Impacts of urban growth on surface water and groundwater quality in the City of Dessau, Germany

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Abstract From the mid nineteenth century, the City of Dessau (Germany) developed as an economic centre. The development of new residential and industrial areas changed the natural landscape having an adverse impact on the surface water, soil water and groundwater regimes. Between 1965 and 1990, public water supply, industry and agriculture pumped some 60 000 m^3 day^{-1} groundwater out of the Dessau aquifer. As a result, groundwater levels fell by 2–3 m over large areas. Since 1990, extraction for drinking water supply, industry and agriculture has decreased from about 60 000 m^3 day^{-1} to as little as about 5000 m^3 day^{-1}. As a result of this, in some parts of the city groundwater levels are now only 0.5–1.0 m below the surface. The rising groundwater levels have caused flooding of existing buildings and structures over large areas. To minimize or prevent damage, extensive engineering studies and works have been carried out to keep the groundwater level as low as necessary. Extensive pollution of both groundwater and soil has been observed in a highly industrialized area at Dessau. Further impacts on groundwater quality are caused by gas stations, petrochemical production plants and related depots. The main pollutants are volatile organic compounds (VOCs), monocyclic aromatic hydrocarbons which include benzene, toluene, ethylbenzene and the three xylenes (*m*-, *o*- and *p*). Local contamination exceeds defined limit values for drinking water. A further problem is the concentration of heavy metals (arsenic, zinc, cadmium and nickel) in these areas.

FROM THE PAST TO THE PRESENT AND THE GEOLOGICAL AND HYDROGEOLOGICAL CONDITIONS

Dessau is the third largest city in the German State of Saxony-Anhalt (Fig. 1), after Magdeburg and Halle. Dessau's population is about 90 000 inhabitants. It is a major industrial centre (e.g. engineering).

The first historical record found was for the year 1213, but later documents revealed that Dessau had already been planned and established as a "market settlement" by the end of the 12th century. From the mid 19th century, the city developed as an economic centre due to its infrastructural link with the German railway network and the proximity of the Elbe River. As the town developed further, surrounding villages became part of the municipal area. Due to the presence of the two rivers, the town expanded mainly towards the west and south. The development of new residential and industrial areas changed the natural landscape having an adverse impact on the surface water, soil water and groundwater regimes. Figure 2 shows the development of the population of Dessau. This development caused a general increase in water consumption.

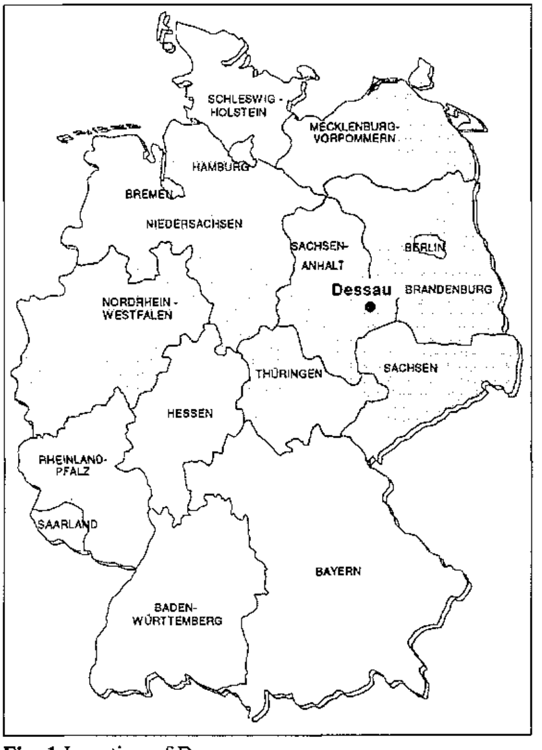

Fig. 1 Location of Dessau.

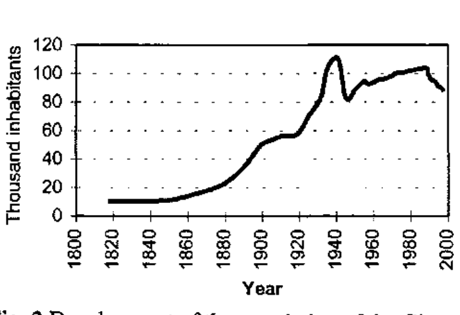

Fig. 2 Development of the population of the City of Dessau.

The local aquifer of the Dessau region is about 15 m thick and consists of Quaternary and Tertiary deposits (Fig. 3). The dominating Quaternary deposits consist mainly of Pleistocene substrata of the Elsterian and Saale glacial. These are overlain by Young Pleistocene to Holocene formations including native and forest soils, as well as meadow loam.

