Pinnacle Gorge forms a major groundwater recharge zone, raising the level of the local groundwater table and seepage from the tailings dam gravitates towards the major drainages. In Pinnacle Gorge, this appears to occur mainly through the more permeable surficial sediments, while in the case of Dome and Panner Gorges, flow appears to occur through fractured bedrock. However, the situation in Panner Gorge is complicated somewhat by the "disappearance" of surficial flow approximately 3 kilometres below the tailings dam, followed by its re- emergence some 3 kilometres downstream, close to the de-watering trench. Measurements indicate that the flows at the two points are similar, though the quality is much better at the de-watering trench.

During the initial stages of mining at Rössing, substantial amounts of water were lost through evaporation and seepage from the tailings dam. The scarcity and high cost of water obtained from the Central Namib State Water Scheme (CNSWS) forced the implementation of stricter water conservation and recycling measures. These measures have greatly reduced the amount of water contained within the tailings dam, with a concomitant reduction in seepage losses.

Prior to the implementation of stricter water saving measures, measurements had shown that the seepage front in Pinnacle Gorge had reached the Khan River by 1982, while other seepage fronts were advancing down Dome and Panner Gorges. By February 1989, the sulphate containment front had advanced down Panner Gorge but had nor reached the Khan River. An efficient system of de-watering trenches and wells along each of the three gorges has greatly reduced the advancement of contaminant plumes in the groundwater. Had these measures not been implemented, water quality in the Khan River would have been substantially degraded, despite its already poor quality.

Data from the monitoring boreholes located along Dome, Pinnacle and Panner Gorges have shown that different chemical components in the seepage move at different rates through the groundwater. This is due to a variety of chemical process, including natural retardation, cation exchange and buffering, that occur within the soils and bedrock. For example, the extensive areas of marble beneath the tailings dam and its environs assist in neutralizing the acidic seepage. Consequently, many of the heavy metals which are more soluble in acidic waters, have not yet been detected in high concentrations in seepage below the tailings dam. Additional control measures will then be necessary.

The existing Rössing seepage control systems appear to be adequate for control of the existing contaminant plumes and will prevent large-scale contamination of the Khan River. However, the buffering capacity and chemical retardation capacity of the soils and rocks are finite and non-renewable. With the available data, it is not possible to estimate how long this chemical retardation will remain effective. Contaminant break-out will take place when the available buffering capacity has been consumed; individual contaminants will then start to move further away from the tailings dam.

The extent of the existing contaminant plumes suggests that some of the perennial vegetation in Pinnacle and Panner Gorges has already been affected. In the absence of distinguishable features of excessive salt stress, such as yellowing and shrivelling of leaves on trees, it must be assumed that the vegetation is able to tolerate much of the increased salt load. Should contaminant break-out from the tailings dam occur, there would be a rapid increase in the groundwater salt load which would probably eliminate all of the perennial vegetation.

4.9.5 Habitat Disturbance and Loss

To date, the total area covered by mining operations at the Rössing mine amounts to approximately 19 km ^{2}, with an additional 3 km^2 at Arandis, Swakopmund and the Rössing Country Club (Table

4.2). In the area of the Rössing mine, it is conservatively estimated that an additional area of at least 6 km^2 has been directly affected, either by wind-blown dust, tailings and radionuclides, or by excessive noise levels that have disturbed animals and birds. In the context of the entire Namib Desert, this figure of 25 km^2 would appear to be small; in a mining context, however, the area is enormous. Most of the affected area covers rugged hills, steep-sided valleys and ephemeral water courses. These habitat types provide important sources of food and shelter for birds and animals while the remarkable plant life of this region flourishes in the dry water courses.

In the case of the Rössing Uranium Mine and its environs, our scanty knowledge of the biota and ecological communities that existed prior to the start of mining activities is hardly sufficient to state unequivocally that particular combinations or communities of rare or endangered species have been eliminated by mining operations. Nevertheless, the available evidence clearly suggests that the area in and around the present mine most likely contained several plant and animal species, which, because of the uniqueness of the Namib Desert fauna and flora, must be considered as components of rare or endangered communities (Channing, 1974; Colahan, 1987; Craven, 1986; Friedman & Galun, 1974; Huntley, 1985; Louw & Seely, 1982; Robinson, 1976; Tarr & Loutit, 1985; Withers, 1979). However, current knowledge suggests that most elements of the biota (particularly the flora and insects) previously inhabiting the Rössing Mine site may reasonably be expected to be replicated in other nearby habitats of the Khan and Swakop Rivers. The scarcity of habitats similar to those affected by the Rössing operations suggest that there may also have been increased pressure on habitat availability further afield from Rössing.

