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SUSTAINABLE DEVELOPMENT OF GEOTHERMAL FIELDS IN THE PANNONIAN BASIN - A CASE STUDY

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ABSTRACT

As suggested by the discusssion of Barker, 1988, on the influence of flow dimension on the late-time behaviour of the generalized line source solution, it was inferred that observed long term reservoir pressure decline was an outcome of the 1D (linear) flow geometry, indicated by well tests. The detrimental effects of the reservoir pressure decline can be partly mitigated by taking advantage of the two-phase flow which occurs when methane, originally dissolved in the geothermal brine, is released within the well bore. Sustainable artesiar withdrawal scenarios for existing geothermal fields are devised, based on an accurate prediction of bottomhole pressure decline trends and an adequate selection of the diameter and length of the production tubing. Overall analysis and forecast are performed by an integrated reservoir & well bore simulator.

INTRODUCTION

Aquifers located in Pliocene detritic deposits of the Pannonian Basin (fig. 1) provide a significant part of the geothermal resources of Hungary, Slovakia, Slovenia, Croatia, Serbia and Romania (Arpasi, 1995, Franko et al., 1989, Rajver et al., 1995, Cubric and Jelic, 1995, Panu, 1995). Multi-layered reservoirs, occuring at 900-2500 m depth, include slightly consolidated sandstones interbedded with shales, saturated with low temperature (50-100°C) geothermal fluids.

As a result of long term withdrawal, the well fields display a steady reservoir pressure decline trend and associated reductions of the extracted flowrates (Franko et al., 1989, Plavita and Cohut, 1990, Arpasi, 1995, Cubric and Jelic, 1995, Szita, 1995). Attempts to control pressure decline by reinjection have been performed in Hungary and Romania. However, Hungarian experiments are reported to be non-conclusive (Szita, 1995), while tests carried out in Romania definitely proved unsuccessful, due to the extremely high wellhead pressures required (50-90 bar).

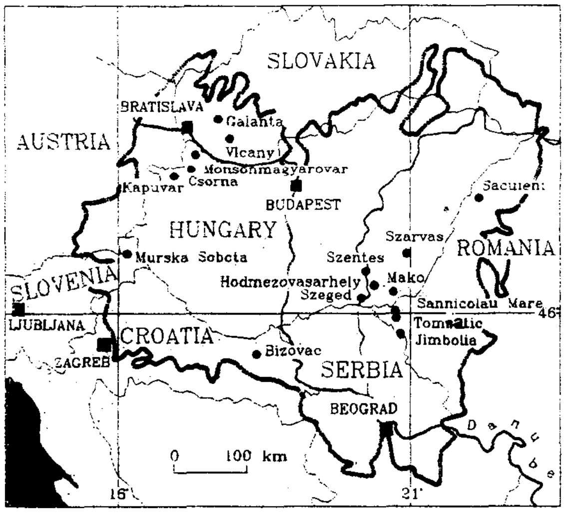

Fig. 1. Panonian Basin. Main geothermal fields tapping Pliocene reservoirs.

RESERVOIR CHARACTERIZATION ACCORDING TO WELL TESTS

Based on single- and multi-well tests and assuming a conventional radial flow model, described by the Theis-Jacob line source solution, reservoirs parameters such as transmissivity (kh) and storativity (ϕh) have been computed for geothermal wells which tap the Pliocene deposits of the Pannonian Basin (Franko et al., 1989, Plavita and Cohut, 1990, 1992). The computed parameters have been used to provide forecasts on the subsequent reservoir pressure drop, either for a specific well field (Plavita and Cohut, 1992), or for a whole region of the Pannonian Basin (Franko et al., 1989). However, no attempt was made to fit a simulated pressure evolution to long term data recorded during exploitation.

