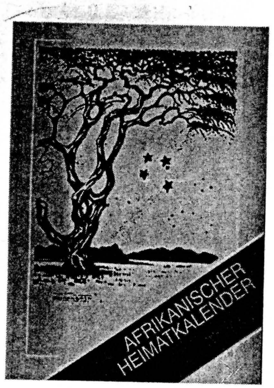

JOURNAL 51
Namibia Wissenschaftliche Gesellschaft / Namibia Scientific Society
Windhoek, Namibia 2003
ISSN: 1018-7677 ISBN: 99916-40-45-2

EFFECT OF GROUNDWATER EXTRACTION ON THE VEGETATION IN THE KHAN RIVER AT RÖSSING URANIUM MINE, NAMIBIA

SANDRA MÜLLER
Rössing Uranium Ltd.
Private Bag 5005, Swakopmund, Namibia, e-mail: sandrakb@rossing.com.na

ABSTRACT

A vegetation monitoring programme has been carried out at Rössing Uranium in the Khan River since 1988 to investigate the effect of groundwater extraction on the riparian vegetation. The survey methods and monitoring results are described in this article. One of the main conclusions is that most large woody species can adapt to a wide range of water table fluctuations. *Faidherbia albida* was found to be more sensitive than *Acacia erioloba* to rapid water level declines and to deep water levels around 15-20 m below surface.

Keywords: vegetation monitoring, impact of groundwater extraction, Khan River, Rössing Uranium, Namibia

1. Introduction

Rössing Uranium is located in the Namib Desert approximately 65 km inland of Swakopmund (Figure 1). The operation consists of an open pit and an acid-leach uranium plant. The area experiences low and erratic rainfall, high temperatures and evaporation rates. Due to the desert environment and the nature and size of the process, considerable attention is paid to sustainable management of the available water resources.

From the onset of operation in 1976, the mine has used brackish water from the Khan River for industrial purposes to reduce the consumption of fresh water. The Khan is an ephemeral river and surface runoff usually occurs only after heavy rainfalls in the upper catchment area. For the remainder of the time, groundwater flows below the surface of the riverbed within deep layers of sand and gravel.

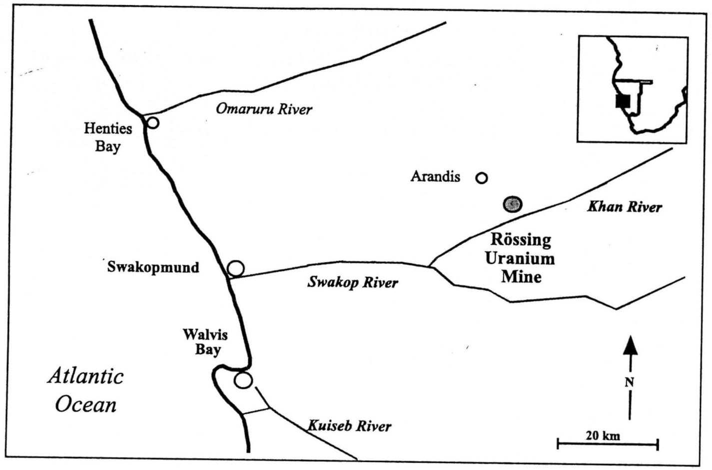

Figure 1: Location of Rössing Mine

2. Background

The Department of Water Affairs (DWA) controls the extraction from the river by means of an abstraction permit. The original permit allowed a quota of 0.87 million cubic metres per annum (Mm³/a), which was defined as the sustainable yield of the aquifer from which the Rössing wellfield draws (Dziembowski 1970). In 1988, the mine extended the wellfield into the "upstream compartment" and applied for an increase to 1.0 Mm³/a in order to maintain high standards of dust suppression. A hydrogeological study indicated that the water table would eventually be lowered to 10 metres below surface, but groundwater reserves at a depth of 10-20 metres below surface would still be available to sustain the vegetation (Groundwater Consulting Services 1989).

Concern was expressed that the trees would not be able to adapt to the falling water table and could therefore be damaged if water was extracted too rapidly (Ashton 1988). Lower water levels could also affect soil conditions and other components of the eco-system. The DWA agreed to grant the increased quota on condition that the riverine vegetation was monitored. The monitoring results would be submitted to the DWA to provide an early warning system and the pumping rate would be revised if abstraction was indeed found to affect the trees. A distinction had to be made however, as to whether the effects are localized and thus due to water abstraction, or due to more widespread regional climatic effects. Therefore the survey would have to be conducted over a wider area, if signs of water stress were noted at the mine (Ashton 1988). The vegetation monitoring programme started in 1988, some 12 years after the start of mining, and continues to the present. No baseline study was carried out in the Khan River prior to the establishment of the mine.

