Options for conjunctive water management to restore fall flows in the Cosumnes River basin, California

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Abstract: Decreasing fall flows in the Cosumnes River in northern California have lead to declining fish populations of endangered Chinook salmon. The role of groundwater-surface water interactions in the decline of fall flows is investigated by means of a numerical groundwater surface water model. Currently channel seepage from the river in the late summer and fall months often exceeds channel inflows and the river falls dry. Scenario simulations suggest that a 50% reduction in regional groundwater pumping would reconnect the river with the regional aquifer and reduce channel seepage losses to an extent that September and October river flows would allow fall migration and spawning of Chinook salmon. The reduction in groundwater pumping, however, would create average annual water shortages of 36% in the model area.

INTRODUCTION

The Cosumnes River in California has historically supported large fall runs of Chinook salmon (TNC, 1997). Recent declines in fish counts have been linked to decreasing fall flows in the river which are in turn linked to groundwater-surface water (GWSW) interactions (TNC, 1997). Severe GW overdraft in the lower basin has resulted in a decline of GW tables of up to 10m (30 feet) in the vicinity of the river between 1984 and 1995 (PWA, 1997). To address similar problems numerical models have been shown to be a viable tool (Chen & Soulsby, 1997). In this study preliminary scenarios are simulated with a numerical GW model to explore options for conjunctive water management that aim at increasing river flows in the fall.

PHYSIOGRAPHIC AND HYDROLOGIC SETTING

The Cosumnes River watershed (3300km2) drains the western slope of the Sierra Nevada The upper basin is characterized by Mesozoic bedrock outcrops. The Michigan Bar gauging station (MHB) marks the transition form Mesozoic bedrock to the alluvial fan topography of the Central Valley. Here the river enters its lower basin and passes the McConnel gauge (MCC) before it reaches its confluence with the Mokelumne River (Fig.1). 75% of the annual rainfall occur between November and March (PWA, 1997). In some years river flows are intermittent and the river falls completely dry below MCC.

Municipal and agricultural overdraft of the regional aquifer has created major cones of depression north and south of the Cosumnes and American rivers. Isotopic composition of GWs in Sacramento County indicates that losing rivers and streams have become the major sources of recharge to the aquifer (Criss & Davisson, 1996).