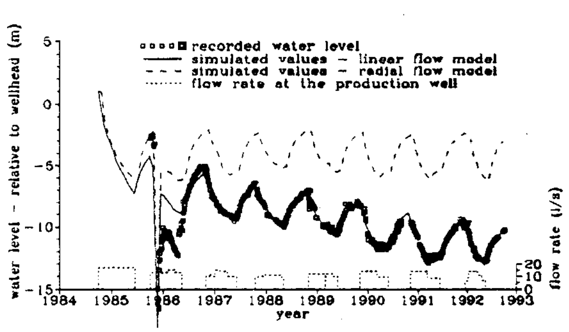

Fig. 2. 1567 Tomnatic observation well. Draw-down history.

When such a comparison is performed (fig. 2), it becomes obvious that although over short periods (a few months) modeled and observation data match, there is no more agreement when the long term (several years) reservoir pressure evolution is considered. According to the model, the maximum draw-down should stabilize after the first production-recovery cycle of one year, while the actual reservoir pressure continues to decline during the whole subsequent period.

The pressure stabilization predicted by the model is characteristic for the assumed 2D flow geometry, as the generalization at arbitrary flow dimensions of the line source solution for a horizontal, infinite reservoir indicates (Barker, 1988): a quasi-steady state can be reached only for flow dimensions equal to 2 (i.e. the commonly assumed radial cylindrical flow described by the Theis-Jacob solution), or more. On the contrary, the draw-down in a well is strongly time-dependent at flow dimensions smaller than 2.

Sediment assemblages in the Pannonian Basin have been shown to derive from the progradation of delta systems into an isolated lacustrine basin (Vakarcs et al., 1994). The sandstones are channel fills and bars, while the siltstones and shales represent lower energy environments, such as interchannel and levee deposits. Under such circumstances, a 1D (linear) flow geometry might prove appropriate in describing the hydrodynamic behaviour of the reservoirs.

Following Barker, 1988, the specific draw-down of a well of effective radius r, which taps a horizontal, homogenous aquifer that extends mainly along one dimension and displays constant throughflow area Ω, permeability k, porosity ϕ and composite (fluid and formation) compressibilty c, is:

$$\Delta p / q = \frac{1}{\sqrt{\frac{k\Omega^2}{\mu}\phi c}} \left(\sqrt{t} - \frac{r}{\sqrt{\frac{4k}{\pi\mu\phi c}}} \right)$$

where, Δp is the differential pressure, q is the discharge and μ is the dynamic viscosity of the fluid in the aquifer. Since the relationship is an asymptotic approximation of the exact solution, for interference tests it can only be used to model late time responses. As for single well tests, it applies to the entire time span over which records are normally performed.

The validity of the 1D model was first tested by plotting the bottomhole pressure recorded during single well build-up or draw-down tests against the square root of time. Figure 3 illustrates the results obtained in the geothermal well field of Jimbolia, Romania. The distinct, increasingly gentler slopes displayed by the diagrams suggest that hydraulic properties (permeability, storage capacity, throughflow area) improve away from the tested well. As a general rule, only poor productivity aquifer bodies have been intercepted by wells drilled so far, hence the pattern of the diagram probably reflects also an hierarchy in distribution: there are frequent linear aquifer bodies of low productivity, yet connected to fewer ones of moderate productivity, that at their turn are connected to even fewer high productivity reservoir sections, a.s.o.

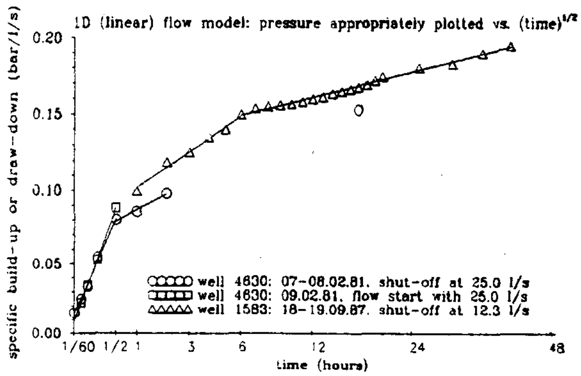

Fig. 3. Jimbolia geothermal field.
Single well bottomhole pressure transients

A rather similar pattern was obtained when plotting against the square root of time the results of a test performed on well FGV-1 Vlcany (Slovakia), published by Franko et al., 1989 (fig. 4).