4.9.6 Visual Intrusion

In many developed countries of the world there is widespread aversion to the appearance of most mineral workings. This is manifest by the almost universal insistence on landscaping being undertaken at new mineral workings. The aesthetic aspect of mining and the environment is difficult to discuss in view of the overwhelming importance of subjective factors and the lack of an objective baseline from which comparisons may be made. An additional complication is that opinion on the visual acceptability of a mining operation varies markedly, often depending on local traditions and preferences, or other non-visual criteria. Thus, the aesthetic design of mineral workings is controlled to a large extent by sociological factors outside the control of the engineer.

In the ideal situation, it should be possible to obtain a baseline measure of landscape value against which alternate designs of mineral operations could be compared to determine which caused the least visual impact. However, many attempts to achieve an objective scale of this type have been made with little success. It therefore appears that the extent and significance of the visual impact of mineral workings will remain a matter of purely subjective judgement for many years to come.

Almost every facet of a mining operation can create an undesirable visual impact, though five main groups are of particular importance in the Rössing context, namely: air and water pollutants, surface excavations, waste rock disposal, fixed plant and infrastructure.

The enormous scale of operations at Rössing can be clearly seen on ERTS satellite images of the central Namib Desert or, more easily, from commercial flights between Windhoek and Swakopmund. From the air, the open pit and the tailings dam, in particular, are prominent at both of these scales of observation. However, the visual impact of the Rössing Mine is dependent largely on the viewer's vantage point. In the horizontal plane, the Rössing mine is sufficiently far from the main Usakos-Swakopmund road that most of its main features are screened by the low rock ridge that separates the mine workings from the tailings dam. The frequent haze that is so characteristic of much of the Namib Desert also obscures the road traveller's view of any dust and fumes emitted from the mine. Similarly, with the development of the tailings dam within a system of dry watercourses at the top of Pinnacle Gorge, the surface of the tailings dam is now slightly below the level of the surrounding desert. The tan coloured tailings blend in with the surrounding desert surface and, since the low profile of the tailings dam does not intersect the skyline, are not visible from the main road.

Under calm weather conditions, the only features that are clearly visible from the main Usakos-Swakopmund road are infrastructure components, namely: the main tarred road and Rössing entrance pillars, the three water reservoirs and the freshwater pipeline, the town of Arandis plus associated powerlines and telephone lines. When blasting is in progress, large dust clouds can occasionally be seen above the site of the open pit.

During east wind conditions, a plume of wind-blown dust from the tailings dam is often visible, though this is sometimes obscured by the general dust haze.

The waste rock dumps within Dome and Pinnacle Gorges are not easily visible from points outside the mine property. However, many of the waste dumps and elements of the fixed plant are visible from the range of hills on the south bank of the Khan River and the Dome Gorge dump is visible from the Dome Gorge - Khan River junction. The waste dumps are extremely intrusive from these vantage points. The only sign of surface water pollution is the tailings pond which is visible from the ring berm wall and from the range of hills separating the tailings dam from the ore processing plant. The discoloured appearance of the water is very unsightly.

Signs of air pollution, in the form of increased dust levels and emissions of steam and fumes from smoke-stacks and the acid plant, are often dependent on prevailing weather conditions. During calm weather, air-borne dust is visible above the open pit, crushers, conveyors and tailings dam; windy conditions accentuate these dust levels. Stack emissions of sulphur dioxide and acid fumes are normally very low and seldom cause unsightly clouds. However, on the odd occasions when the acid plant has had to shut down operations, emissions are temporarily increased to unsightly levels.

In a mining operation the size of that at Rössing, it is inevitable that certain features will be considered visually intrusive. However, the remote location coupled with careful siting of the major works has greatly reduced these impacts to date. Nevertheless, it can be expected that further development of the Rössing Mine will exacerbate the visual impact of the mine workings, particularly those of the tailings dam, waste rock dumps and dust emissions.

4.9.7 Socio-Economic Changes

The impacts of economic and social changes due to a particular mining operation depend very largely on the attitude of the general public to mining which, in turn, is often determined by the state of the local economy and the nature of the community.

