4.11. Groundwater resources modeling of the Lenjanat aquifer system

A. Gieske and M. Miranzadeh

The Esfahan hydrological province in central Iran is essentially a closed catchment with one perennial river, the Zayandeh Rud. The region has traditionally been supported by irrigated agriculture, predominantly with river water, but also with groundwater tapped by kanats and hand-dug wells. More recently, population growth and industrial development have increased the demand for water, and at present, both the quantity and quality of fresh-water resources are under threat. Groundwater plays an important role as an additional source of water in three different ways: domestic supply to Esfahan, for conjunctive use in major irrigation systems, and in providing drinking water to small villages and small-scale irrigation schemes in more remote areas. The groundwater has been monitored with respect to water level and quality in the Esfahan Province since the early 1980s.

There is a highly complementary relationship between the use of surface water and groundwater. In times of drought, surface water is less easily available and as a result the abstraction of groundwater is intensified leading to decline in groundwater levels (Droogers and Miranzadeh 2001) and loss of groundwater quality. When the Chadegan Dam fills up after good rains or snowfall, surface water is used predominantly again and groundwater levels may slowly recover as a result of natural recharge by precipitation—by infiltration from the Zayandeh Rud or by excess irrigation water leaching to the groundwater table. This study looks at groundwater flow patterns and trends in Lenjanat District, which lies upstream of the major irrigation districts. This area has been a major source of groundwater recharge to the Zayandeh Rud in the past but it is not so clear what the situation is at present.

4.11.1. Sources of information

The modeling of groundwater resources and trends in the area has been made possible by using several different sources of data. The groundwater level database, kindly made available by Mr. A.A. Saberi (Ministry of Energy, Esfahan Office), consists of more than 60,000 well-level observations for over 700 observation wells in the entire Zayandeh Rud Basin, covering the period from 1987 to 2000. A distinction is made between shallow and deep wells. The groundwater levels of 1997 (1,376) were used for the steady state modeling.

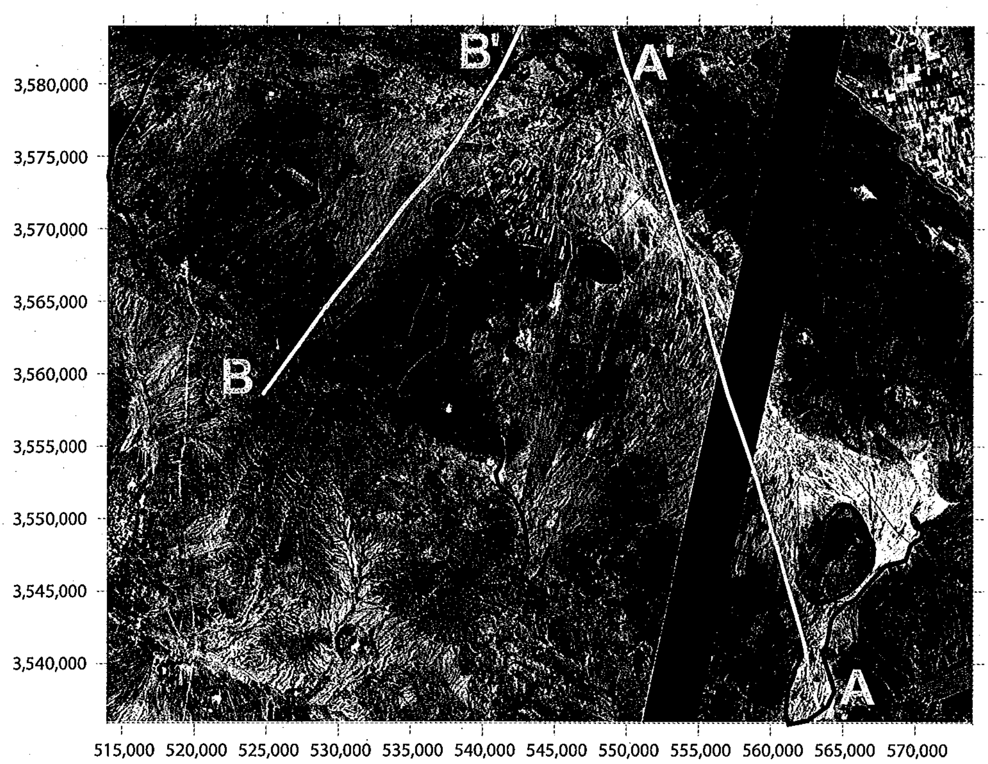
Abstraction data were also provided for wells, kanats and springs. Many springs lie on the boundary between mountains and plains but some lie close to the Zayandeh Rud indicating that groundwater does flow towards the river, or has flowed towards the river in the recent past. The kanats are more evenly distributed over plains and mountains. Most of the inflow from the mountainous area into the plains occurs through subsurface flow. Total abstraction information is summarized in table 4.13 and based on this information, the steady state model uses 200 MCM yr^{-1} of abstractions as an initial value.