3. Composition of the vegetation

The vegetation of the area around Rössing mine forms part of the transitional zone between the Central Namib and Semi-Desert Savannah floristic regions (Giess 1971). The savannah elements of the vegetation are usually located along riverbeds and watercourses while the semi-desert and desert forms occur away from the drainage lines.

The vegetation in the Khan River consists mainly of small, scattered groups and individuals of indigenous drought-tolerant perennial species. These are mostly larger woody shrubs and trees that colonize sandbanks in the riverbed and flood terraces along the banks. Alien species like *Prosopis* sp. and *Nicotiana glauca* are quite common and annual species can become abundant after flood events.

Ashton (1988) conducted an initial survey of the Khan River near Rössing Mine and found most of the trees and shrubs alive and in good condition, although several examples of standing-dead acacias were seen. Virtually all of the species were present as adult plants and very few seedlings were present. These seedlings seemed to be of the same age, possibly having germinated after the exceptional floods of 1985.

4. Design of the monitoring programme

Six monitoring sites (transects 1-6) were chosen over a distance of 22 km. The monitored area starts 5 km upstream of the mine, extends for 6 km along the mine frontage and ends 11 km downstream (Figure 2).

Khan River production boreholes (⊙) and vegetation monitoring sites (**O**)

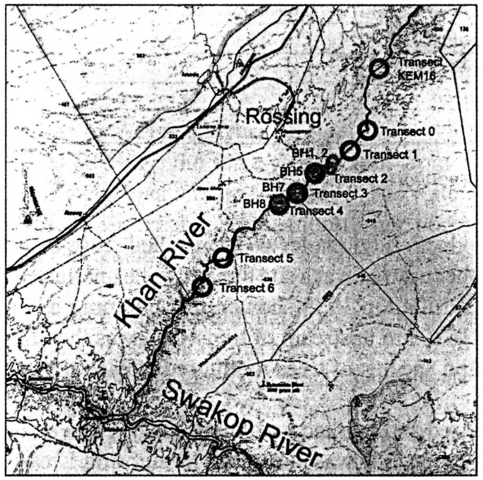

Figure 2: Localities in the Khan River near Rössing mine

The presence of about 10 trees within an area of 1 ha was the main criterion in deciding whether or not a site was suitable. Unequal spacing between the transects reflects the scarcity of suitable groups of trees. Each monitoring site is located on a raised river terrace on the inner face of a river bend where the trees are largely protected from flood scouring.

Tree number	Transect KEM16	Transect 0	Transect 1	Transect 2
T1	*Acacia erioloba*	*Acacia tortilis*	*Faidherbia albida*	*Faidherbia albida*
T2	*Acacia tortilis*	*Faidherbia albida*	*Faidherbia albida*	*Faidherbia albida*
T3	*Ficus sycomorus*	*Acacia erioloba*	*Faidherbia albida*	*Acacia erioloba*
T4	*Faidherbia albida*	*Acacia erioloba*	*Faidherbia albida*	*Acacia erioloba*
T5	*Faidherbia albida*	*Acacia erioloba*	*Faidherbia albida*	*Acacia erioloba*
T6	*Faidherbia albida*	*Acacia erioloba*	*Faidherbia albida*	*Acacia erioloba*
T7		*Acacia tortilis*	*Faidherbia albida*	*Prosopis* sp.
T8		*Acacia erioloba*	*Faidherbia albida*	*Acacia erioloba*
T9			*Faidherbia albida*	*Acacia erioloba*
T10			*Faidherbia albida*	
Tree number	**Transect 3**	**Transect 4**	**Transect 5**	**Transect 6**
T1	*Acacia erioloba*	*Acacia erioloba*	*Acacia erioloba*	*Faidherbia albida*
T2	*Acacia erioloba*	*Acacia erioloba*	*Acacia erioloba*	*Acacia erioloba*
T3	*Acacia erioloba*	*Acacia erioloba*	*Prosopis* sp.	*Acacia erioloba*
T4	*Acacia erioloba*	*Acacia erioloba*	*Acacia erioloba*	*Acacia erioloba*
T5	*Acacia erioloba*	*Faidherbia albida*	*Acacia erioloba*	*Faidherbia albida*
T6	*Acacia erioloba*		*Acacia erioloba*	*Acacia erioloba*
T7	*Acacia erioloba*			*Acacia erioloba*
T8	*Acacia erioloba*			
T9	*Acacia erioloba*			

Table 1: Tree species monitored

Because two new production boreholes were installed close to transect 1 in 1993, transect 0 was established further upstream at a site thought to be unaffected by abstraction. However, monitoring boreholes drilled in 1995 showed that pumping had in fact lowered the water level. Transect KEM16, 6 km upstream of transect 1, was therefore added in 1996. Table 1 shows the numbers and species of trees monitored at each transect.

