Simulation of an Aquifer-Storage-and-Recovery (ASR) System for Agricultural Water Supply using the Farm Process in MODFLOW for the Pajaro Valley, Monterey Bay, California

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ABSTRACT

The productive agricultural areas of Pajaro Valley, California have exclusively relied on ground water from coastal aquifers in central Monterey Bay. As part of the Basin Management Plan (BMP), the Pajaro Valley Water Management Agency (PVWMA) is developing additional local supplies to replace coastal pumpage, which is causing seawater intrusion. The BMP includes an aquifer storage and recovery (ASR) system, which captures and stores local winter runoff, and supplies it to growers later in the growing season in lieu of ground-water pumpage. A Coastal Distribution System (CDS) distributes water from the ASR and other supplemental sources. A detailed model of the Pajaro Valley is being used to simulate the coupled supply and demand components of irrigated agriculture from 1963 to 2006. Recent upgrades to the Farm Process in MODFLOW (MF2K-FMP) allow simulating the effects of ASR deliveries and reduced pumping for farms in subregions connected to the CDS. The BMP includes a hierarchy of monthly supply alternatives, including a recovery well field around the ASR system, a supplemental wellfield, and onsite farm supply wells. The hierarchy of delivery requirements is used by MF2K-FMP to estimate the effects of these deliveries on coastal ground-water pumpage and recovery of water levels. This integrated approach can be used to assess the effectiveness of the BMP under variable climatic conditions, and to test the impacts of more complete subscription by coastal farmers to the CDS deliveries. The model will help managers assess the effects of new BMP components to further reduce pumpage and seawater intrusion.

INTRODUCTION

Pajaro Valley is adjacent to Monterey Bay in central California (fig. 1) and is one of the most productive agricultural regions in the world. However, increases in population and transitions to crops that consume additional water have increased the demand for water within the Pajaro Valley. The valley comprises 31,080 hectares (120 mi^2), about half of which is prime farm land that relies almost exclusively on ground water (Lear, 2000). The aquifers extend offshore where they crop out along the seafloor and along the northern sides of Monterey submarine canyon. The aquifers are thus susceptible to seawater intrusion from ground-water pumpage in excess of natural recharge and deep percolation from irrigation (Hanson, 2003a,b). While a small amount of urban supply is diverted from local creeks, irrigated agriculture is solely supplied by ground-water pumpage. These aquifers have been subject to overdraft and related seawater intrusion (fig. 1) since the 1940's (Hanson, 2003a), owing to a steady increase of ground-water development. Currently, more than 74 million m^3 (60,000 acre-ft) of ground water are extracted annually (Lear, 2000). The water levels throughout most of the basin have not significantly recovered since the drought of the late 1980s. As a part of the mitigation process, PVWMA developed a BMP designed to balance water supply and demand through the acquisition of supplemental water and conservation practices. New programs for increasing conservation, improving efficiency of water use, and developing additional local sources of water also could help to reduce the current annual overdraft. The final strategy adopted by the PVWMA Board was called the "Modified BMP 2000 Alternative," and included the following five major projects and programs: 1) CDS pipelines, 2) Recycled Water Project, 3) Harkins Slough Recharge Project, 4) 1.37 meter (54-inch) Import Water Pipeline Project (11,900 acre-feet of imported supply) with local ASR, and 5) a Water Conservation Program (PVWMA, 2007) (fig. 1). As part of the BMP, a CDS was constructed to supply water recovered from the Sunset Dunes ASR. This ASR was designed to percolate, store, and recover water supplied to the ASR by a diversion of local runoff from Harkins Slough. Water from other supplemental wells and, later, from the Recycled Water Project also will be delivered through the CDS to supply the agricultural water demand. The Farm Process for MODFLOW (Schmid et al., 2006) can simulate these supply and demand components and is needed to help water managers assess the impact of the various components of the BMP on the mitigation of the ground-water system overdraft. A regional hydrologic model, PVMF2K, is being developed to provide managers with this tool (fig. 1). Delivery priorities are simulated and can be modified on a monthly basis to evaluate different scenarios of priority deliveries.