Table 4.13. Estimated water abstractions from the Lenjanat aquifer.

	Ministry of Energy Lenjanat & Ben Saman 1997-1998	Lenjanat District 1988	Lenjanat Plains Aquifer 1988
Wells (deep & shallow)	150	187	158
Kanats	156	135	75
Springs	41	32	7

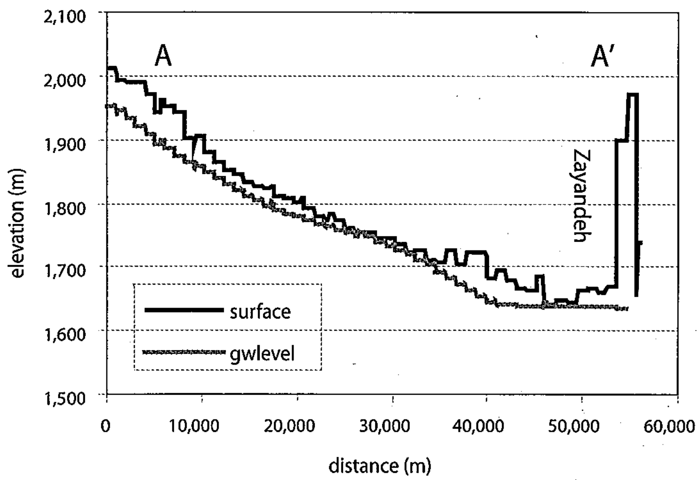
With annual precipitation only 200 mm yr^{-1}, the direct recharge from rainfall is probably less than 6 mm yr^{-1} and can be ignored. Aquifer transmissivity and storativity values were derived from pumping tests from three representative wells, and the data was analyzed with the AQUITEST software package. Large variations in storage coefficients point to varying confined-unconfined conditions, such as is frequently the case when an alternating and laterally heterogeneous sequence of fine and coarse deposits is found.

Figure 4.41. Composite of two ASTER images of Lenjenat aquifer.



Composite of two ASTER for 2001 in false colour. The aquifer boundary is depicted by the thick red line, irrigated areas by red patches. The black area in the center is the Mobarake Steel Mill. Alluvial fans cross the area, running north-north-easterly towards the Zayandeh Rud River, which form the northern boundary of the aquifer.

Figure 4.42. Cross-section of the aquifer from the South to North.



Cross-sections (figure 4.42.) indicate that the groundwater levels generally follow the topography, and near the river they reach the Zayandeh Rud's water level. When abstractions are not too high, groundwater will seep into the river.

The thickness of the saturated zone and the depth to the aquifer's bottom is difficult to ascertain. The aquifer's thickness is probably highly variable in view of the small rocky hills that are visible on the surface. One should visualize the aquifer as a weathered sedimentary rock of low permeability with an irregular surface, overlain by successions of coarse erosional deposits and fine sand-clay layers.