The trees were numbered and marked with metal tags. A base point at each transect and the position of each monitored tree was surveyed. Monitoring is carried out every six months at the start and end of the growing season. The survey consists of fixed-point photographs, measurements and observations. Measurements include the height and girth of the trees or main stems. Heights are measured using a theodolite and reported as the difference between the base of the trunk and the tip of the tallest branch visible from the instrument position. The girth is measured with a tape at a height of 1.2 m above ground level, normally where the metal tag is attached. Observations are made of the general condition, presence of leaves, flowers and fruit. Estimates of leaf coverage, leaf condition, dead branches and abundance of seeds are recorded in a semi-quantitative manner.

Photographs are taken from a base point at fixed angles. They are marked with the relevant tree numbers and survey date and filed in chronological order. The files and evaluation reports are sent to the DWA for review each year.

The overall condition of a tree is classified according to the observed parameters of dry branches, leaf coverage, presence of flowers and seeds. To show this graphically, numbers were assigned to the descriptions as follows: Excellent condition = 4, Good = 3, Reasonable = 2, Poor = 1 and Dead = 0. Graphs of condition over time were prepared by calculating the average condition of all trees at a specific transect for each year. These will be discussed in 5.2.

5. Monitoring results

Vegetation surveys took place every year in March/April and September/October since April 1988. The observations were analysed in combination with hydrogeological data to determine the effect of abstraction on the vegetation. Results were compiled in annual reports to the DWA and are now presented in this article. The relationship between water table variation and the vitality of the riparian vegetation is analysed in the following section. The first part looks at the effect of recharge and extraction on the water table, while the second part describes the condition of the various transects over time.

5.1. Response of the Aquifer to Water Extraction

According to records kept at Rössing, the mine's extraction from the Khan River varied from 0.2 to 1.0 million cubic metres per annum (Figure 3). The water level shown in Figure 3 is the average of figures measured in several monitoring boreholes spread over the monitored area (Figure 2). The readings are in metres above mean sea level (mamsl).

The aquifer was fully recharged by the exceptional floods of 1985, but high pumping rates in 1988 to 1991 caused a marked decline of the water table in the wellfield. Rising water levels were related to recharge from flood events. Significant floods characterised by full-width flow over several days and discharge of the Khan into the Swakop River, occurred in 1990, 1997 and 2000. The flood volumes after 1986 in Figure 4 are estimates, because no readings were taken at the Ameib gauging station near Usakos during this time (DWA, pers. comm.). Water from small floods does not usually reach the aquifer, but supplies additional moisture to the vegetation for a short time.

Rainfall measured at the mine's weather station is shown in Figure 5. Runoff from the mine area after local rainfall in 1993 and 1995 provided some recharge to the Khan River wellfield. This recharge and the reduced pumping rate helped to limit the decline of the water table until 1996. The 1997 and 2000 floods in the Khan River filled the aquifer almost to the original level. However, the recovery of the water table was more pronounced in the upstream and wellfield sections, while the downstream area at transect 6 received very little recharge. Reasonable extraction limited to the sustainable yield of the aquifer led to a slower decline of the water table after the recent recharge events (Figure 3). It is important to note that the water levels would drop due to evapotranspiration and outflow to the Swakop River even if no pumping took place at Rössing Mine. A hydrogeological model of the mine area (Aquaterra 2003) showed that the vegetation along the monitored section of the Khan River consumed around 8500 m^3 of groundwater per month. While 80% of this volume were provided by throughflow, 20% were taken from storage and this would lower the water table by approximately 5 cm/month.