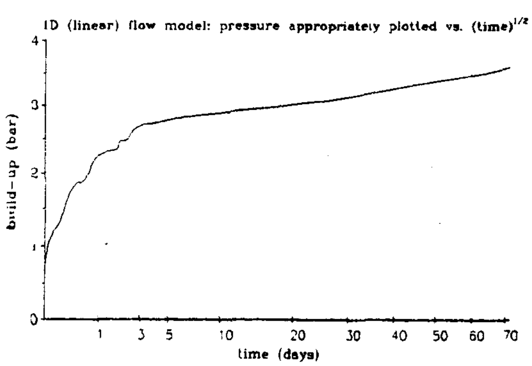

Fig. 4. FGV-1 Vlcany geothermal well
Single well bottomhole pressure transients

The correlation between pressure decline, flow rate and time, derived for the ultimate, late time period of the well tests, was subsequently used to simulate the evolution of pressure in the reservoir over the 10-15 years since exploitation started. Figure 2 illustrates the draw-down history matching conducted for an observation well in the geothermal well field of Tomnatic, Romania. It clearly indicates that the assumed 1D reservoir model is more appropriate than the alternative, 2D model.

OVERALL PRODUCTIVITY ASSESSMENT, INCLUDING WELL BORE EFFECTS

Methane, originally dissolved in the geothermal water of the Pliocene reservoirs (1-2 m^3/m^3 gas/water ratio), is released in the upper section of the well bores (Franko et al., 1989, Plavita and Cohut, 1990, 1992, Cubric and Jelic, 1995, Panu, 1995, Szita, 1995). The resulting two-phase flow regime controls the correlation between the bottomhole pressure evolution and that of the wellhead pressure.

A well bore simulator, based on Orkiszewski, 1967, algorithm, is used in connection with a reservoir simulator, within the integrated software package GEOTHERM, developed by DATA EXPERT. The fundamental scheme of GEOTHERM can be described as follows:

RESERVOIR BEHAVIOUR

TEMPERATURE	PRESSURE
Variable temperature input at the inflow depth is considered, in the form of an inflow temperature versus total extracted fow rate correlation.	Distinct procedures are available for two basic assumptions: ♦ time-independent reservoir pressure (the procedure devised for this case also assumes that the effects of interference of other wells in the field can be neglected); ♦ reservoir pressure decline during exploitation, by assuming 1, 2 or 3D radial flow geometry;

WELL BORE BEHAVIOUR

COOLING	PRESSURE DROP
A power law relates the cooling of the geothermal fluid along the well bore (linear temperature drop assumed) to total extracted flow rate.	Pressure drop within the actual casing and tubing configuration of the well can be simulated for liquid only and two-phase (either bubble, or slug flow) conditions.

The predictions provided by these basic functions are integrated into assessments of the wellhead thermal and discharge performance.

DEVELOPMENT OF A SUSTAINABLE EXPLOITATION SCENARIO

An example of sustainable exploitation scenario devised by using GEOTHERM is given for well 1524, in the geothermal field of Sannicolau Mare, Romania. The considered well does not interfere with other wells in the field, as it taps a distinct reservoir.

First the well bore flow regime parameters (roughness and free methane content) are calibrated, by checking simulated pressure profiles against recorded downhole pressure profiles (fig 5). In the given example, a first guess of "zero gas/water ratio" proves to be unsatisfactory: in the upper section of the well bore, where presumably free gas is released from the solution, the deviation between the simulated and the recorded pressures is severe. Yet when an appropriate gas/water ratio of 1.55 m^3/m^3 is chosen, the deviation becomes close to zero all along the well bore. A significant deviation still persists only at the wellhead, as a result of carbonate scaling which sometimes may clog the upper few tens of meters of the existing production tubing.

