Water–energy nexus in irrigation supply systems using a demand-based dynamic nodal network model

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INTRODUCTION

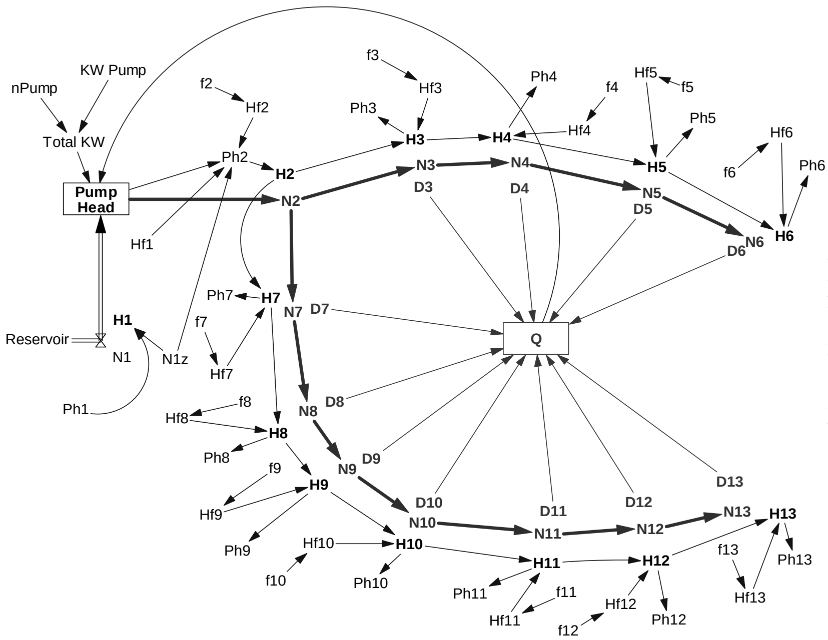
Scarcity, high price tag and environmental footprints of water and energy use are now well-recognized wicked problems in irrigated agriculture. Efficient irrigation technologies are an important means for boosting crop productivity; however, the benefits of improved yields may be at the cost of increased water and energy inputs and associated environmental impacts (Pimental *et al.*, 2004). These issues have become more pressing for water-scarce and environmentally-aware countries like Australia. In response, the Australian government has initiated a 10-year $10 billion "Water for Future" programme to improve irrigation infrastructure, efficiencies and to give the environment its fair share. This article is one of the outcomes of research that investigated water–energy nexus on a large irrigation area in southeast New South Wales, Australia. Three types of infrastructure are mainly in place in the study area to deliver irrigation water to the farms, namely: (1) Gravity-based open channel network that mainly delivers water to farms growing broad acre crops. High seepage and evaporation loss is associated with this system; (2) Gravity-based open channel network with on-farm storages where water is supplied to the on-farm reservoirs. Water is then pumped from the on-farm reservoir to mainly operate sprinkler/drip system(s) to irrigate crops when required. This involves additional evaporation loss from on-farm storages which would otherwise have been socialized if left in the original source storage; (3) an emerging technology, the integrated high pressure (IHP) system. It consists of a centralized pump(s) station and a number of farms connected to it. The system is designed to deliver water with certain pressure head to operate farm pressure irrigation equipments without need for on-farm pumping. The IHP system can be an On-demand supply system, where a constant pressure is maintained in the mains and the farmers start irrigation when needed by opening the control valve manually or wirelessly, or a restricted supply system where there is restriction on frequency of water orders. Lamaddalena & Sagardoy (2000) noted that when restricted frequency demand is applied, all farmers tend to over-irrigate because of uncertainty in water availability. In contrast, using the on-demand operation farmers irrigate when it is needed. Farmers are required to place a water order with the irrigation company in advance (order time varies with irrigation supply system).

WICKED WATER PROBLEM

The problem addressed in this article is: "solutions to maximize water savings with minimum cost" in irrigation systems. The average seepage and evaporation losses from 2700 km of channel network of the study area (Murrumbidgee Irrigation, 2009) fluctuate within 5–15% of gross irrigation diversions, depending upon climate conditions and diversion volume. These losses can be eliminated by replacement with a piped system, which generates high energy bills.

TOOL TO SOLVE THE PROBLEM

A lumped static spreadsheet-based model was developed and results were published by Ahmad & Khan (2009) to compare water and energy savings between the abovementioned irrigation supply systems by water and energy life cycle analysis of crop production. The current article presents a demand-based dynamic nodal network model which was developed to simulate water use and energy consumption by 11 citrus farms connected to the IHP system. The pressurized flow was simulated using Bernoulli's and Darcy-Weisbach equations implemented using Vensim system dynamics modelling tool (Ventana, 2004). The operating criteria were to fulfill flow and minimum pressure head requirements at each outlet. The model was calibrated by varying the pipe friction factor. The energy consumption was computed using the pump energy equation based on total dynamic head. The schematic of the developed dynamic model is shown in Fig. 1.



Q: total irrigation demand; Di, Hi, Phi and Hfi are irrigation demand, total head, pressure head and friction head loss, respectively, at a node Ni; Pump Head is total dynamic head added by pump(s)

Fig. 1 Schematic of the dynamic pressurized irrigation supply system.

Table 1 Comparison of the three irrigation supply systems.

Supply network system	Seepage loss	Evaporation loss	Supply reliability Order time	Delivery risk	Energy use/ML	Cost/ML
Open channel	High	High	48 (hours)	High	None	Low
Open channel with on-farm storage	High	Very high	10–15 (days)	Medium	Very high	Very high
Pressurized pipe network (IHP)	None	None	24 (hours)	Low	High	Medium

KEY LESSONS

The comparison of the three irrigation supply systems against various criteria for the study area is given in Table 1. The "order time" is defined as the time a farmer has to place a water order in advance. The "delivery risk" is the possibility of water made available being less than required, late delivery or delivery failure. The "very high" unit cost for "open channel with on-farm storage" is attributed to higher pumping costs for installation and operation of individual pumps on the farms. While IHP system warrants more water savings, the open channel system is most cost effective. Looking at irrigation scheme scale a combination of these supply methods is recommended to achieve optimal savings in water, energy and cost.

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