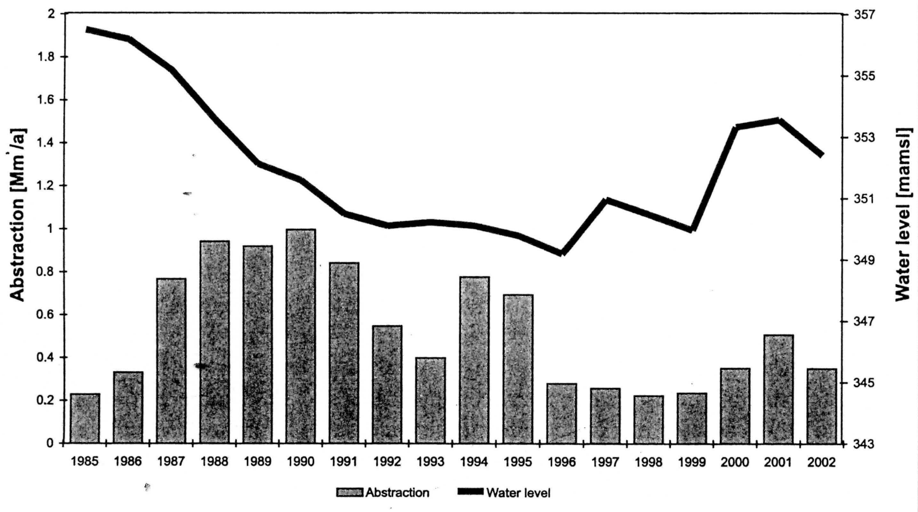

Figure 3: Extraction and average water level

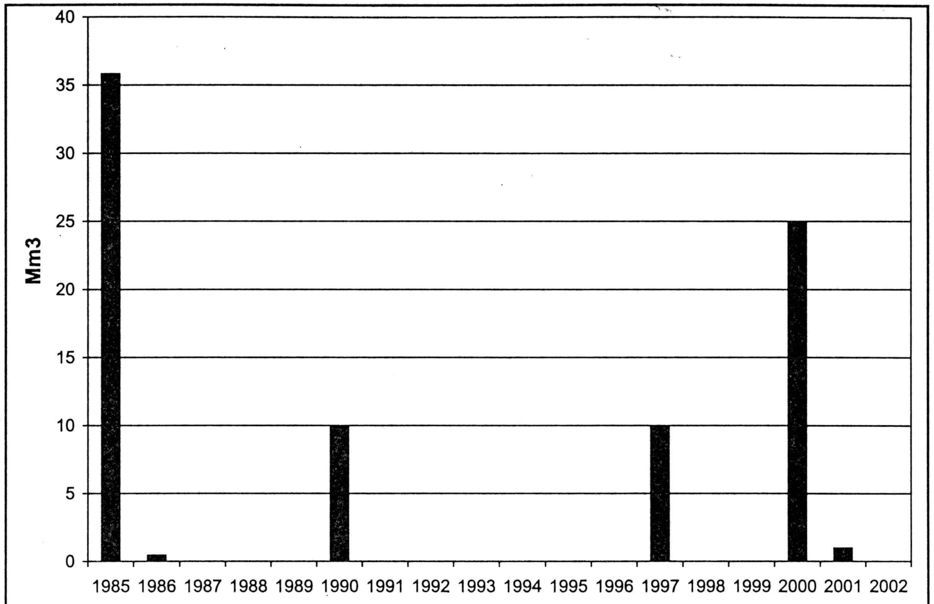

Figure 4: Estimated flood volumes at Ameib

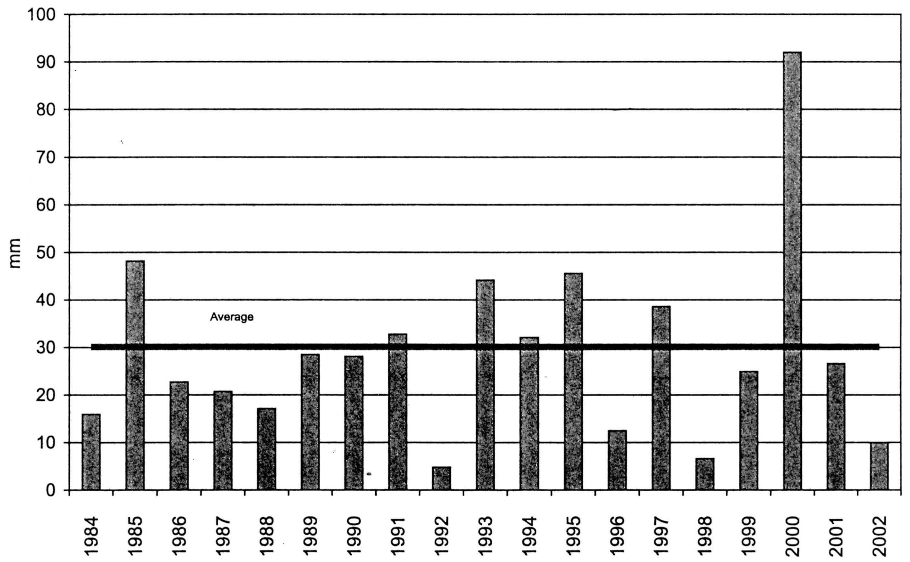

Figure 5: Annual rainfall at Rössing Mine

5.2. Response of the Vegetation to Water Level Fluctuations

As shown in Figure 3, pumping and lack of recharge lowered the water table in the wellfield between 1986 and 1996. The aim of this section is to investigate the response of the vegetation to water level variations.

Graphs of condition over time (Figure 6) were prepared by calculating the average condition of all trees at a specific transect for each year. The following graphs show the general condition compared to the water level at a monitoring borehole close to each transect. As mentioned in section 4, the overall condition of a tree is classified as follows: Excellent condition = 4, Good = 3, Reasonable = 2, Poor = 1 and Dead = 0.

