GROUNDWATER EXTRACTION IN THE WERRIBEE IRRIGATION DISTRICT AND THE POTENTIAL FOR SALT WATER INTRUSION

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ABSTRACT

A network of channels supplies diverted river water to the Werribee Irrigation District for irrigation of market gardens. Historically the surface water supplies have been supplemented by groundwater extraction from the shallow alluvial sediments and basalts that underlie the district. In 2002 the surface water deliveries were drastically reduced due to drought and associated low river flows. As a result the rate of groundwater extraction from the aquifer increased to meet the shortfall in water supply for irrigation. The combination of reduced recharge through irrigation accessions and the increased pumping stresses placed on the aquifer led to a dramatic drawdown in groundwater heads. Fears of salt water intrusion led to the enforcement of restrictions on groundwater extraction. A numerical groundwater model was formulated and calibrated against measured groundwater responses across the aquifer. Modelling results suggest that safe levels of groundwater extraction are limited by the potential for saline water leakage from the Werribee River and by the potential for salt water intrusion from the ocean. A resource management policy has been developed that relies heavily on the numerical groundwater model to predict the potential saline water inflows under various extraction conditions.

KEYWORDS

Groundwater model saltwater intrusion irrigation

BACKGROUND

The Werribee Irrigation District is located approximately 30km West of the City of Melbourne in Victoria, Australia. The irrigation district covers approximately 40km^2 on the eastern side of the Werribee River Delta (refer to Figure 1). The wastewater irrigation plots and effluent lagoons of Melbourne Water's Western Treatment Plant are adjacent to the study area on the western side of the river. The area is extensively developed for market gardens that produce seasonal vegetable crops for the local market. The aquifer in the Werribee Irrigation District is a shallow unconfined system within the alluvial sediments and volcanics found in the Werribee River Delta. Irrigation water supply in the region is obtained from a system of concrete lined open channels operated by Southern Rural Water and from privately owned bores that are used to extract water from the aquifer. The irrigation channel system is fed from a weir on the Werribee River and is accordingly subject to rainfall related supply constraints. Drought conditions over the past few years, especially prior to the 2004/05 season, have restricted the amount of water available for delivery through the channel network. This has led to an increased reliance on groundwater extractions to supply the irrigation water required to meet crop demand. Between 2002 and early 2004 the aquifer experienced unparalleled demand from irrigators. The resultant pumping stresses have led to excessive drawdown in the sensitive coastal and estuarine region with accompanied concerns regarding the potential for salt water intrusion.

The principal management issue facing the resource administrators is the need to understand whether recently observed declines in water levels in the aquifer are potentially harmful to the sustainability of the aquifer and what level of pumping and drawdown could be tolerated before the groundwater quality is adversely impacted. The value of the groundwater resource and the understanding that detrimental effects of salt water intrusion can persist for many years or decades, even after the heads have recovered, has provided added impetus to the groundwater investigations being undertaken.