4.11.2. Model results

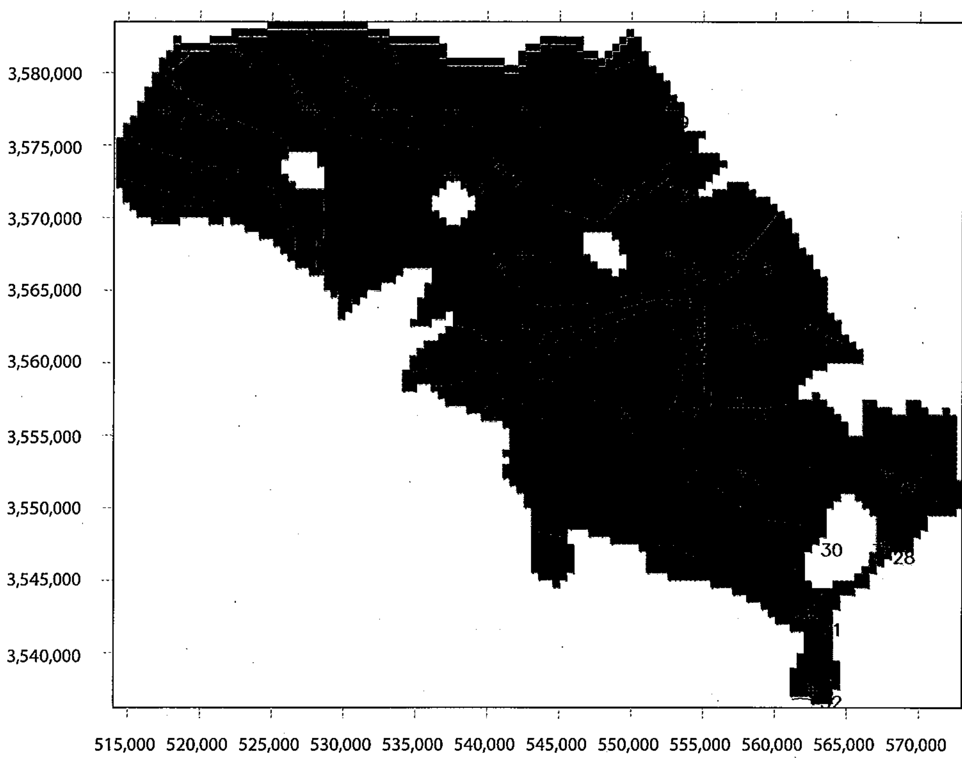
The outcome of the modeling process is a steady state volumetric budget, which is given below as table 4.14. The total seepage into the river is 76 MCM yr^{-1}, the total abstraction from the wells, kanats and springs amounts to 192 MCM yr^{-1}, while the total recharge is about 267 MCM yr^{-1}. The model shows that under these conditions the groundwater flow components are in balance. If the total outflow is larger than 267 MCM yr^{-1} then groundwater levels will drop.

The groundwater will flow perpendicular to the contour lines shown in figure 4.43, mostly in a northeasterly direction. The flow from the bottom-right corner of the figure is expected to flow straight north. However, the exception to this is the outflow from the large alluvial fan (see figure 4.41). The flow here appears to the east, which probably may be explained by a zone of low transmissivity on the north side of the fan.

Table 4.14. Volumetric budget for the steady state model.

	m^3d^{-1}	MCM yr^{-1}
Seepage into the river	207,003	76
Wells, kanats, springs	524,754	192
	TOTAL	267
Lateral and diffuse recharge	731,757	267

Figure 4.43. Groundwater level contour map from the PMWIN and MODFLOW modeling.