Traditionally, Namibia's economy has relied heavily on exports of primary merchandise and imports of manufactured goods. Minerals and agricultural produce comprise some 91 % of total exports, with the overwhelming majority contributed by minerals. By 1981, uranium mining at Rössing had overtaken diamond mining as the largest single contributor to the gross domestic product (GDP) of Namibia and was the largest single earner of foreign exchange. However, this position was precarious and depended largely on world uranium demand and market prices (Hartmann, 1987). With the recent independence of Namibia, previous trade restrictions have fallen away and the position is expected to improve.

Apart from uranium mining's direct contribution to the income generated in the economy, it also generates income indirectly through its acquisition of intermediate goods and services in its production process. These features place the national economy in a fragile position; even a 50 % reduction in uranium exports would, at 1980 estimates, have amounted to direct and indirect losses of some R 248 Million, or 19.5 % of the GDP. In addition to the income generated within the country by production processes, further value is added to the economy through spending processes.

In 1985, the Rössing Uranium Mine employed approximately 15 % of the total Namibian work force employed in the mining sector. This employment boost started in the early 1970's and was particularly welcome at a time when many Namibian mines had either decreased or stopped production. The high wages paid to employees, as well as the provision of family accommodation, excellent fringe benefits and training schemes, have tended to stabilize the workforce and create a labour elite or middle class. The emergence of trade unions and the provision of channels for consultation between employees and management has increased labour's share of the value added to mining production. With the variety of ethnic and cultural backgrounds comprising the workforce, the mine's principle of equal pay for equal work has led to a general upliftment of all personnel.

The many socio-economic impacts that the Rössing Uranium Mine has had are particularly noticeable at the regional and local level. These have included the creation of several hundred new job opportunities together with the institution of extensive and intensive training schemes. In addition, the development of extensive new housing schemes, schools, hospitals and recreational facilities has had an enormous "ripple effect" throughout the region. The urban centres most closely affected have naturally been Arandis and Swakopmund, where most of the mine personnel reside and spend their money. The improved infrastructure such as road, rail, air and telecommunications links with other major centres, and improvements to the supply of water and electrical power, have also contributed to general economic upliftment in the region.

5. PROJECTED FUTURE MINING OPERATIONS

5.1 Introduction

Since the start of mining operations in 1976, approximately 696 million metric tonnes of uranium ore and waste rock have been extracted from the Rössing open pit. Based on current estimates of proven ore reserves and mining operations continuing at full capacity, mining is expected to continue until the year 2018 when economic ore reserves are exhausted. By 2018, approximately 1890 million metric tonnes of waste rock and ore will have been extracted from the Rössing open pit (Table 5.1).

Prior to this, it is expected that alternate uranium deposits in the vicinity will have been surveyed to assess their economic viability. The implications of such additional mining activities will affect any decommissioning plans for the Rössing Uranium Mine. However, while such alternate uranium deposits would undoubtedly extend the useful life of the processing plant and infrastructure at Rössing, the impacts arising as a result of their exploitation are outside the scope of this study.

5.2 Mining Operations

Open pit mining operations at Rössing are expected to continue as a series of "benches" as the open pit is deepened and extended. Mining activities will, however, be concentrated towards the north-west arm of the uranium deposit (See Figure 2.3), and some back-filling of the open pit with waste rock will be possible. The conventional mining techniques of drill, blast, load and haul that are presently used will undoubtedly continue to form the basis of future operations. There is a probability that in-pit crushing and an ore conveyor system will be incorporated into the open pit operation to optimize haultruck loads (S. James, personal communication, 1990). The present system of three eight-hour shifts per day will be retained in future operations.

It is expected that future mining operations will result in the volume of the Rössing open pit increasing by a factor of approximately 2.7 during next twenty-eight years. By 2018, the open pit is expected to reach bench 35, equivalent to a depth of about 500 metres, and cover an area of approximately 700 hectares. Based on the projected tonnages that will be mined during the remaining life of the Rössing mine (Table 5.1) and an extraction efficiency of roughly 85 %, approximately 118 000 tonnes of U_3O_8 will be produced.

5.3 Processing Operations

5.3.1 Existing Processes and Techniques

For the foreseeable future, it is anticipated that all uranium processing operations currently in use at the Rössing Uranium Mine will continue to be operated as they are currently configured. These techniques have been developed and refined over some 15 years of operation and have proved to be cost efficient and very effective (Vernon, 1987).