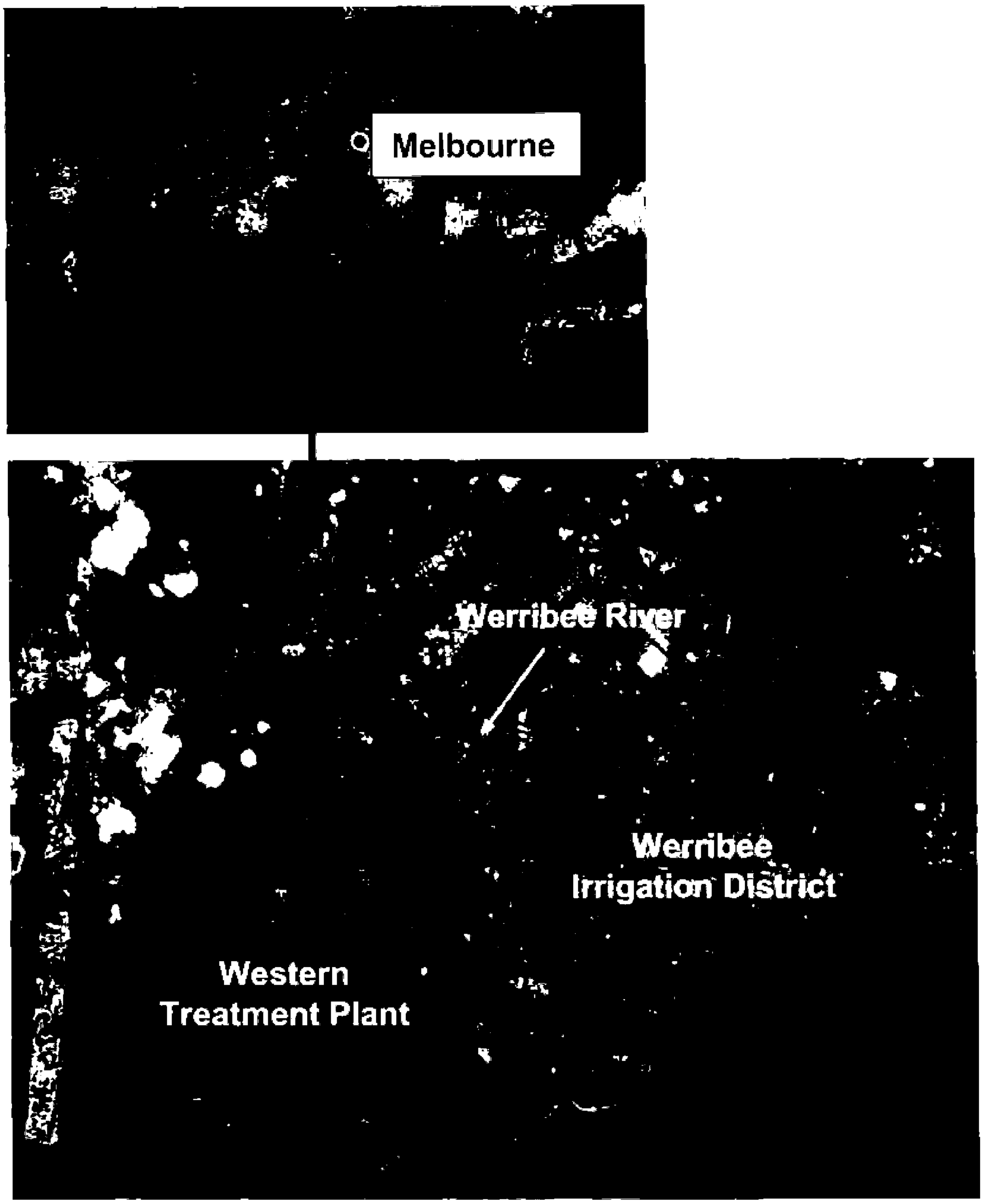

Figure 1 Location of the Werribee Irrigation District

HYDROGEOLOGY

The shallow aquifer in the Werribee River Delta is found in the Quaternary alluvial sediments and fractured basaltic lava flows that overly marine clays and silts of the Newport Formation. The aquifer is generally less than 50m in thickness. The general stratigraphy of the aquifer on a north-south section is shown in Figure 2. The most permeable horizons are believed to be the fractured basalts and the coarser sediments immediately overlying the basalts.

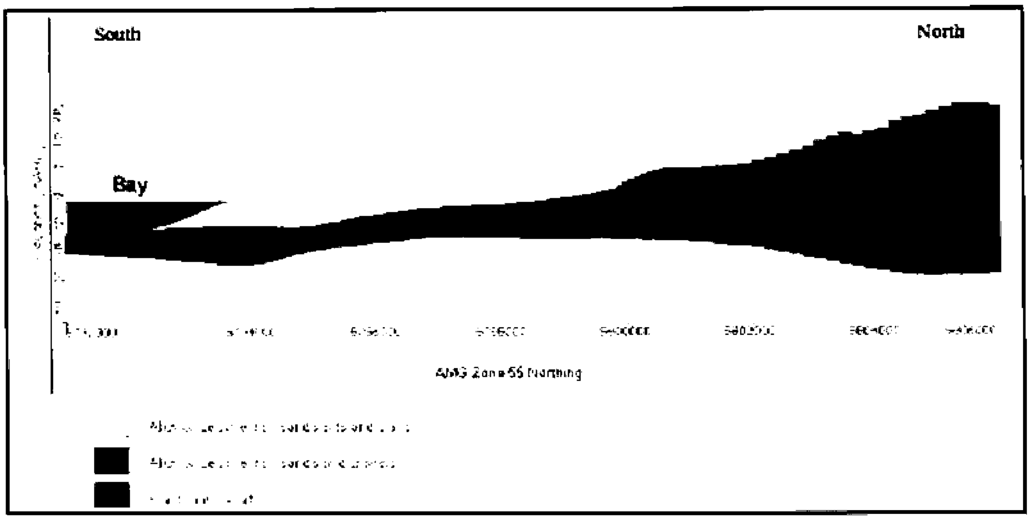

Figure 2 Stratigraphy of the Werribee Delta

In the undisturbed state (ie. pre-irrigation) groundwater flowed in a generally north to south direction and discharged to the bay and to the Werribee River. Recharge to the aquifer in the study area was limited to direct infiltration and deep percolation of rainfall and lateral groundwater flow into the area from the north.