Upstream of the mine at KEM16 the water table was relatively shallow and the trees remained in good to excellent condition during the last seven years. At transect 0 however, the water table was lowered in 1995/6 and the condition dropped from good to reasonable. Recharge in 1997 and 2000 restored the trees to a generally good condition. A very similar trend was observed at transect 1. Transect 2 is situated close to the production boreholes and the water table was already affected by pumping when the vegetation survey began in 1988. The lowest levels are incongruously associated with the highest marks for tree condition. Transect 3 remained in reasonable to good condition independent of water level variations, except for a slight decline in 1990/1, which might have been caused by the fast drop of the water table. The same decline in condition can be observed at transect 4, but there was a more pronounced recovery after the 1995 and 1997 recharge events. The trees at transect 5 appear to be accustomed to a low water table, as there was hardly any response to the decline observed during the 1990s. The change from good to reasonable condition at transect 6 in 1993 could be related to the deep water table and lack of recharge.

These are very general conclusions, as the condition of a transect depends to some extent on the tree species monitored and the status of specific trees at the start of the survey. For instance, an old tree in decline can lower the average figure for the entire transect. An evaluation of measured tree heights and girths was carried out to confirm the semiquantitative assessments of tree condition.

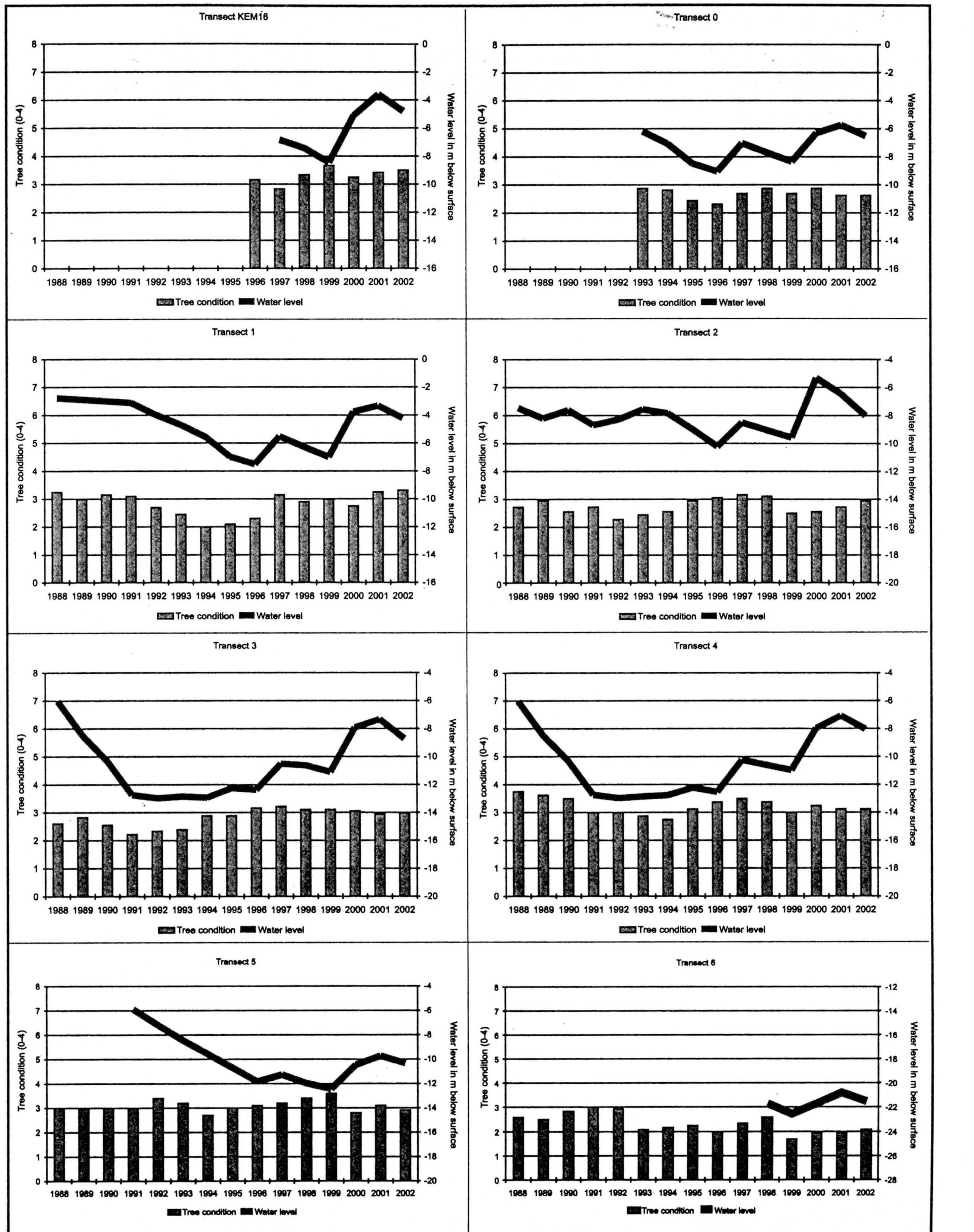

Figure 6: Tree condition in relation to water level

5.3. Tree Height and Girth

The tree height and girth data collected since 1988 were evaluated to identify trends in the growth pattern. Tree heights were compared to the depth of the water table and to changes in water level to see if these factors influenced the growth of trees.