The conveyer belt systems linking the primary crushers with the coarse ore stockpile and the secondary crushers are the sources of considerable amounts of wind-blown dust. Whilst it is likely that some form of shrouding will have to be installed to reduce these dust levels, this will increase the wind loading on the conveyer system. Incorrect shroud design could lead to serious damage of the conveyer system during the strong winds that prevail during the winter months. In turn, this would result in unacceptable interruptions to the uranium processing plant.

The geological nature of the remaining uranium-bearing alaskites at Rössing is similar to the ore that has been mined to date. As such, no changes to the current coarse grinding, leaching and ion exchange processes are envisaged at present. As before, close control will be maintained over the consumption of acid and other reagents used in the process, so as to minimize costs whilst attaining U_3O_8 production targets (Vernon, 1987).

At present, the Rössing Uranium Mine sulphuric acid plant has a production capacity of some 700 tonnes of sulphuric acid per day, sufficient to satisfy most of the mine's requirements (Vernon, 1987). The acid plant requires an assured supply of pyrite, preferably in a flotation concentrate form, which is presently supplied from the Otjihase Copper Mine near Windhoek. In future, it may be necessary to obtain pyrite supplies from some (as yet undetermined) alternative source.

Proposed modifications to the pattern of tailings deposition and improved control over recycling of the tailings dam solution have important economic and environmental implications. These are dealt with in Section 5.4.2.

5.3.2 Possible Future Developments

Two possible future developments in uranium processing are receiving attention at the Rössing Uranium Mine, namely: heap leach and alkali extraction techniques (B. Kloot, personal communication). Both of these techniques offer exciting possibilities for increasing the efficiency of uranium extraction, though each technique has specific applications.

The heap leach technique seems to hold particular promise for processing low grade uranium ore that is currently stockpiled since it is uneconomic to process. The full scale incorporation of a heap leach process is likely to require a relatively small additional area and will improve the reuse efficiency of tailings dam solution as leachate. However, unless appropriate control measures are taken, the technique could also increase human exposure to dust and radiation levels.

The possibility of using an alkali extraction as opposed to the acid extraction technique currently in use at Rössing will only be considered should uranium need to be extracted from an alternate, carbonate-rich rock type rather than the Rössing alaskites. However, this technique has no bearing on Rössing's current operations and is therefore not considered further.

5.4 Waste Disposal

With the complex nature and low uranium content of the main ore-body at the Rössing Uranium Mine, it is inevitable that enormous quantities of waste will be generated during the mining and processing operations. Since it is likely that future mining and processing operations will remain substantially the same as those employed at present, it is unlikely that the composition of the waste rock and tailings will differ significantly from those produced at present. Once again, therefore, the safe and efficient disposal of waste rock and tailings will continue to present problems of scale.

5.4.1 Waste Rock

The predicted cumulative total tonnages of waste rock and the different ore grades to be mined during the predicted lifespan of the Rössing Uranium Mine are shown in Table 5.1. Waste rock will continue to be dumped in the designated dumping areas around Dome and Pinnacle Gorges. Ultimately, it is envisaged that both of these gorges will be completely blocked with waste rock; Dome Gorge being filled to within some 50 metres of its junction with the Khan River. In addition, waste rock will also be used as back-filling in the mined-out north-western portion of the open pit (R.L. Murphy, personal communication).

TABLE 5.1: Predicted cumulative total tonnages of waste rock and different ore grades that will be mined during the future mining operations at Rössing Uranium Mine. (All values are given in millions of metric tonnes; data provided by A. Knowles, Rössing Uranium Mine).

Year	Waste Rock	Low Grade	High Calc	Ore	Total
1990	452,3	44,3	7,0	192,3	695,9
1995	598,0	57,6	10,7	254,4	920,7
2000	743,7	74,5	14,6	316,4	1149,2
2005	879,5	89,7	17,8	378,5	1365,5
2010	1019,3	104,7	25,0	440,5	1589,5
2015	1114,3	122,0	61,4	502,6	1800,3
2018	1143,2	128,4	78,9	539,8	1890,3

5.4.2 Tailings

At the Rössing Uranium Mine, all tailings will continue to be slurried to the existing tailings dam. Because of the low uranium content of the ore, virtually the entire mass of input ore, plus waste process liquids, will be deposited in the tailings dam. Based on the projected tonnages of ore that will be mined during the next 28 years (Table 5.1), approximately 347 million tonnes of tailings will be deposited during this period. This figure is approximately 1.8 times greater than the existing quantity of tailings and demonstrates the enormous additional quantities involved.