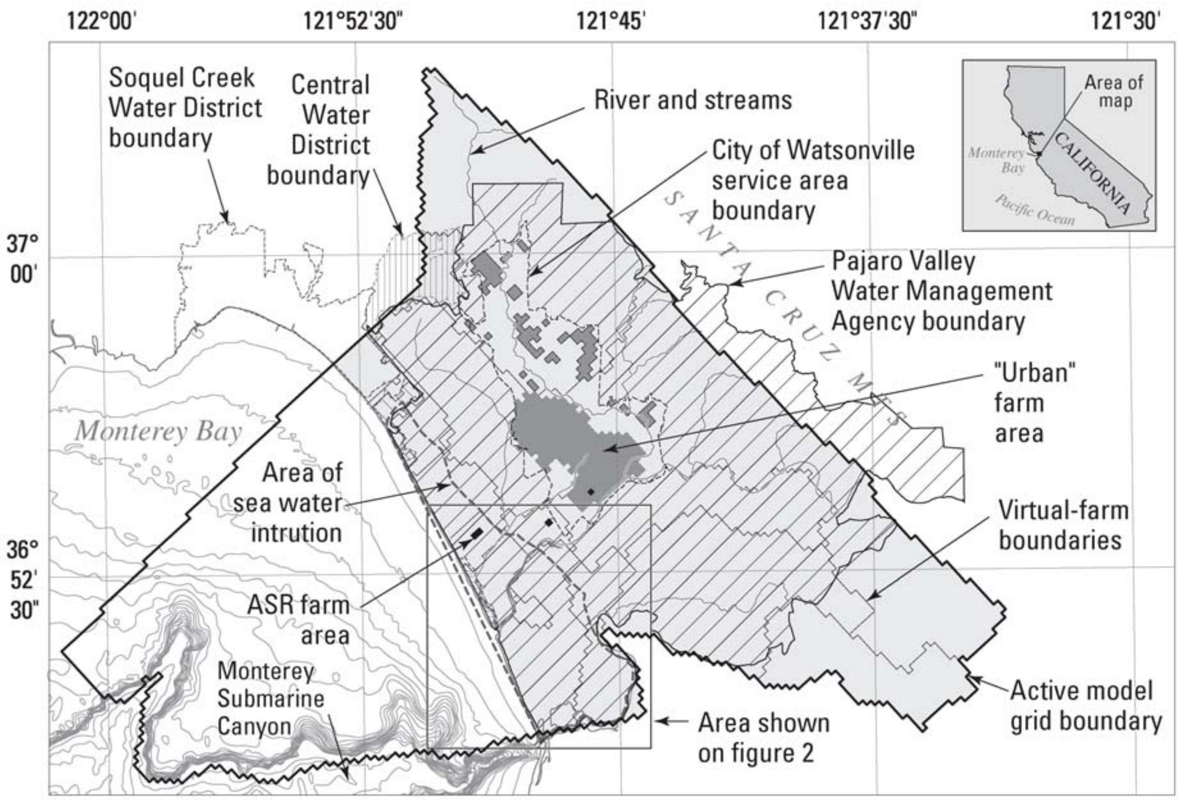

Figure 1. Map showing PVMF2K model region, water-balance subregions and water districts, and area of seawater intrusion, Pajaro Valley, California.

SIMULATION OF WATER-SUPPLY COMPONENTS AND DELIVERY

The new PVMF2K model simulates the ground-water, surface-water and landscape (evaporation, transpiration, recharge, and runoff on the land surface) use and movement of water using MODFLOW-2000 with the Farm Process (MF2K-FMP) (Harbaugh et al., 2000; Schmid et al., 2006). The model simulates 24 water-balance subregions, 20 land-use categories, and pumping from 1,032 wells. It incorporates 53 stream segments, including 16 stream inflows, 3 diversions, and 2 stream outflows to Monterey Bay (fig. 1). The PVMF2K is designed to separate the supply and demand water-budget components and dynamically simulate the existing operations, as well as the new BMP projects. (fig. 1). The model contains six layers that represent the major aquifers and confining units within the regional flow system. Model cells are comparable to the average parcel size, 62,500 m^2 (15 acres). The model uses monthly stress periods to simulate 44 years (1963-2006) of inflows and outflows from agricultural and urban development, and from natural vegetation. The model accounts for the consumption and movement of water from precipitation, runoff, and irrigation. Inflow as ground-water recharge includes deep percolation of rainfall, stream seepage, excess water from applied irrigation, ground-water underflow to and from adjacent valleys, and inflow from the ocean in the offshore portion of the model. Outflow as ground-water discharge occurs includes ground-water pumpage, evapotranspiration, ground-water underflow to adjacent areas, and intermittent baseflow in streams. Some outflow occurs to Monterey Bay when water levels are elevated above the equivalent freshwater head of the submarine outcrops. The renewable resources in the ground-water system are from the shallower aquifers (Hanson, 2003a, b), but multi-aquifer farm and municipal-supply wells also extract water from deeper aquifers. The PVMF2K model simulates multi-aquifer farm wells through a linkage between the FMP and the Multi-Node Well (MNW) package (Halford and Hanson, 2002), and simulates multi-aquifer municipal-supply wells directly with the MNW package. The ASR recovery wells, blend wells and supplemental wells also are treated as MNW wells with a specified limiting head restrict their capacity to deliver water to the CDS system.