The calculated transmissivity of the aquifer is 1×10^{-2} to 1×10^{-4} m^2 s^{-1}, hence the permeability is quite suitable for groundwater movement. The Meso-oligocene Rupelian clay of the Tertiary forms the base of the aquifer over vast areas.

The groundwater flows northwards. In the area where the Mulde River flows into River Elbe it turns from east to west. At some locations in Dessau, the groundwater

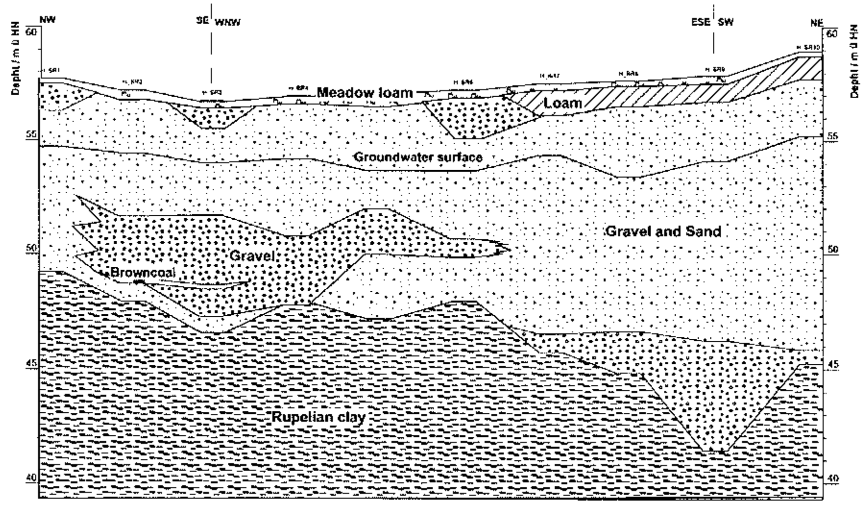

Fig. 3 Hydrogeological cross-section (new dewatering system).

level is less than a metre below the ground surface. An efficient drainage system then becomes an important necessity for any receiving and discharge of both surface water and groundwater. The drainage system of the Dessau region is formed by the Taube River and its tributary drainage ditches. The drainage ditches are shallow and narrow (decimetre range). Only the ditches to the southwest of Dessau are incised deeper into the aquifer—a result of melioration activities. That system, however, had little effect due to weeds, litter and refuse in the ditches and some interference by construction work. It had to be considered in the subsequent studies as it is used for the discharge of pumped groundwater.

DEVELOPMENT OF GROUNDWATER UTILIZATION

Pumping of groundwater until 1990

Initially potable water for the inhabitants was derived from single wells or from the river. The first central drinking water supply was established in 1876. A central element of this system was formed by a water pipe about 16 km long. After a couple of months the wells were shut down because of the ferric load (>10 mg l^{-1}). At that time any water treatment of ferric loads was fairly unknown.

In order to provide a better quality water supply to the population, new wells were drilled. Better water quality was found on the right Mulde riverbanks (downstream orientated). In 1885 a new water supply system was established.

One result of the industrial development was a progressive increase in water consumption. Newly established industrial companies organized their own water supply (e.g. Junkers-Flugzeugmotoren-Werke-AG). Figure 4 shows the pumping rate of the central water supply catchment of Dessau from 1895 to 1940.

Due to the constantly increasing water consumption a new system of drinking water supply had to be established in 1940. The capacity of the old water supply system was insufficient. In the area of Quellendorf (~10 km southwest of Dessau) new

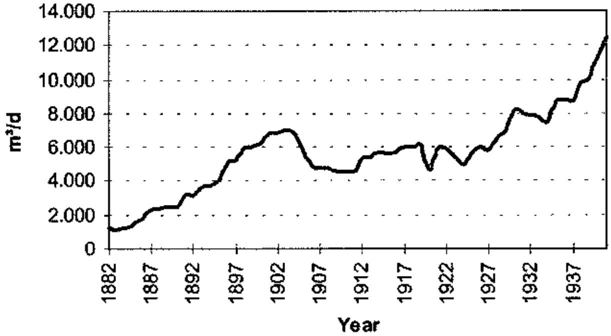

Fig. 4 Abstraction trends of the catchment from 1885 to 1940.

boreholes were drilled. Since 1943, Dessau has been connected via a pipeline with the catchment around Quellendorf, providing 6000–7000 m day^{-1}. Another system was installed at Kochstedt—a suburb of Dessau—with a capacity of 2200 m day^{-1}.