Clearly, these additional tailings will have a significant effect on the ultimate size and extent of the tailings dam. Current expectations are that the north-western ring berm wall will be raised to a final height of 597 metres above sea level, with an ultimate crest level of 640 m.a.s.l. at the eastern side (Figure 3.9).

The existing system whereby tailings are discharged at the raised periphery of the tailings dam has been reviewed and an alternative scheme proposed (Robertson & McPhail, 1989). The proposed system, whereby tailings are discharged into a system of smaller paddocks is likely to be in full operation by the end of 1990. Optimization of the paddock system will be conducted during 1990 and 1991.

The paddock system will enable deposition of coarse and fine particulates to be controlled through the careful location of paddock cross-walls. This will promote drainage directly to the pool area, reducing the quantity of water that is "locked up" in the tailings and reducing the area of wetted beach. In turn, this will reduce the tailings pond area and hence evaporative losses, while improving the efficiency of tailings transport and recycling of return dam solution (Robertson & McPhail, 1989).

5.4.3 Control of Dust and Radiation Emissions

Strong east winds during the winter months will continue to exacerbate wind erosion and dust dispersion, particularly from the tailings dam, ore stockpiles and the crusher and conveyer circuits. Additional erosion of the tailings slopes and beaches will also occur as a result of occassional summer rain storms. A failure to develop and maintain adequate remedial measures will inevitably increase the area that will require clean-up and isolation on decommissioning. Routine monitoring of radon emissions and dust levels at several points on the mine property will continue to form a vital part of the mine's safety programme. Similarly, appropriate measures to control dust and radiation emissions will form an essential part of the Rössing Uranium Mine's operations (Jooste, 1990).

Routine dust control activities, such as the wetting down of all unsurfaced roads and ore crushing circuits will continue unchanged, using recycled tailings seepage and saline water. However, the progressive deepening of the open pit will inevitably lengthen the haulage roads, thereby increasing the quantities of water required for wetting down operations.

Improved tailings disposal and increased recycling of return dam solution will tend to decrease the quantities of seepage water reaching the cutoff trenches in Panner and Pinnacle Gorges. While this has obvious advantages for reducing the spread of groundwater contamination, it will reduce the quantities of water available from these sources for wetting down roads and muck piles.

Stabilization of the particulate ore dumps and tailings dam will require considerable effort. In particular, attention will have to be paid to providing adequate cover of the tailings dam surface and slopes to reduce radon exhalations and dust dispersion. Chemical sprays have shown some promise in sealing the surface of tailings, but they are largely inadequate during the strong east winds. On the other hand, promising results have already been obtained with alluvium layers, suggesting that this technique holds the greatest promise for effective surface stabilization. It is likely that alluvium layers will be used in conjunction with a carefully planned pattern of tailings discharge into a paddock system, to reduce wind erosion and radon emissions.

During the remaining life of the mine, the tailings dam will increase in height and will become more susceptible to the effects of wind erosion, particularly at the north-eastern end. It is therefore vital that effective erosion control measures be implemented at an early stage. The earlier experimental work with salt-tolerant vegetation on the slopes of the tailings dam is unlikely to be continued because the plants are unable to withstand prolonged periods without water. However, some large shrubs and trees could be established along those drainage lines where tailings seepage is relatively shallow. In addition, the trials with old Wabco tyres could be extended to include other solid structures such as the so-called "sand fences" (Robertson & McPhail, 1989) to reduce near-surface wind velocities. This would reduce the extent of wind erosion and complement the use of surface sprays or alluvium layers.

5.5 Infrastructure

Future mining operations at the Rössing Uranium Mine will continue to depend heavily on the existing regional infrastructure. With the attainment of independence in Namibia and its planned withdrawal from the Rand monetary control area, foreign investments will be an extremely important source of finance for the development and extension of Namibian infrastructure and industry. Nevertheless, at the local and regional level, it will be necessary for individual communities and organizations to assume increased responsibility for the provision and maintenance of their own essential infrastructure components.

5.5.1 Water Supplies

In the future, assured supplies of fresh water will continue to play an important role at the Rössing Uranium Mine. The bulk of Rössing's freshwater requirements will continue to be met by the Central Namib State Water Scheme (CNSWS), though the declining water content in the Rooibank well field at Walvis Bay has greatly increased the pressure on available water supplies. It is almost inevitable that additional water will have to be obtained from wells or sand dams in the Omaruru River delta (Section 2.7.3).