ASR AND COASTAL SUPPLY AND DEMAND

The operation of the CDS is simulated for the last 5 years of the 44-year simulation (2002–06) (fig. 2). The CDS is initially represented by two water-balance subregions (“virtual” farms) that initially receive water in lieu of pumpage for the period 2002-06. As the CDS pipelines are extended in 2007 two additional virtual farms are added to the delivery system (fig. 2). Up to 8,712 ha/yr (2,000 ac-ft/yr) can be diverted from Harkins Slough between January and May. This water is delivered to the Sunset Dunes ASR pond where it recharges the water table and is pumped back during the growing season from May to October. The implementation of the CDS and related deliveries occurs in phases as the BMP components and pipeline facilities are constructed (fig. 2). Because some years are drier than others, water is diverted from Harkins Slough when available as local runoff. The climatically variable amount of streamflow diversion is simulated using the SFR package linked to FMP. In addition, because there is no in-line storage in the CDS, the delivery of water from the ASR operation is augmented with pumpage from supplemental wells (fig. 2). Upon completion of the Waste-Water Treatment Plant (WWTP) recycle plant, the CDS also will receive deliveries of treated waste water, which will be blended with additional ground water supplied by City of Watsonville wells (figs. 2, 3A). The crop water demand in the water-balance subregions governs the amount of delivery required from the local supply sources (fig. 3A, B). The user-specified order of simulated deliveries used with MF2K-FMP is aligned with the priorities set by PVWMA: The priorities, from highest to lowest, are ASR, recycled water (once available), remote supplemental wells, blend wells, and, finally, local coastal wells (fig. 3B). The Harkins Slough diversion supplied 4.3 million m^3 (3,470 ac-ft) of water to the ASR operation between 2002 and 2006 (fig. 4). The CDS delivered 2.6 million m^3 (2,100 ac-ft), which represents about 61 percent of the total water diverted and delivered to the ASR. Deliveries of recovered ASR recharge represent about 21 percent of the water recharged at the ASR and 35 percent of the total water delivered by the CDS. Thus, some local recharge is occurring from water not directly recaptured by the ASR operation.

CONCLUSIONS

The use of MF2K-FMP allows the simulation, analysis, and assessment of deliveries from an ASR and supplemental sources with the PVMF2K model. The MF2K-FMP dynamic simulation of water supply and demand components in the Pajaro Valley determines the hierarchy of simulated delivery priorities. These deliveries are simulated replacement for coastal pumpage that also are controlled indirectly by the supply from the Harkins Slough diversions from the previous recharge period and the capacity of the restricted ASR recovery wells (fig. 2, 3), which are simulated with head-limited capacity for deliveries from the ASR-recovery, blend and supplemental wells These deliveries partly offset the coastal pumpage that has exacerbated the overdraft and related seawater intrusion in Pajaro Valley, California. This hierarchy of delivery requirements is used by MF2K-FMP to estimate the effects of these deliveries on coastal ground-water pumpage and recovery of water levels at the coast in the PVMF2K model. The simulated priorities can be changed on a monthly basis, which enables evaluation of different delivery scenarios. This integrated approach allows for the assessment of the project under different climatic conditions, including wet periods and droughts, and for the testing of the effects of more complete subscription by coastal farmers to the CDS deliveries. The model will help managers assess the effects of new BMP components to further reduce pumpage and seawater intrusion.