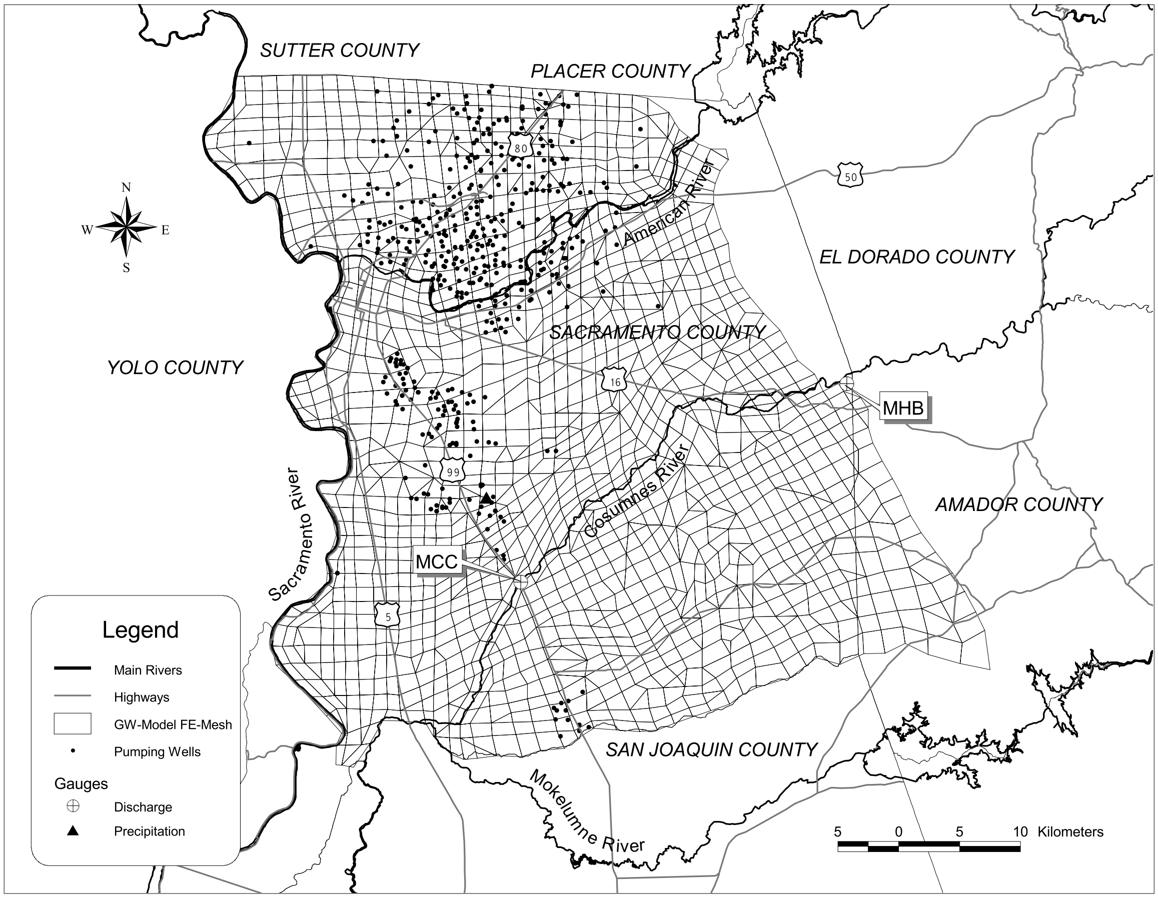

Fig. 1 *Geographic setting of the study area and extent of the groundwater model domain*

REGIONAL GROUNDWATER SIMULATIONS

The groundwater model

The integrated groundwater surface water model (IGSM), intended for simulating the major components of the hydrologic cycle, is used in this study. Evapotranspiration, surface runoff, infiltration, crop water demand and recharge through deep percolation and river seepage are internally calculated for each time step. A water budget routine includes distributed pumping based on agricultural crop water demand, SW diversions and water imports and exports and allows assessment of complex water management scenarios.

Input data and boundary conditions

Model input files and mesh geometry were provided by the Sacramento County Water Agency (SCWA). The geologic model consists of a pleistocene alluvial aquifer, a second aquifer represented by the fresh-water bearing zones of the tertiary Mehrten formation, and a third aquifer made up of the deeper tertiary alluvium which bears non-potable water. (Montgomery & Watson, 1993a). The western no-flow boundary of the model marks the geologic boundary between alluvial deposits of the lower basin and the Mesozoic bedrock of the Sierra foothills. Except for a portion of the western boundary along the Sacramento River, where heads are fixed at sea level, all other model boundaries are general head boundaries. Precipitation and river inflows are provided by the 1921-1990 hydrologic record. Land use distribution is based on 1990 conditions.

Scenario simulations

To obtain a first assessment of long-term impacts of regional GW conditions on river flows in the fall three simulations are carried out. The first simulation represents the 1990 water use in Sacramento County, which is referred to as “baseline condition”. The other two simulations represent scenarios, in which measures are taken to alleviate GW overdraft. If water demands in the model domain are not covered by fixed supplies additional distributed pumping or SW diversions can be utilized to cover the demands. The model is run with the 69-year hydrologic record of stream flow and precipitation as hydrologic boundary condition. This record covers very dry years (1977 / 40% of average precipitation (AP)) and very wet years (1983 / 210% of AP). Table 1 explains the parameters and variables used in the simulations. Scenario 1 describes conditions in which additional stress on GW resources is reduced by intensifying the use of SW. Scenario 2 represents a hypothetical “what if”-scenario where 1990 pumping rates are reduced by 50% and neither distributed pumping nor SW diversions can be used to meet additional demands. The latter scenario addresses the question of what measures would be necessary to hydraulically reconnect the Cosumnes River with the regional aquifer.