After World War II, the urban water supply system had to be fixed, most buildings and pipes having been destroyed. On 7 March 1945, an air strike destroyed 84% percent of the city centre. Little post-war information on water consumption is available but starts around the year 1960. This also was the beginning of the second major industrial development of the city.

Between 1965 and 1990, public water supply, industry and agriculture pumped some 60 000 m^3 groundwater per day out of the Dessau aquifer. This amounts to ~40 000 m^3 day^{-1} for industrial, ~10 000 m^3 day^{-1} for agricultural and ~10 000 m^3 day^{-1} for urban water supply. High-capacity pipelines were built as a central segment of the water resource management strategy for the huge industrial area south of Dessau (around the cities of Wolfen and Bitterfeld). These pipelines connected the region with remote catchments, such as the Harz Mountains and Elbe River. The pipeline-network became a substantial element of the East-German policy for water resources management. In 1972 Dessau's water supply was connected with the central drinking water scheme. Recently Dessau's drinking water consumption has been about 10 000 m^3 day^{-1}. The water is provided by the central drinking water scheme. Some 4000 m^3 day^{-1} is taken from the Elbe River and Harz Mountains, respectively.

Groundwater extraction since 1990

After the German Reunification the water supply—based on groundwater extraction—changed remarkably. Many previously existing waterworks were shut down, public ones as well as industrial ones. This was due to severely declining groundwater extraction rates. Since 1990, abstraction for drinking water supply, industry and agriculture decreased progressively from about 50 000 m^3 day^{-1} to as little as about 5000 m^3 day^{-1} (Fig. 5). As a result, in some parts of the town groundwater levels are presently only 0.5–1.0 m below the surface. In the City of Dessau, rebounding groundwater levels have caused flooding of existing buildings and structures over large areas. Heavy rainfall in 1994 led to an extreme situation with large-scale flooding particularly in the municipal district of Alten. According to measurements of the

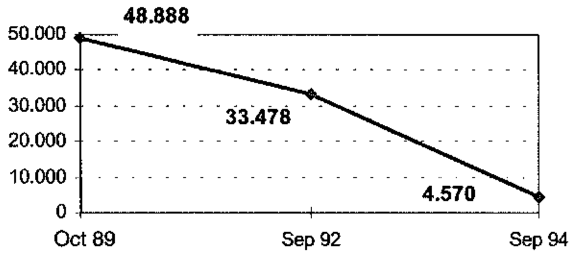

Fig. 5 Extraction trends in Dessau.

Federal German Weather Bureau, the total precipitation recorded at Quellendorf (reference station for the Dessau region) was 690 mm in 1994, i.e. about 30% more than the long-term average of 530 mm. Following heavy rains, monitored groundwater levels were 0.2–0.3 m higher after about five days. (The location of Dessau's groundwater wells is shown in Fig. 6.)