The operation of treatment lagoons and effluent irrigation in Melbourne Water's Western Treatment Plant represents an important recharge mechanism for that part of the aquifer to the west of the river. While there is no direct evidence to suggest that water from the Western Treatment Plant crosses the plane of the river in the underlying aquifer, it is possible that this mechanism may provide additional recharge to the aquifer in the Werribee Irrigation District. Such recharge is expected to be enhanced at times when groundwater levels beneath the irrigation district are depressed due to groundwater pumping.

The introduction of irrigation and associated wide scale groundwater extraction has had a profound influence on groundwater levels through two opposing mechanisms. On the one hand groundwater extractions have led to declining groundwater levels in the aquifer. At the same time deep percolation and vertical drainage of irrigated water forms an important groundwater recharge mechanism that helps to maintain groundwater levels. Of particular interest in this regard is the widespread use of channel-delivered surface water for irrigation over much of the aquifer. Irrigation of surface water provides a means by which the aquifer can be recharged without the drawdown associated with groundwater pumping. The impact of irrigation on groundwater levels can be seen in Figure 3 showing the water levels measured in several monitoring bores from 1986 to 2005. Water levels can be seen to peak in about March every year. Since March is the driest month, it is clear that the annual cycle in water levels is responding to more than just rainfall. It is concluded that deep percolation of irrigation water is a major contributor to recharge of the aquifer.