The average change in height at all transects including growth and decline was 0.35 m from 1988 to 1998. The average increase in height of 0.92 m was balanced by a decrease of -0.56 m (Figure 7). The maximum growth was recorded at transect 2, while the highest decline occurred at transect 1. A difference in growth rate was observed for the various tree species. *Faidherbia albida* showed an average growth of 0.45 m, *Acacia erioloba* 0.28 m and *Prosopis* sp. 1.01 m (only two trees monitored), while the two *Acacia tortilis* trees declined by -0.29 m. The sparse leaf coverage, infrequent blooming and seed production indicate that conditions in this part of the Khan River are not ideal for *Acacia tortilis*. *Faidherbia albida* develop long tall branches, which grow faster than *A. erioloba* branches, but can easily dry up and break off in times of drought. The size or age of the trees had no influence on the growth rate, except for very old trees, which are static or decaying.

Declines in tree height were observed at transects with high and low water levels (Figure 7). The water levels in the graph are the average figures measured in monitoring boreholes close to the transects (Figure 6). Data were available for transects 2-4 since 1988, transects 0, 1 and 5 since 1991 and transect 6 since 1998. The average rate of water level decline per month (disregarding rises due to recharge events) during the monitored period was -0.07 m at transects 1 and 2, -0.03 m at transects 3 and 4, -0.04 m at transect 5 and -0.07 m at transect 6.

High growth rates were recorded at transect 2 where the water level was closer to surface than at transects 3-5. The general decline at transect 6 can reasonably be correlated with the exceptionally low water table in this area. The striking decrease in trees heights and low growth rate at transect 1, and to some extent at transect 0, in spite of the shallow water table is explained by the rapid rate of drawdown in this area in 1994/95. New production boreholes in the upstream part of the wellfield close to transect 1 were pumped from 1993 to 1995. The water table was lowered by 0.17 m per month in 1994 and 0.10 m per month in 1995. Figure 8 shows the rates of decline measured at individual monitoring boreholes.