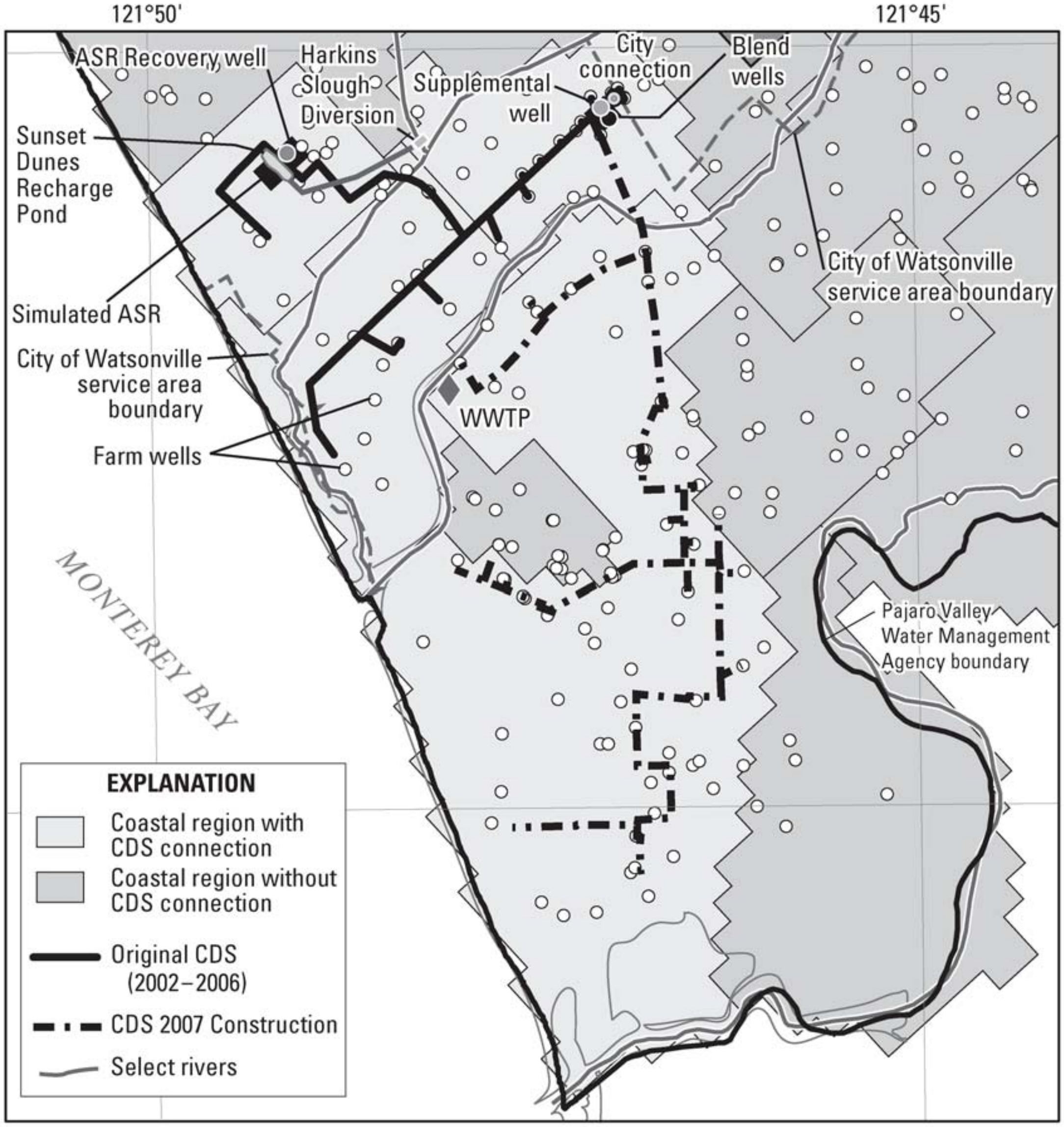

Figure 2. Map showing CDS portion of PVMF2K onshore model region, selected water-balance subregions, selected wells, Aquifer-Storage-and-Recovery System (ASR), and Coastal Distribution System (CDS), Pajaro Valley, California.