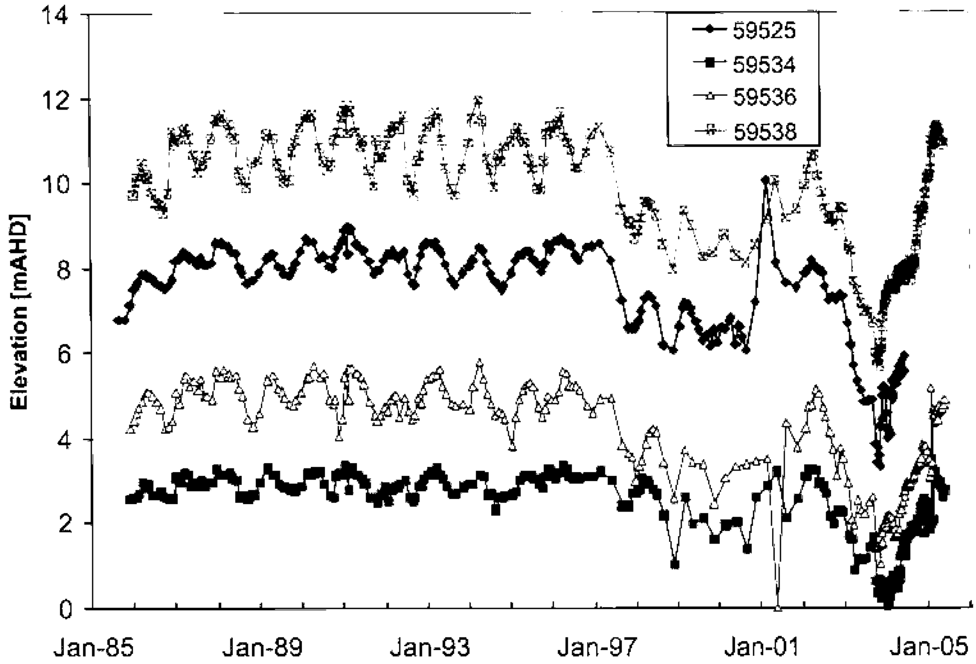

Figure 3 Groundwater levels measured in monitoring bores

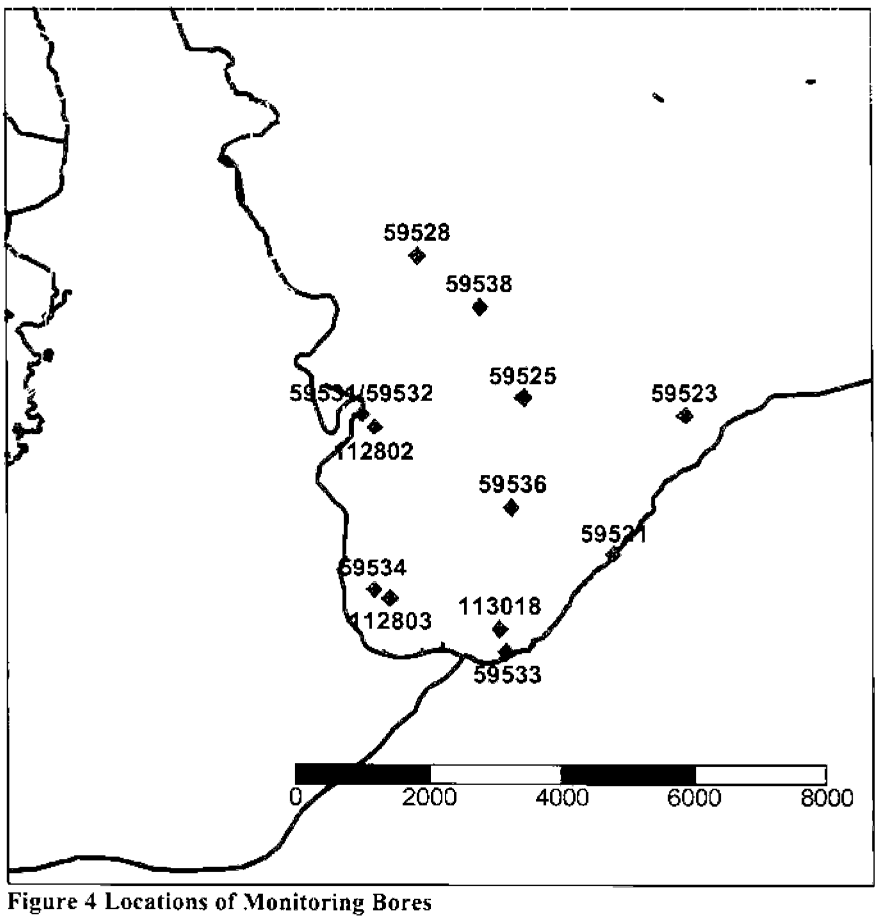

Figure 4 Locations of Monitoring Bores

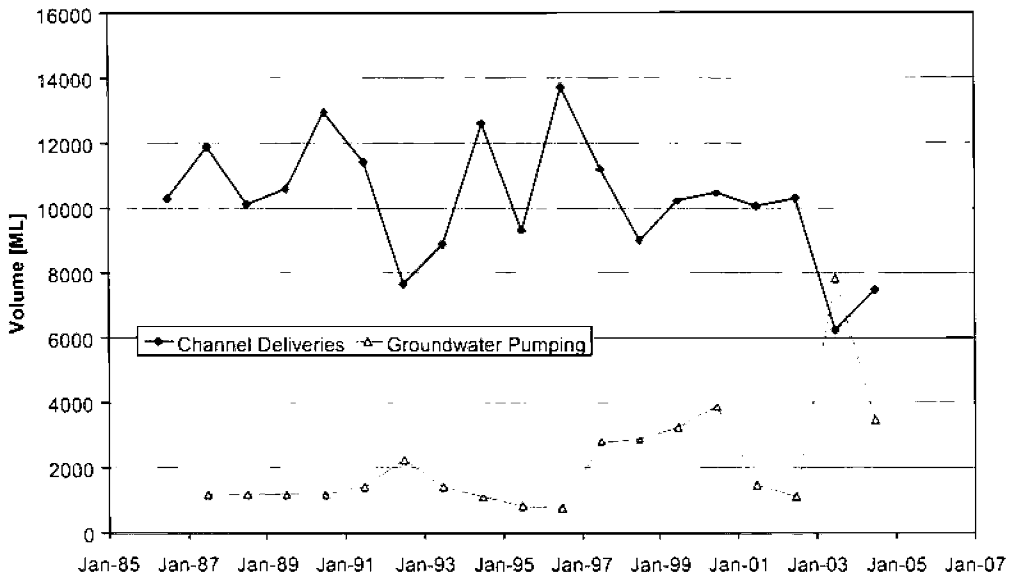

Figure 5 Estimated groundwater usage and channel deliveries

RECENT TRENDS IN GROUNDWATER EXTRACTION AND LEVELS

Records of historic groundwater usage and channel deliveries are presented in Figure 5. Groundwater usage in this period was not measured (metering of groundwater pumping was introduced in 2004) and as such values presented in Figure 5 are estimates based on assumed crop demand and the volumes of irrigation water available from other sources. Figure 5 indicates that until 2003 annual groundwater extractions were less than 4000ML. The rate of groundwater usage increased dramatically in 2003 in response to reduced volumes delivered through the channel system.

The combined impact of reduced irrigation due to a shortfall in channel deliveries and the increased groundwater pumping resulted in substantial declines in groundwater levels in 2003. This effect can be seen in groundwater hydrographs presented in Figure 3. The drawdown effects are also shown schematically in Figure 6 showing the potentiometric surface measured in April 2002 and in November 2003

Changes in groundwater flow direction caused by the drawdown observed in November 2003 are presented in Figure 6. It can be seen that at the height of groundwater drawdown there are gradients from the river to the east that represent a reversal in direction of the movement of groundwater in the undisturbed aquifer. Such gradients allow saline water to enter the aquifer from the river and also allow the flow of water