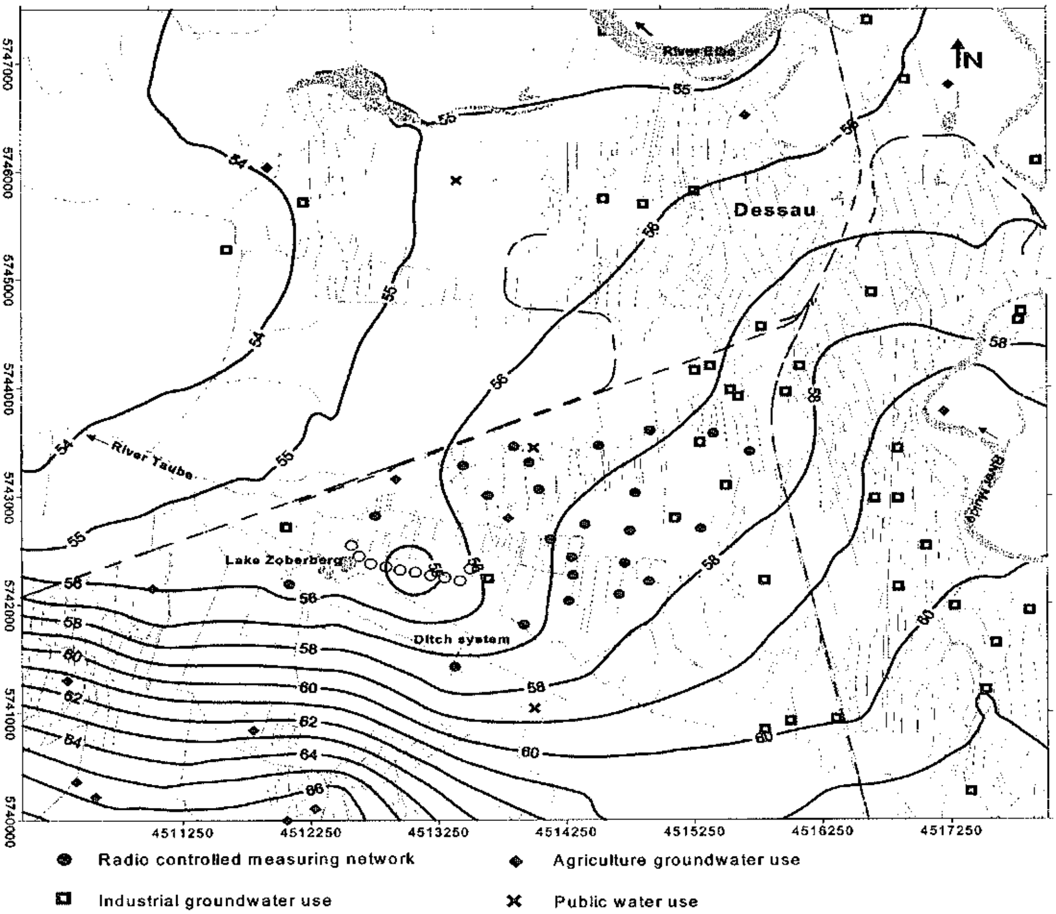

Fig. 6 Groundwater contour map with the old points of groundwater use in Dessau, and showing the new dewatering system with the radio controlled measuring network (near Lake Zoberberg).

Changes in the surface water, soil water and groundwater regimes of Dessau

The development of new residential and industrial areas has changed the natural landscape and influenced adversely the surface water, soil water and groundwater regimes of the city. One result of the urbanization is the change in the relative proportions of runoff, recharge, interflow (soil water and the unsaturated zone) and evapotranspiration. Table 1 illustrates the altered conditions.

Extensive sealing of the land surface is strongly correlated with an increasing amount of surface runoff. The evapotranspiration (ET) also diminishes. In some areas precipitation is almost completely available for infiltration, and hence for groundwater recharge to the aquifer. Studies on geohydraulic modelling revealed some spatial patterns of urban groundwater recharge.

Naturally recharge ranges from 63.1 to 126.2 mm $year^{-1}$ in the area of Dessau. In the CBD of Dessau, where ~80% of the land surface is covered either by concrete or tar, annual recharge equals 252.5 mm, whereas a 60% covering allows a recharge rate of 189.34 mm $year^{-1}$.

For the City of Dessau, DESWA (the local water-supplier) estimates a total annual groundwater consumption of about 4.5×10^6 m^3. Due to leaking pipelines some 10% is lost, which equals about 1230 m^3 day^{-1}. The central purification plant of Dessau purifies some 6×10^6 m^3 day^{-1}. Looking at the inputs, this surplus is derived from precipitation being discharged into the canal system initially.

Up to 1989–1990, public water supply, industry and agriculture pumped about 50 000 m^3 of groundwater daily. As a result, groundwater levels fell by 2–3 m over large areas. The flooding of existing buildings and structures was mainly ignored. At this time the importance of the drainage system was completely forgotten. Parts of this system were destroyed and became useless while groundwater levels were continuing to rise.

The shutdown of water supply facilities in the Dessau region in 1990, as well as the end of groundwater withdrawal for industrial purposes, 1990–1992, caused a decrease of extraction rates to about 5000 m^3 day^{-1}, and consequently a progressive rise of the groundwater table. Heavy rainfall in 1994 made the situation even worse. Presently some locations in Dessau show groundwater levels less than 1 m below the ground surface. In Dessau-Alten and Zoberberg groundwater had penetrated into the basement of existing buildings.

Table 1 Changes of runoff, evapotranspiration, interflow and recharge (mm $year^{-1}$) with greater urbanization.

Sealing %	Runoff	Evapotranspiration	Interflow	Recharge	Precipitation
0	26.50	318.00	121.90	63.60	530
5	38.16	313.76	115.54	62.54	530
40	170.13	253.87	63.60	42.40	530
60	257.58	204.58	37.63	30.21	530
80	340.79	159.00	14.84	15.37	530
100	424.00	106.00	0	0	530

INVESTIGATION AND TECHNICAL MANAGEMENT FOR POORLY DRAINED AREAS IN THE DISTRICT OF DESSAU-ZOBERBERG

With the construction of the residential area of the Zoberberg district in the western part of the town, groundwater lowering facilities were first set up in the 1970s. Lake Zoberberg (which originated from the excavation of building materials) and single wells were used for that purpose.