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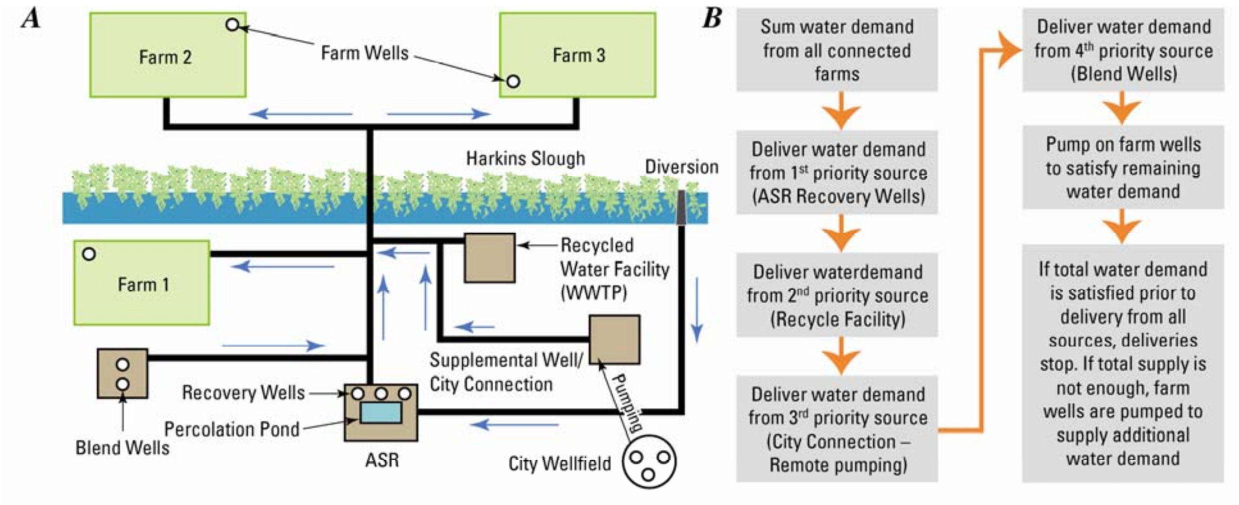

Figure 3. Diagrams showing (A) the structure of local deliveries and (B) the order of operation of the simulation scheme for ASR and CDS deliveries to the regions serviced by the CDS, Pajaro Valley, California.

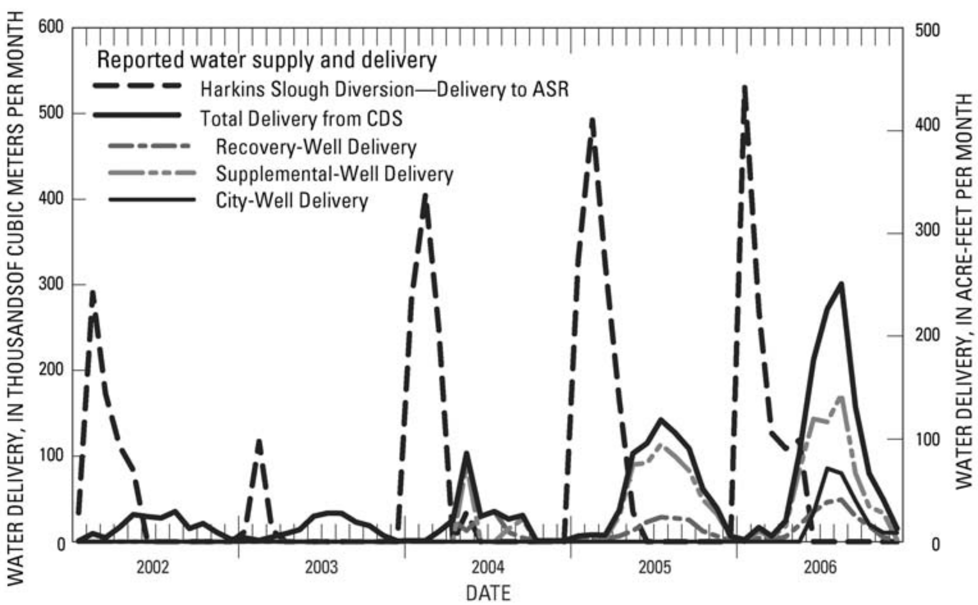

Figure 4. Graph showing ASR recharge and components of the CDS deliveries, Pajaro Valley, California.