Extraction of saline groundwater from the bed of the Khan River will also have to be continued; at present (1990), these wells supply some 3000 m^3 of water to the mine each day. Should water supplies in the CNSWS continue to decline, it will be necessary to increase water recycling on the mine and extract additional groundwater from the Khan River. If additional groundwater supplies are extracted from the Khan River, it is likely that Rössing will have to construct a dam in the Khan River to retain flood waters.

5.5.2 Power Supplies

The existing 220 kV electrical power supply to the Rössing Uranium Mine via a single circuit overhead transmission line from the SWAWEK switching station at Omburu will continue for the foreseeable future. Local switching sub-stations will continue to distribute electrical power within the mine property and at Arandis. The average maximum power demand and annual power consumption at the Rössing Uranium Mine is unlikely to differ significantly from the present levels of 38 MW and 21 million KWhrs, respectively.

In the event of power failures, the four diesel-driven 1.7 MW emergency generators will supply power to the leaching plant, boiler plant, acid plant and management sections.

5.5.3 Transportation

The existing road, rail and air transport systems in the area are likely to be adequate for continued operations at Rössing. Other than the required extensions to the open pit road system as mining progresses, no additional developments are likely to be necessary.

5.5.4 Sewage and Refuse Removal

The existing activated sludge systems for sewage treatment and disposal at the Rössing Uranium Mine, Rossec and Namib Lodges, Arandis and the Rössing Country Club will be adequate for future developments at the mine. Composted sewage sludge will continue to be used as a soil conditioner in gardens on the mine premises. Liquid final effluent from the sewage treatment plants will continue to be used for wetting down roads near the open pit. No expansions to the capacities of these works will be required since the staff complement at the mine is likely to remain relatively stable in the future.

Similarly, the existing system whereby domestic and industrial refuse is removed each week for burial in the waste rock dumps will be adequate for future developments.

5.5.5 Borrow Areas

Active borrow pits will be maintained in Pinnacle Gorge and to the west of the tailings dam. These will supply surfacing material for roads in the open pit and alluvium for covering exposed tailings surfaces. Virtually all of the borrow pits developed during earlier mining operations will gradually be covered by expanding waste rock dumps.

5.6 Housing and Recreation Facilities

The provision of good housing, social amenities and recreational facilities will continue to form an important part of the remuneration package for each Rössing employee. All employees are provided with a company house, either in Arandis or in Swakopmund, at a nominal rental.

5.6.1 Accommodation

The town of Arandis presently covers an area of approximately 135 hectares and accommodates Rössing's less skilled workers. Since these grades of employees form a relatively constant proportion of the Rössing work force, it is unlikely that Arandis will undergo significant expansion. In the event that additional business premises are developed in Arandis, some additional housing will be required. Similarly, the suburbs of Tamariskia and Vineta in Swakopmund which house the higher employee grades are expected to expand slightly when some additional housing units are provided.

5.6.2 Social Amenities and Recreational Facilities

The social amenities and recreational facilities provided at Arandis and the Rössing Country Club are expected to undergo a moderate degree of alteration and expansion. This is likely to be greatest in Arandis, when new business premises are developed in the town and community interests widen.

6. POSSIBLE IMPACTS LIKELY TO ARISE AS A RESULT OF FUTURE MINING OPERATIONS

6.1 Introduction

The projected future mining activities that are expected to occur at the Rössing Uranium Mine were described in Chapter 5. Whilst this description is rather generalized, it provides a basis for comparison with the activities that have already taken place. Furthermore, the description allows evaluation of the scale of impact that each type of activity is likely to have on the physical, biological and socio-economic environment described in Chapter 2. The rationale and grading system used to assess the scale and importance of these impacts is the same eight-point scale that was described in Section 4.1.

During the remaining mine life, it is anticipated that there will be considerable change in both predictive technology and the development of more effective stabilization and abatement measures (Robinson & McPhail, 1989). This will necessitate frequent revisions of earlier impact predictions and assessments of improved decommissioning techniques.

It is important to note that future mining activities are unlikely to cause new impacts, rather they will extend or accentuate the severity of existing impacts. For this reason, matrix tables showing the scale of impacts of projected future mining activities would be largely repetitive of those shown in Section 5 and have therefore not been included here.