from the Western Treatment Plant to cross the plane of the river and enter the aquifer beneath the irrigation district. Recent measurements of electrical conductivity in the monitoring bore network have revealed a substantial increase in electrical conductivity in bore #59531 located on the left bank of the river. Gradients towards the coast are also substantially decreased in November 2003 possibly leading to the landward migration of sea water from the bay under density driven gradients.

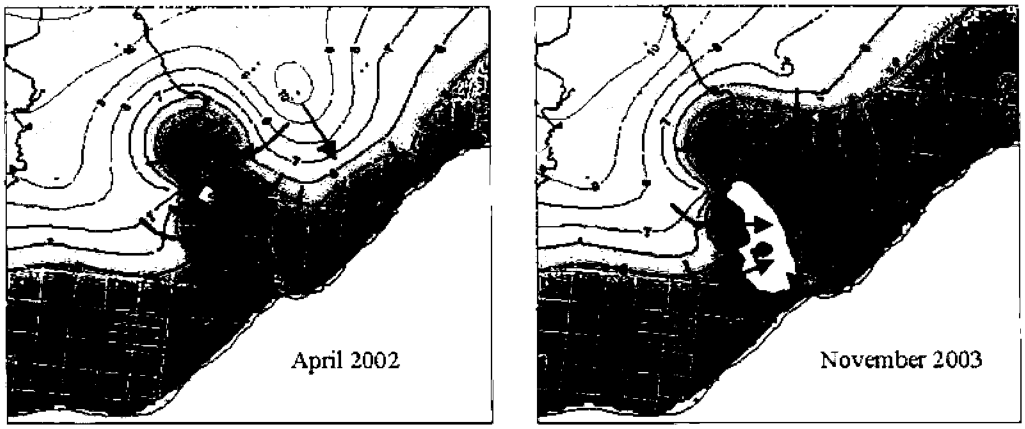

Figure 6 Changes in Potentiometric Surface Associated with Increased Groundwater Extraction

GROUNDAWATER MODELLING

A three dimensional groundwater flow model of the aquifer was developed in the MODFLOW 2000 modelling code (Harbaugh et al. 2000). The model was calibrated to observed groundwater levels in both steady state and transient modes. Transient model calibration involved the replication of groundwater heads in thirteen monitoring bores over the period 1986 to present. A typical calibration result at a nested piezometer site is presented in Figure 7.

The calibrated model includes estimates of groundwater – river interaction and Figure 8 shows the predicted flux of river water (from the tidal reach of the river) into the aquifer over the period of calibration. A substantial increase in the flux of river water into the aquifer is predicted in response to the dramatic declines in groundwater levels in 2003 and 2004. Figure 8 also shows the electrical conductivity measured in the bore #59531 over the same period. There appears to be direct correlation between the predicted recharge flux from the river and the observed increases in electrical conductivity.