Table 1 Parameters and variables for baseline and scenario simulations.

	Parameter / variable	**Baseline**	**Scenario 1**	**Scenario 2**
general	Simulation period	*69 year period*	*69 year period*	*69 year period*
	Initial conditions	*1990 GW levels*	*1990 GW levels*	*1990 GW levels*
static	Landuse	*1990 land use*	*1990 land use*	*1990 land use*
	Pumpage	*1990 pump rates*	*1990 pump rates*	*50% of 1990 pump rates*
	SW-diversions	*1990 diversions*	*1990 diversions*	*1990 diversions*
time variant	Stream/River inflows	*1921-1990 record*	*1921-1990 record*	*1921-1990 record*
	Precipitation input	*1921-1990 record*	*1921-1990 record*	*1921-1990 record*
	Distributed pumpage	*to cover shortages*	*no*	*no*
	Additional SW-diversions	*no*	*to cover shortages*	*no*

After these scenario simulations had been carried out an independent review of IGSM [personal communication Dr. Eric M. LaBolle, 2000] revealed several limitations of the code and demonstrated through benchmark testing against a standard code that application of IGSM can be error prone. In the current application these errors will manifest most significantly in the case of (or in transition from or to) direct hydraulic contact between the stream and aquifer. Thus, most of the simulations presented here are relatively unaffected. For scenario 2, where hydraulic contact is reestablished, computed absolute aquifer heads, stream flow and stream recharge to the aquifer are error prone and should be viewed with caution. Errors will likely be most severe in time steps over which stream flows or GW heads change drastically (e.g. late spring). During the months of concern in this study stream flow and GW head changes are gradual, reducing the likelihood of large errors in computed stream flow. Due to the unique conditions under which our simulations were performed, we do not believe that the recently discovered limitations of IGSM affect the conclusions drawn from the simulation results. For further analyses an alternative model is being developed.

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RESULTS

GWSW interactions and river seepage

To evaluate GWSW interactions simulated GW heads at the river channel were compared to river channel elevations. GW heads in October, when fall fish migration would occur, are plotted relative to the river channel elevation for a dry year (1977), a wet year (1983) and an average year (1990). Fig. 2A shows the GW heads at the river channel for baseline conditions. Heads for all three years are below the channel elevation except for the lower river reaches below MCC under the wet 1983 conditions. The river is hydraulically disconnected from the regional aquifer. In scenario 1 (Fig. 2B) the restriction of additional distributed pumping results in a recovery of GW tables of up to 7m. Only for the wet year (1983) and only in the lower river reaches GW tables rise above the channel elevation. In scenario 2 (Fig. 2C) GW tables come up above the channel for all years to reestablish a hydraulic contact between the river and the aquifer.