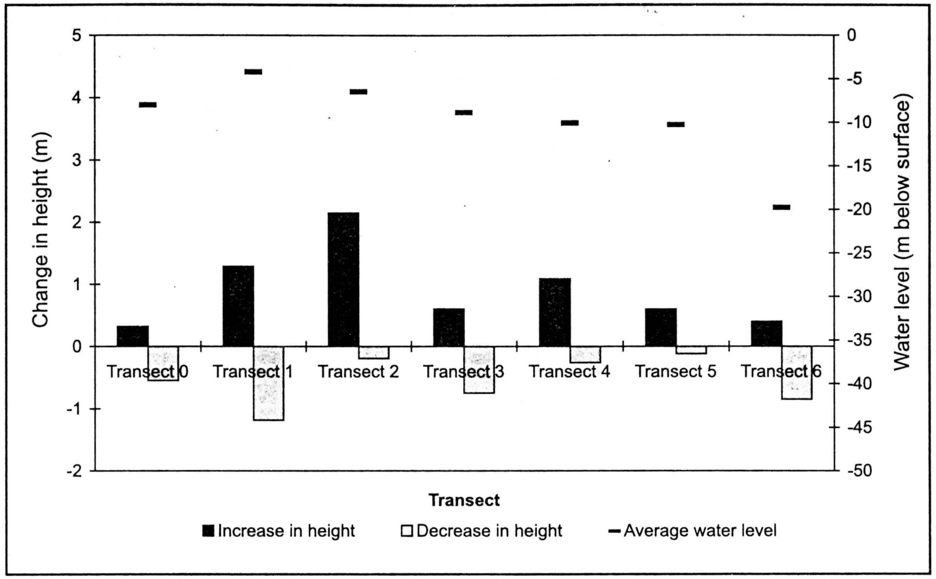

Figure 7: Average change in tree height in relation to water level

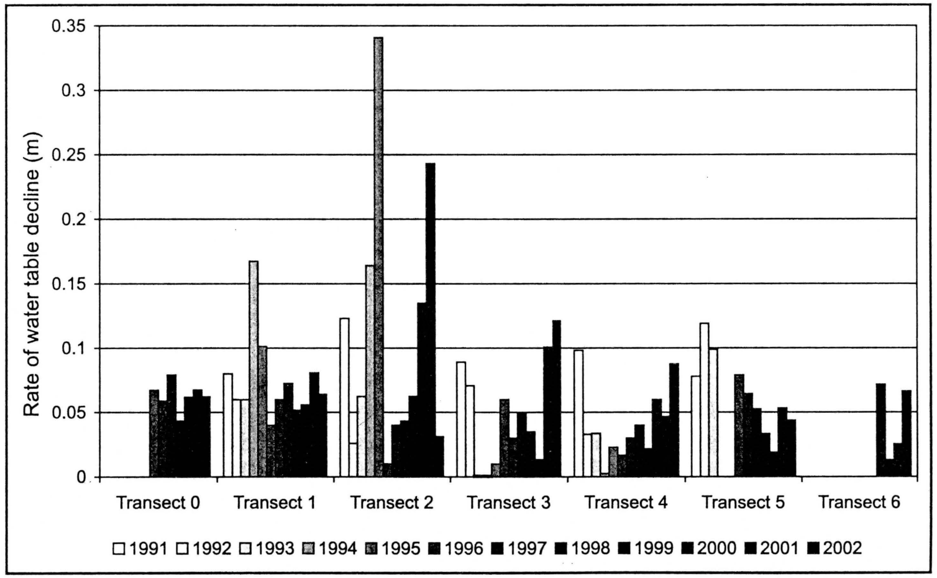

Figure 8: Average annual rates of water table decline in m/month

Transect 1 illustrates that a rapid drop of the water level can damage trees even at shallow water levels. The DWA in a letter to the mine (DWA 1992) referred to literature stating that the roots of bigger or older *Faidherbia albida* do not have the capability to follow a declining water table. The monitoring data indicate that the roots were not able to follow the water table when it was lowered faster than 0.1 m per month. The consequence was at first a reduction in leaf density and reduced production of flowers and pods. If the decline continued, the highest branches would lose their leaves, dry up and later break off.

Acacia erioloba trees were apparently less sensitive to water level variations. They are the predominant species at transect 2, which is in the centre of the main wellfield (Figure 7). This transect showed the highest growth rates in spite of the largest water level declines (Figure 8).

The tree girth showed an overall increase from 1988 to 2002 at all transects (Table 2). Variations from year to year were caused by pieces of bark flaking off or, in a few cases, measurements taken at slightly different heights along the trunk.

Transect	Increase in girth (m)	Decrease in girth (m)
Transect KEM16	0.13	0.00
Transect 0	0.06	0.00
Transect 1	0.16	0.00
Transect 2	0.23	0.00
Transect 3	0.11	0.00
Transect 4	0.25	0.00
Transect 5	0.16	0.00
Transect 6	0.11	0.00

Table 2: Average change in tree girth

5.4. Effect of Drought on the Vegetation

The monitoring indicates that the vegetation in the Khan River is adapted to long droughts, which must have been a feature of the local climate at least for hundreds of years. The drought affects the vitality of the trees, which seem to go into "hibernation" to conserve water. As soon as the availability of water improves the trees recover within a few weeks and start producing denser foliage, blooms and new shoots.

5.5. Natural Loss and Decay of Trees

Monitoring showed that trees could be damaged or dry up due to natural causes. For instance, two young *Faidherbia albida* trees at transect 1 were washed away in the 2000 floods. A small *Nicotiana glauca* at transect 3 dried up after two years of monitoring and was later washed away. A young *Prosopis* sp. at transect 5 was damaged by unknown persons in 1988 and again in 1992, but the plant is still surviving. An old *Acacia erioloba* (tree 7) at transect 3 dried up fairly quickly between September 1998 and March 1999, while other *A. erioloba* next to it remained healthy. A peculiar phenomenon in the Khan River, e g at transects 4-6, is the tendency of *Salvadora persica* to grow under, around and over *Acacia erioloba* until the latter trees are completely covered. As this cover reduces the exposure of the affected trees to sunlight they lose most of their leaves and appear standing dead.

6. Conclusions

The described observations of tree heights, depth to water table and rate of water level decline lead to the following conclusions.

6.1. Depth to Water Table

Water levels measured upstream of the wellfield indicate that the natural range of variation extends from approximately 1-10 m below surface. Additional drawdown to about 13 m below surface was caused by groundwater extraction and affected the vitality of the trees, e g at transects 3 and 4, to some extent. This could indicate that the vegetation needs some time to adjust to the new water table position and then returns to a normal growth pattern. Transect 2 supports this theory. The deep water table at transect 6 affects the condition and growth rate of trees in this area. The water table decline of -0.07 m per month is not regarded as excessive, but insufficient water level data are available to draw firm conclusions.

6.2. Water Level Variations

Monitoring results at transect 1 in the upstream part of the wellfield showed that a rapid drop of the water level can damage trees even at shallow water levels. *Faidherbia albida* at this transect were affected by a fast decline of the water table in 1994/5. It appeared that the roots were not able to follow the water table, while it was lowered faster than 10 cm per month. The consequence was a reduction in leaf density and production of flowers and pods. If the decline continued, the highest branches would lose their leaves, dry up and later break off. At a certain point this process became irreversible even if the water table rose again. *Acacia erioloba* is apparently less sensitive to water level variations as observed at transect 2, which showed the highest growth rates in spite of the largest water level declines.