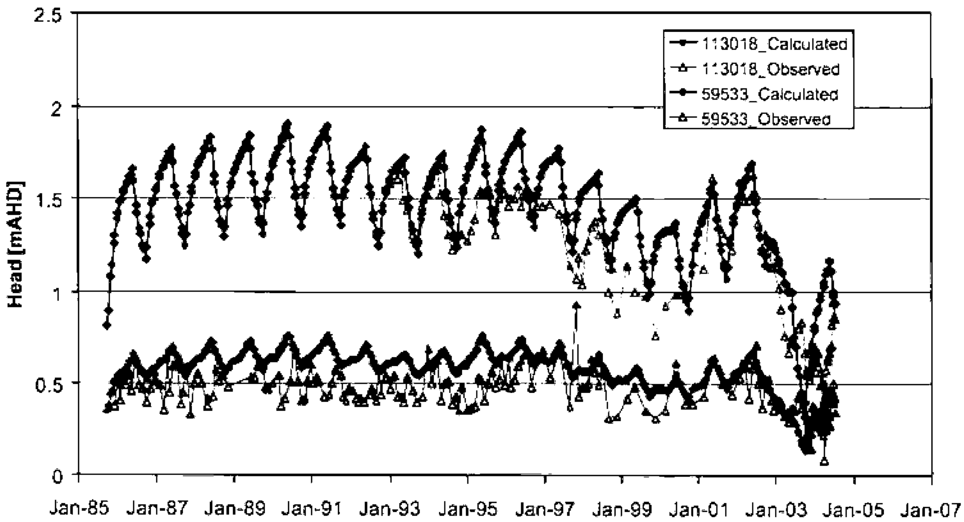

Figure 7 Calibration Result for Nested Bores #113018 and #59533

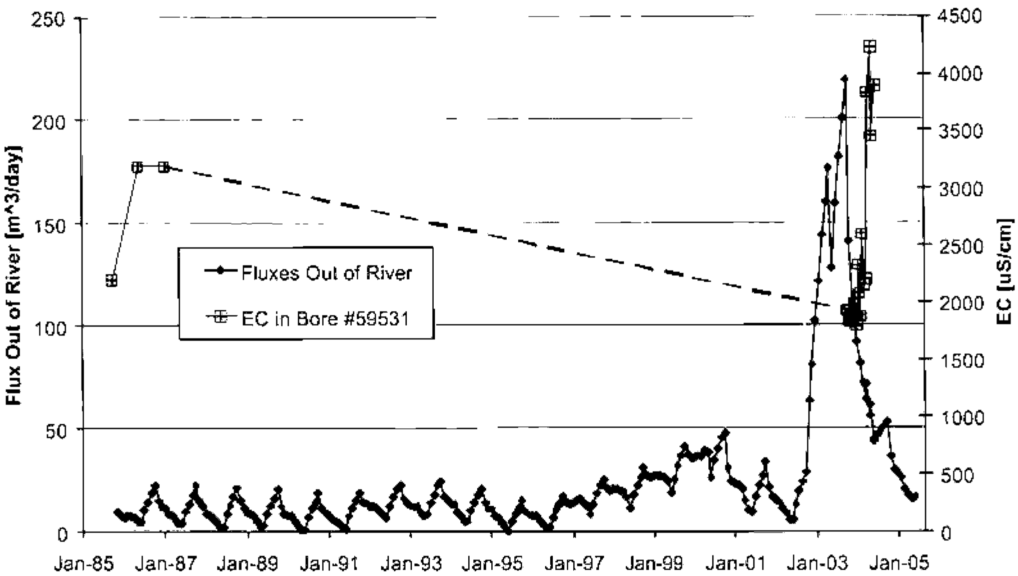

Figure 8 Predicted Fluxes of Water Out of the Werribee River and Electrical Conductivity Measured in Bore #59531