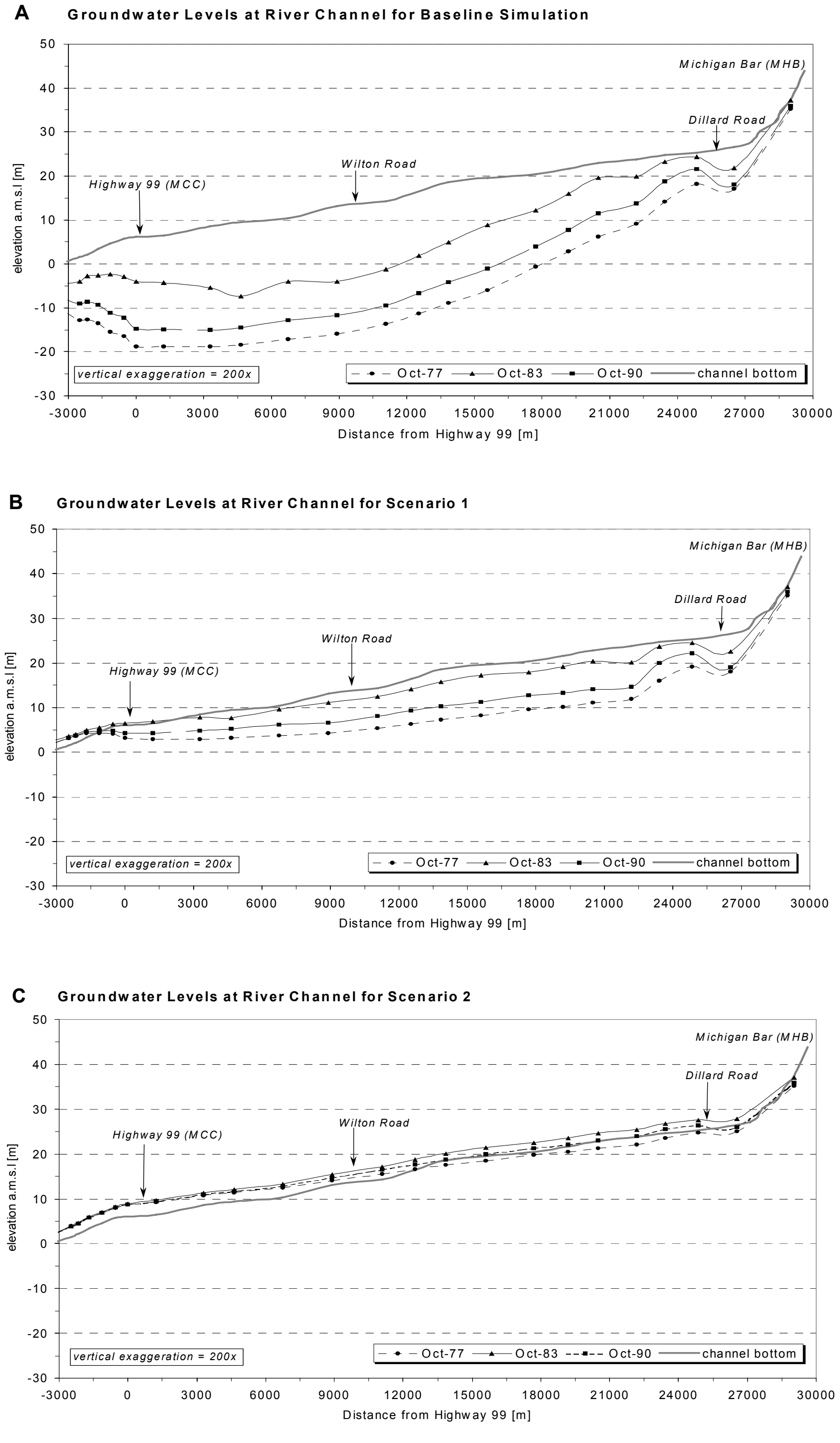

Fig. 2 *Computed groundwater heads at the Cosumnes River channel for three simulation runs [in meter a.m.s.l.]*

Average annual water flux between the river and the aquifer for all simulations, as shown in Fig. 3, indicate net seepage losses (recharge) from the river even under complete hydraulic connection between river and aquifer (scenario 2). However, reduced gradients between river and aquifer, as a result of GW table recovery, cause an average decrease in river seepage losses of 70% for scenario 2 (28% for scenario 1).