Further, the relationship which describes the reservoir behaviour (pressure versus flow rate and time) is calibrated against the history of shut-off piezometric levels and against shut-off and flowing well bottomhole pressures (fig. 6).

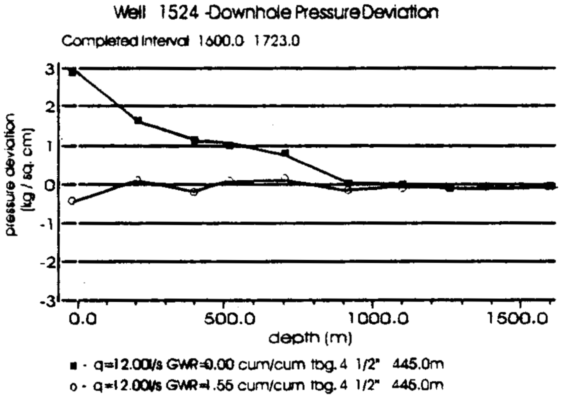

Fig. 5. Recorded minus simulated downhole pressure profiles

Finally, the simulated bottomhole pressure is used in connection with simulated "up the well bore" pressure drops, in order to reconstruct the wellhead pressure evolution, which is checked against actually recorded wellhead pressures (fig. 6). When an overall satisfactory match between the recorded and the modeled pressure values has been achieved, the simulation is extrapolated in the future, according to a hypothetical withdrawal scenario (fig. 7).

The configuration of an artesian well bore discharging two-phase (gas-water) fluid normally includes a production tubing, introduced inside the casing. Its main purpose is to force the two-phase flow through an area smaller than that of the casing, which, according to specific conditions, may result in a significantly smaller pressure drop and in correspondingly enhanced artesian flowrates, or prolonged artesian lifetime. The tubing can be also extracted periodically, to be cleaned of scaling products.

As a result of complex behaviour due to two-phase flow, optimum tubing selection is a trial and error process, conducted by observing the criterion "the highest wellhead pressure for the required flow rate".

As figure 7 indicates, for the same exploitation scenario, alternative tubing configurations result in

