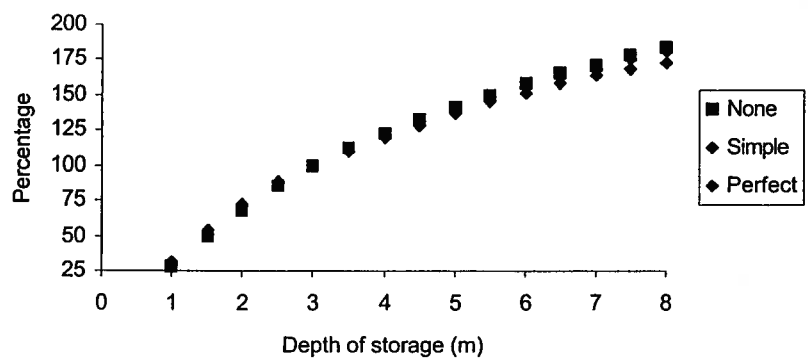
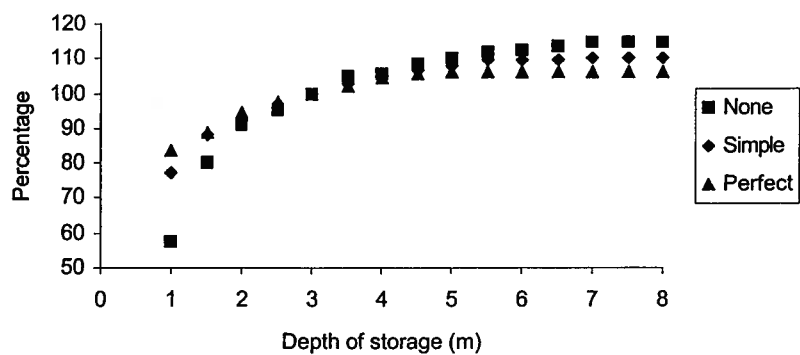


Figure 4. Average production (relative to 3 m) for 73 years at Farm 1 for 3 water-stacking methods





Graph 3: A line graph showing an increasing trend. The y-axis is labeled 'Y-axis' and the x-axis is labeled 'X-axis'. The data points are connected by a line, showing a steady increase from left to right.

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