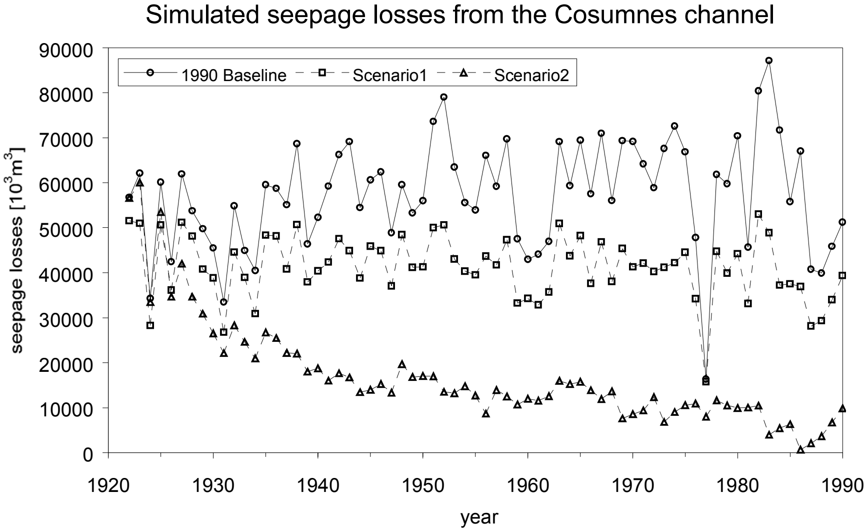

Fig. 3 *Computed annual net seepage losses in the Cosumnes River over the simulated 69-year hydrologic period (1921-90)*

River flows and water use budget

To assess the impacts of changing seepage losses on river flows in the fall simulated mean monthly flows at MCC for the 1989 and 1990 water years were compared to measured upstream inflows at MHB. Measured flows at MCC, for direct comparison, were not available, as operation of the MCC gauge ceased in 1982. Fig. 4A shows the hydrographs for baseline conditions and scenario 1. In the early fall when upstream inflows increase due to first rainfalls most river flow is lost to seepage between MHB and MCC. GW recovery in scenario 1 only marginally increases flows at MCC. For scenario 2, (Fig. 6B), seepage losses are greatly reduced resulting in river flows at MCC almost at the upstream inflow levels. Mean monthly flows are in excess of 2m3/s, which would ensure sufficient flow depth to allow fish migration.