7. Aquifer management

Groundwater extraction exceeding the sustainable yield of the aquifer lowers the water table faster than it would drop under natural conditions. This can affect the riparian vegetation as described in the previous sections. Sound aquifer management practice will therefore adjust the extraction to the sustainable yield and reduce the rate of water table decline.

As of 1995, the yield of the Khan River aquifer was determined every year after the rainy season and the extraction target was set accordingly. Volumes pumped and water levels are monitored monthly and used to update the water reserve estimation (Figure 9). Pumping will be suspended when the limit of 1.0 million cubic metres is reached, so that sufficient groundwater remains in the aquifer to sustain the vegetation.

Experience indicates that the rate of water table decline should be below 0.1 m/month. As shown in Figure 8 since 1996 this rate was only exceeded at transect 2 in 2000 and 2001 and at transect 3 in 2002. This was after the recharge event of 2000 when water levels were much higher than before (Figure 3). Under normal conditions the pumping rates are controlled to avoid a drawdown of more than 0.1 m/month.

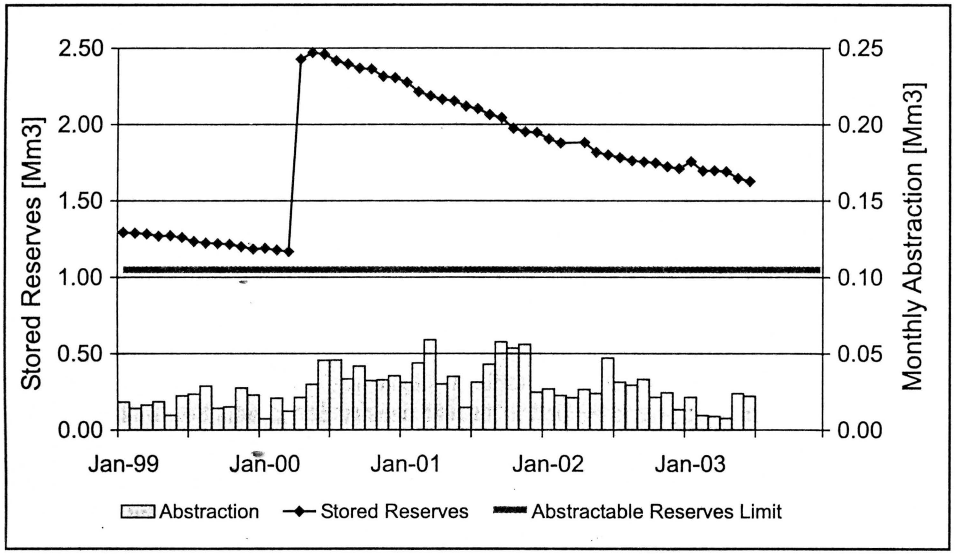

Figure 9: Water reserves and monthly abstraction

References

AQUATERRA CONSULTING 2003. Rössing Groundwater Model: Updated Calibration and Tailings Operations and Closure Predictions. Unpublished Report to Rössing Uranium Ltd, Swakopmund.

ASHTON, P. J. 1988. *Monitoring Programme Required to Evaluate the Impact of Water Abstraction on Riparian Vegetation in the Khan River*. Unpublished Report to Rössing Uranium Ltd, Swakopmund.

ASHTON, P. J. 1996. *A Review of the Vegetation Monitoring Programme Conducted at the Rössing Uranium Mine, Namibia*. Unpublished Report to Rössing Uranium Ltd.

DEPARTMENT OF WATER AFFAIRS 1992. Letter to the General Manager Rössing Uranium Limited dated 20-07-1992.

DZIEMBOWSKI, Z. M. 1970. *Aquifer Constants of Alluvial Sediments in the Khan and Swakop Rivers near Rössing*. Geological Survey, Pretoria.

GIESS, W. 1971. A preliminary vegetation map of South West Africa/Namibia. *Dinteria* 4: 1-114.

GROUNDWATER CONSULTING SERVICES 1989. *Yield/Reliability Analysis, Discussion of Hydrogeological Parameters and Methodology*. Unpublished Report to Rössing Uranium Ltd.

Curriculum vitae

Sandra Müller was born in Adenau, Germany, in 1957. She studied Geology at the University of Cologne and obtained a "Diplom" (M Sc) in 1986. After arriving in Namibia in 1987, she was employed as a geohydrologist at the Department of Water Affairs, working on water supply projects and state water schemes until 1994. In 1995, she took up the position of hydrogeologist at Rössing Uranium Ltd, where her main duties are water quality control and aquifer management. This includes monitoring the effects of mining and water extraction on the vegetation on and around the mine site.