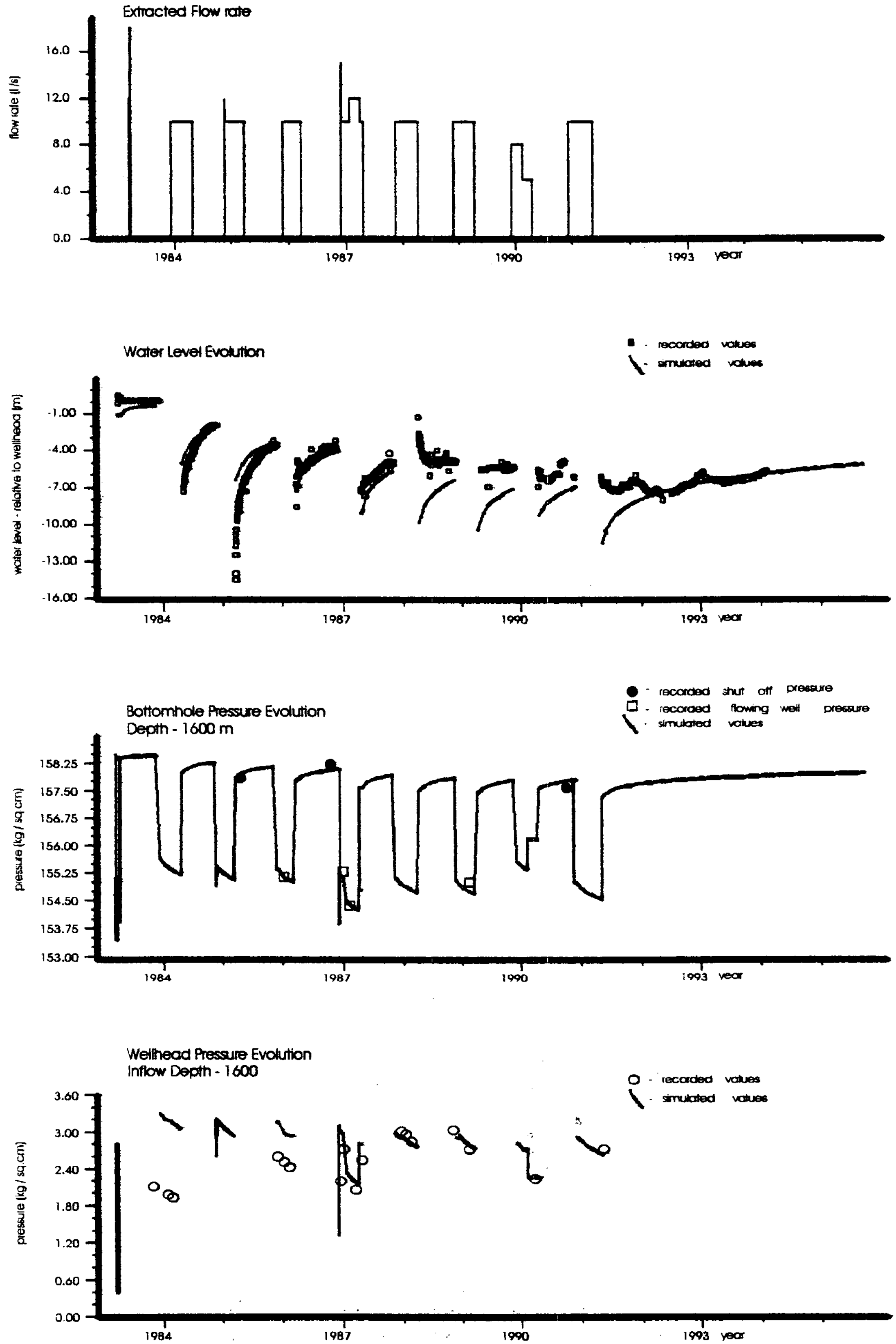

Fig. 6. Well 1524 Sannicolau Mare
Production history

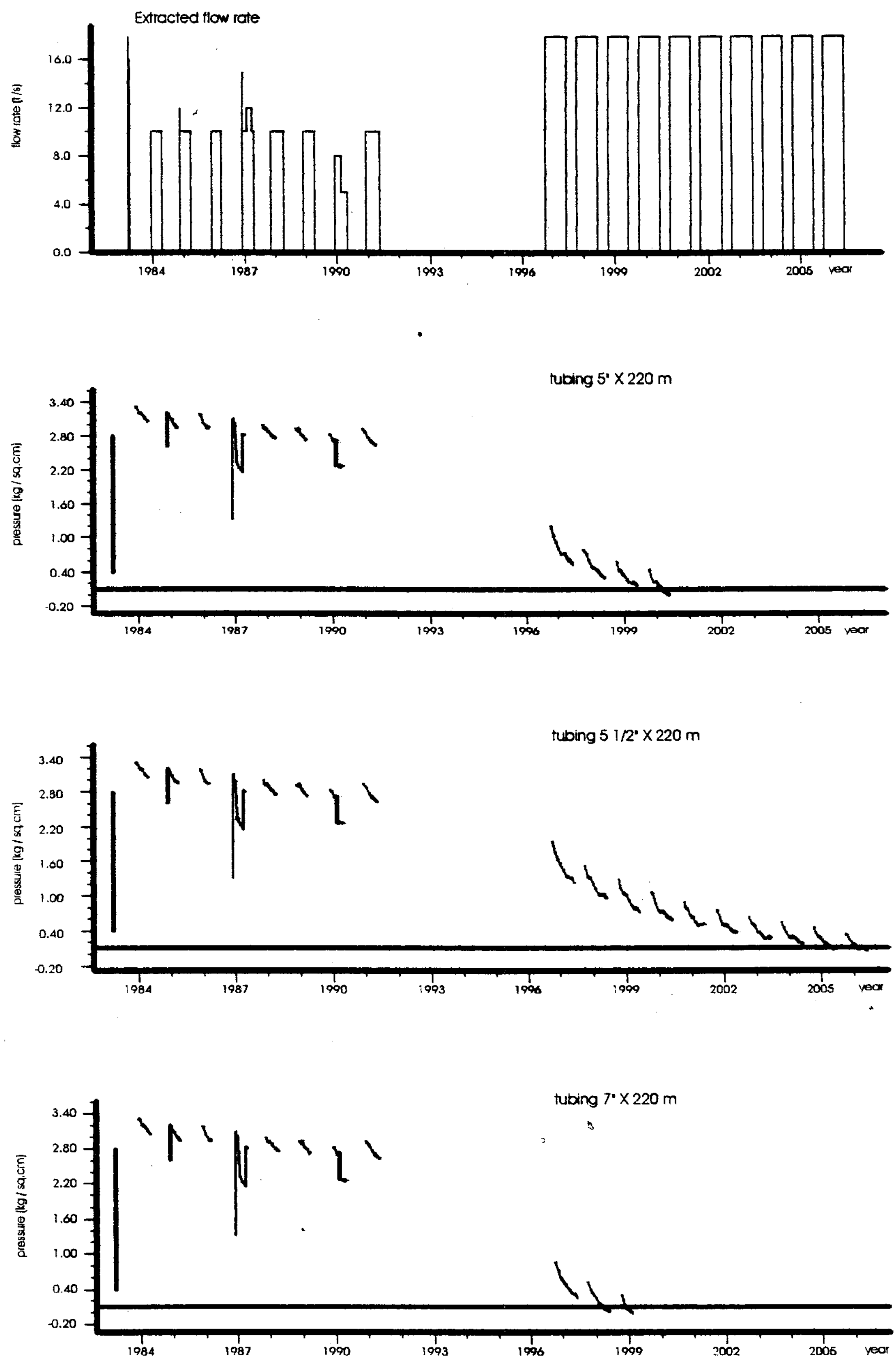

Fig. 7. Well 1524 Sannicolau Mare
Simulated wellhead pressure history and forecast

dramatically different artesian lifetimes. The most critical parameter appears to be the tubing diameter: 5 1/2" can secure an artesian lifetime of 10 years, as compared to both the immediately narrower 5" and the immediately wider 7", which are not able to sustain the required free flow regime for more than 4, and respectively 3 years.

For a given tubing diameter, the tubing length has to be appropriately selected as well. Wellhead pressures secured by stepwise increasing tubing lengths are successively computed for the considered provisional flow rate (fig. 8). The tubing length which provides the highest wellhead pressure is identified as a result.