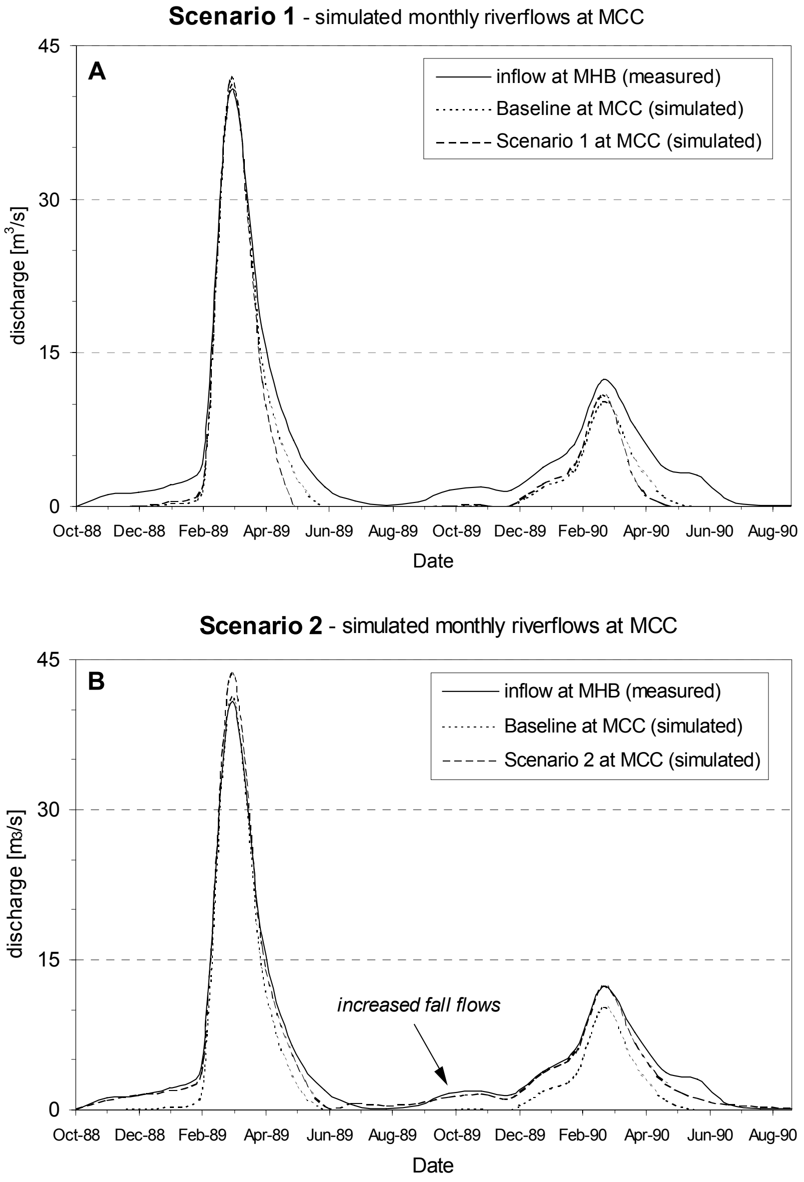

Fig. 4 *Simulated monthly river flows at MCC and measured upstream inflows (MHB) for the 1989 and 1990 water years*

Table 2 lists the different components of the water use budget for the model domain and their mean percentages (over 1920-1990) of total water demand. Under baseline conditions the entire water demand is met. In scenario 1 10% of the demand can not be covered despite an increase of 5% in SW diversions. For scenario 2, where GW pumping is further restricted, 36% of total demands can not be covered

Table 2 Water use budget for entire model area in % of total annual water demand.

Water budget component	Baseline	Scenario 1	Scenario 2
Specified groundwater pumping	56	56	28
Additional distributed pumping	8	0	0
Surface water diversions	25	30	25
Water imports	11	4	11
Water shortage	0	10	36
Total water demand = $1014.3*10^6$ m^3	Σ 100	Σ 100	Σ 100

CONCLUSIONS

The baseline simulation and data show that under 1990 water use conditions the lower Cosumnes is disconnected from the regional aquifer and looses most its water to seepage in the late summer and fall. Relying on more SW diversions instead of distributed GW pumping would slightly raise GW tables but would not reestablish a complete hydraulic connection between the river and the aquifer. The model suggests that Fall flows would increase only marginally and on average 10% of total annual water demands in the model area would not be met. Simulations for scenario 2 suggest that a 50% reduction in GW pumping with no distributed pumpage and no additional SW diversions would reconnect the river with the aquifer. Fall river flows downstream of MHB would potentially be restored to levels that would allow fish migration. Average annual water shortages under these conditions would further increase to 36%.

This study demonstrates the potential for using numerical GWSW models in water resources management. It could be shown that GWSW interactions are an important factor in the decline of fall river flows in the lower Cosumnes basin. The sharp decline of seepage losses within the first 20 years in the scenario 2 simulation (Fig. 5) suggests that for a significant reduction in pumping a substantial improvement in fall river flows could be achieved within 15-20 years. Recovery of GW levels seems to be a necessary condition to restore fall flows under the given climatic conditions (hardly any rain from May to October) unless artificial flow compensation would be considered. A 50% reduction in water demand, however, is unrealistic with the projected water demand development in Sacramento County (Montgomery & Watson, 1997). Artificial recharge (AR) during the wet season could be a tool to improve the situation and the feasibility of AR in some areas of the county has already been tested (Luhdorff & Scalmanini, 1998). An additional opportunity for GW recharge is provided by ongoing efforts to restore a “quasi”-natural flood regime in the lower Cosumnes basin where during the wet season large areas of the floodplain are inundated for longer periods of time (PWA, 1997). Scenarios that include these AR efforts and reasonable measures to reduce GW pumping need to be developed and tested to assess, if fall flows in the Cosumnes River could be restored without creating critical water shortages. The study presented here attempts to take a first step in that direction.

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