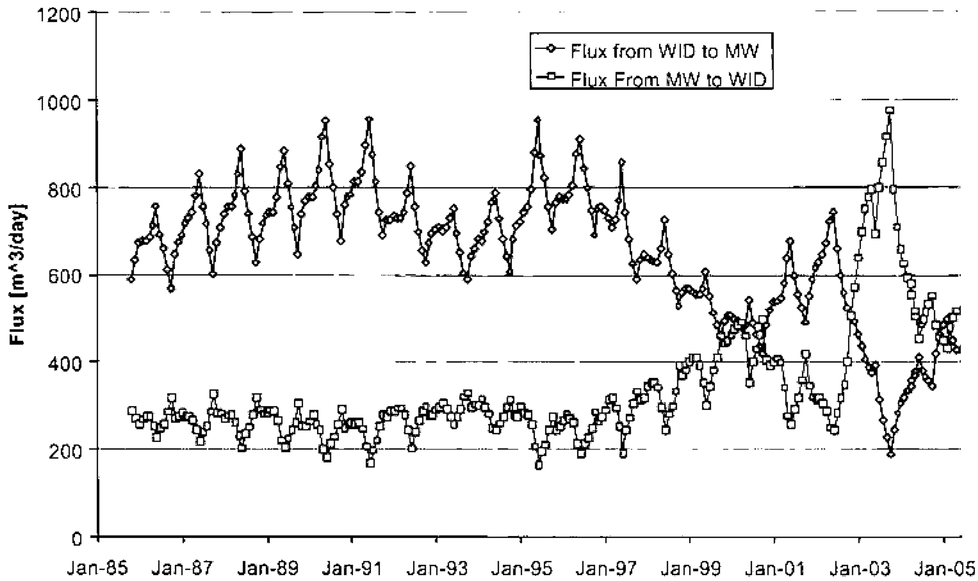

Figure 9 Predicted Fluxes of Groundwater To and From the Western Treatment Plant

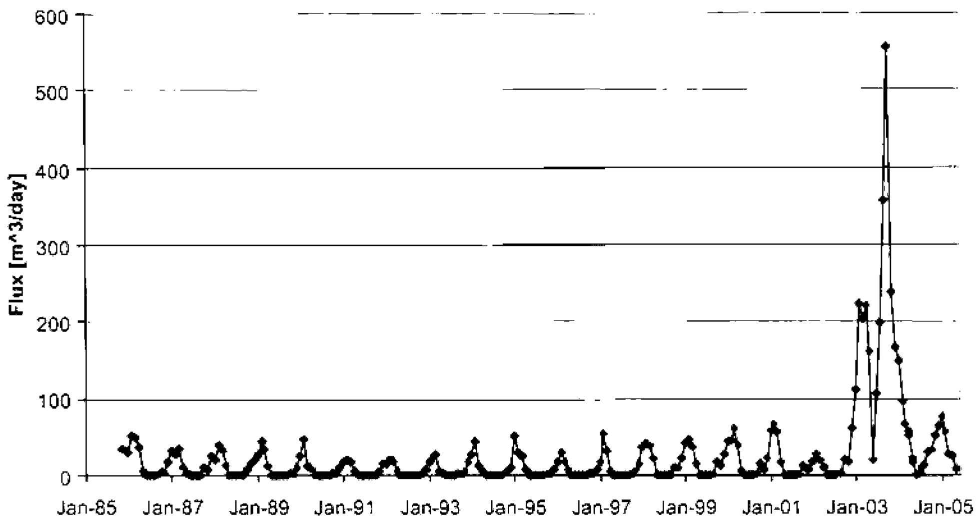

Figure 10 Predicted Flux of Groundwater From the Ocean

CONCLUSIONS

Prior to 2003 groundwater from the aquifer beneath the Werribee Delta had been used for many years without any apparent adverse impacts. An apparent balance between groundwater extractions and aquifer recharge, as enhanced by irrigation accessions, ensured that groundwater heads were maintained at a level that prevented seawater intrusion from the coast and maintained groundwater discharge to the River. This balance was disrupted in 2003 when a shortfall in surface water deliveries led to increased groundwater demand and a coincident reduction in irrigation derived recharge. The resultant declines in groundwater levels created an immediate danger of salt water intrusion from both the ocean and from induced leakage from the tidal reaches of the Werribee River. Additional threats to groundwater quality associated with induced fluxes of irrigated wastewater from the Western Treatment Plant entering the aquifer from flow beneath the Werribee River have also arisen.

Groundwater modeling has helped define the potential threats to groundwater quality by quantifying the fluxes of water into the aquifer from the river, the ocean and from flow beneath the river. The model is being used as a tool to manage groundwater allocation and is being used in predictive mode to help determine the maximum levels of extraction that can be sustained in the short and long term.

REFERENCES

Harbaugh, A.W., Banta, E.R., Hill, M.C., and McDonald, M.G. (2000) MODFLOW-2000, the U.S. Geological Survey modular ground-water model -- User guide to modularization concepts and the Ground-Water Flow Process: U.S. Geological Survey Open-File Report 00-92, 121 p.