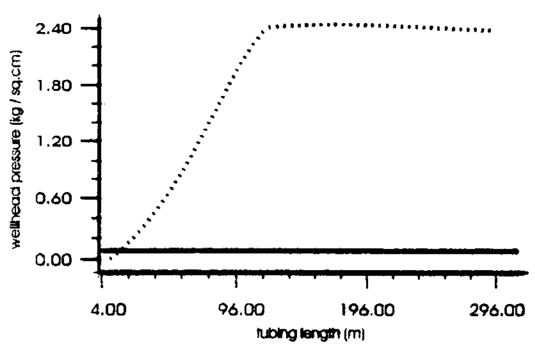

Fig. 8. Well 1524 Sannicolau Mare. Simulated wellhead pressure as a function of the 5 1/2" tubing length, for a discharge of 18 l/s.

CONCLUSIONS

1. Inability to control declining reservoir pressures and to secure desired artesian discharges hindered the exploitation of Pliocene geothermal reservoirs in the Pannonian Basin.

2. An appropriate reservoir engineering approach integrates the influence of specific factors: the prevailingly 1D reservoir development and the extensive two-phase flow within the well bore.

3. The related software GEOTHERM readily evaluates existing and alternative exploitation schemes. Attributes of sustainable development scenarios devised in this way are not only the rates and duration of withdrawal, but also the adopted well bore configuration.

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