The stormwater system of the new residential area was connected to the lake. The stormwater drain entering at a level of 52.5 m a.s.l. imposes a maximum permissible lake level which requires the periodic withdrawal of water from the lake. Without such withdrawal the lake's level would rise by about 3.0 m, a process that backs up drainage through the rainwater system. During that time $\sim 1.0 \times 10^6$ m^3 of ground- and stormwater had to be pumped from Lake Zoberberg.

Existing groundwater lowering facilities in the Zoberberg residential area (individual wells, Lake Zoberberg) lost efficiency due to partial ferric incrustation. A detailed regional model was developed for an area of about 30 km^2. Finer resolution resulted in a more precise model considering local conditions, and also allowing estimation of the discharge of extracted groundwater into the ditch system.

The model could prove the effectiveness of the new drainage systems in their environment. This helped to optimize the siting and operation of the systems. Technically, groundwater lowering is accomplished by a new pumping field with ten wells. The groundwater obtained is discharged into the ditch system of the Taube River in its upper reaches. Relevant groundwater level measurements are an essential prerequisite for the efficient and, hence, low-cost operation of the groundwater lowering systems. In conformance with the foundation the groundwater level, must not exceed 56.0 m a.s.l.

The new drainage system has been working since 1994. Ten wells pumping 5000 m^3 groundwater per day. In 1998, three new wells were built for completion of the drainage system. The groundwater extraction field of Dessau is about to expand further.

The stormwater system of the new residential area was directly connected to the old pumping station. Since 1995, Lake Zoberberg has had a water level ranging between 55.6 and 55.9 m a.s.l.

Periodic measurements of groundwater levels provided information on general trends of the water level developments. At the same time the hydraulic effect of the ditch system was recorded by measuring its flow rates. Temporary groundwater extraction in connection with construction work and the associated discharges into the ditch system were considered. This revealed some preliminary information about the interactions between surface water and groundwater.

The groundwater level in Dessau-Alten is recorded with a remotely controlled measuring network. Thirty newly sunk groundwater measuring points (100 mm diameter) have been equipped with in-well data loggers (sensors) for automatic measurement of groundwater level and water temperature. Measurements are taken twice a day and passed on by telemetry links. The latter is connected, via a modem, to a computer for data processing, storage and output. The measuring network automatically records the contour of the groundwater surface in an area of about 10 km^2. This provides an efficient control of the new pumping field. In 1996 and 1997 some fifteen data loggers were operating in the district of Dessau. This brand new system provides an automatic recording of the groundwater contour covering the entire City.

The measurements are processed in a database that can be connected and updated with data from other measuring points, as well as with water levels in the ditch system, water levels in the main receiving channels and any relevant groundwater withdrawal and/or flow rates. With this, the groundwater dynamics in the urban area of Dessau can be compiled and documented area-wide for a given period. The database can also be used to update and re-calibrate the existing geohydraulic model. Interference with the system can thus be checked and quickly assessed.

THE IMPACT OF INDUSTRIALIZATION ON GROUNDWATER QUALITY

Extensive pollution of both groundwater and soil was observed for a highly industrialized area in Dessau. Further impacts on groundwater quality are caused by former gas stations, petrochemical production plants and related depots. Some of these facilities have been operating for about 60 years. The oldest parts are located close to the railway (that connects Bitterfeld and Dessau). After 1900, groundwater protection was not compulsory and consequently neglected. This circumstance led to some severe groundwater contamination. The main pollutants are volatile organic compounds (VOCs), monocyclic aromatic hydrocarbons which include benzene, toluene, ethylbenzene and the three xylenes (*m*-, *o*- and *p*). Locally contamination exceeds the defined limits for drinking water.

A different problem is the concentration of heavy metals (such as arsenic, zinc, cadmium and nickel) in these areas. Leaking underground depots at gas stations are a major source of groundwater contamination. In these areas high concentrations of aromatic hydrocarbons and monocyclic aromatic hydrocarbons can be frequently observed. These concentrations also exceed the limits for good drinking water quality. Higher concentration of aromatic hydrocarbons and heavy metal were found in areas which formerly served as military facilities.

Most probably the pollution of groundwater and soil detected around Dessau occurs in almost all urbanized areas. Continuous groundwater analysis carried out for the area of Dessau underline this assumption. Detailed analyses of groundwater conditions were taken as baseline information for remedial measures. Meanwhile further investigations have been launched.

In general, the pollution load has been reduced since 1990—the reunification of East and West Germany. Analysis of surface water from the Mulde and Elbe rivers revealed a general improvement of water quality in terms of hydro-environmental pollution.