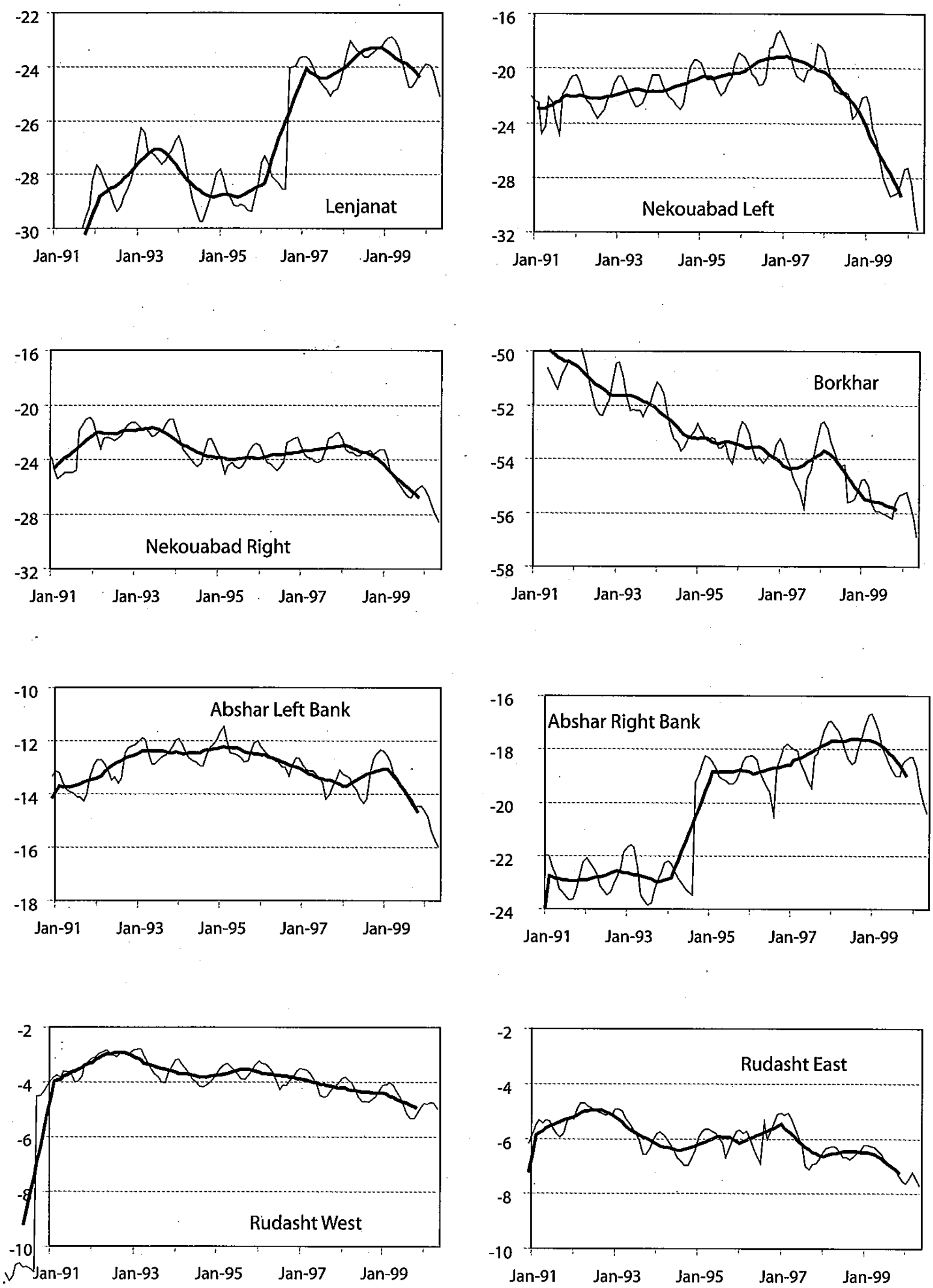


4.11.3. Temporal aspects

Two ways of the estimation of trends in groundwater conditions over time are looking at discharges of un-pumped water sources (kanats and springs), and the measurement of water levels of wells.

Records of representative kanat and spring discharges are available from 1,367-1,379 (1988-2000). On average, the discharge from kanats and springs is reduced by about 2 percent annually over the period 1988-2000, although there are a few locations where discharges have actually increased during the same time period. The importance of long-term data sets is clear, because there is high year-to-year variability due to aquifer recharge and irrigation return flows.

Figure 4.44. Estimated annual decline in meters of water levels in representative wells.



Well-water level fluctuations show a similar pattern, with most areas showing a substantial decline over the 12 years. As a first approximation of changes in water levels, linear regression coefficients were determined for each of the representative wells or a period of 6-10 years of records. These regression coefficients are used as an estimation of annual water level declines, and the results are shown in figure 4.44.

There is a substantial drawdown of groundwater in the northwest portion of the aquifer, towards the Zayandeh Rud River, and in the southeast corner. Both of these areas appear to be using a lot of groundwater for irrigation, as indicated by the density of irrigated areas shown on the ASTER images. The central portion shows modest increases in groundwater levels, indicating sub-surface recharge is sufficient to meet demand in that area. However, the overall trend for the basin is negative with average water levels dropping by some 0.2 m yr^{-1}.

4.11.4. Conclusions and discussion

A steady-state model was developed using PMWIN as pre- and postprocessor for MODFLOW. The 1-layer model used 500x500m cell size, with 4,996 active cells with a total area of 1,249 km^2. The steady state water budget shows that with a total recharge of 267 MCM yr^{-1}, a total abstraction (wells, kanats, springs) of 192 MCM yr^{-1} and seepage into the Zayandeh Rud of 76 MCM yr^{-1} overall, these components are in equilibrium. However, much depends on the aquifer's hydraulic transmissivity and conductivity values. If these decrease, then so does the total recharge and with that, all components are changed.

If abstraction increases beyond 192 MCM yr^{-1} then, according to the model, a new steady-state will be reached with lower ground-water levels. This in turn increases the hydraulic gradients. If there are increasing abstractions, ground-water levels near the Zayandeh Rud will be drawn lower than the river level, leading to losses from the river to the aquifer. This will likely have a considerable impact on the hydrology of the river itself, reducing flows to downstream areas.

The aquifer is not in a steady state at present, which is shown by the decreasing groundwater levels and the diminishing discharge from the kanats and springs. Therefore, over-abstraction is clearly taking place. The northwest and northeast corners of the aquifer are clearly areas in need of detailed attention, because well levels here are going down at a rate of 0.5 m yr^{-1}, whereas the yield of springs and kanats is only 50 percent of what they were 10 years ago.