The areas that are likely to be disturbed directly by each facet of the future mining operations at the Rössing Uranium Mine have been estimated and are shown in Table 6.1 for the period 1991-2018. The areas impacted by earlier mining activities (during the period 1970-1990) have also been included in Table 6.1 for comparison. It is important to note that many of the figures are approximations that have been derived from scanty data. The importance of these impacts is described later in this chapter.

6.2 Mining Operations

During the next 28 years, the Rössing open pit is expected to increase in area to approximately 700 hectares, equivalent to a 75 % increase. Once again, the most severe impacts will be those due to the continuation of elevated noise, dust and radiation levels, together with increased loss of scenic diversity. Other moderately negative impacts include additional loss of plant, animal and bird species in the area, probable changes to the groundwater chemistry and microclimate, and an increase in the erosion potential of the sandy soils and untarred road surfaces.

Continuous noise disturbance will be most intense in areas close to drill rigs and loading shovels, causing important negative impacts. This will be accentuated by engine noise from road scrapers, haultrucks and water bowsers. Once again, the twice-weekly blasts will cause short-lived, intense noise disturbance that will be audible for a distance of several kilometres.

Watering down activities will be increased as the open pit is widened and deepened, with moderately important negative impacts through contamination of groundwater. When the open pit base is lower than the Khan River it could cause a change in the direction of groundwater flow, increasing the rate of groundwater infiltration into the open pit. Should this occur, additional dewatering pumps will need to be installed in the open pit and, on the positive side, will provide additional water for watering down roads and rock piles.

TABLE 6.1: Cumulative areas of disturbance for each facet of the mining activities at Rössing Uranium Mine. The period 1970-1990 covers the exploration and current mining activities, while the period 1991-2018 covers the proposed future activities. (N.B. areas given are cumulative totals rounded to the nearest hectare at the end of the period in question, for each activity, which may be composed of scattered components).

Activity	Area of disturbance (1970-1990)	(hectares) 1991-2018
Exploration camp	2	2
Construction camp	4 *1	4
Geological survey (drilling site)	35 *2	35
Pilot plant	4 *2	4
Waste disposal area	<1	<1
Road construction	16 *2	16
Open pit and margins	400	700 *11
Coarse ore stockpile	11	11
Fine ore stockpile	<1	<1
Waste Rock dumps	535 *3	854 *11
Processing plant	100	100
Borrow pits	50 *4	50
Mine offices and gardens	25	25
Powerlines	15 *5	15
Railway line	7	7
Airstrip and hangars	15	15
Water supplies		
Freshwater supply + pump station	70 *6	70
Khan River pipelines + pumps	2	4 *11
Khan River 3 temporary dam walls	20	20
Dewatering trenches and wells	1	1
Drainage ditches and culverts	1	1
Seepage dams and reedbeds	2	2
Security fencing	4 *7	4
Road (gravel surface)	43	50 *11
(tarred surface)	26	26
Housing and recreation facilities		
Arandis (total)	135	145 *11
Namib Lodge and Rossec Lodge	20	20
Swakopmund suburbs	75 *8	80 *11
Rössing Country Club	100	100
Tailings dam and periphery	585 *3	700 *11
Sewage treatment plants (+ ponds)	7 *9	7
Industrial waste disposal	<1 *10	<1
Sanitary landfill	<1 *10	<1

1 = Site restored after mine came into operation.
2 = Most sites now covered by open pit and dumps.
3 = Estimated from aerial photos and maps.
4 = Many now covered by tailings dam and open pit.
5 = Length of line with 10m wide access strip.
6 = Length of pipeline with 10m wide access strip.
7 = Length of fence with 5m access strip.
8 = Averaged at 0.1 hectare plot size.
9 = Includes Rössing, Arandis, RCC.
10 = Buried in waste rock dumps.
11 = Estimated by Rössing staff.

However, it is not clear whether or not the increased seepage of water into the open pit will have an additional important negative impact in reducing the flow of underground water in the Khan River.

Elevated dust levels generated during drilling, blasting, loading and hauling operations will continue to be accentuated by strong winds, particularly during the winter months when east winds predominate. The appropriate corrective and protective measures that are currently used must be maintained to reduce the exposure of open pit personnel to dust and radiation levels.

Future mining operations are unlikely to increase the area impacted by the coarse and fine ore stockpiles (Table 6.1); impacts due to these two features are therefore likely to be unchanged. These will comprise locally elevated dust and radiation levels, increased erosion potential and potential groundwater contamination. Once again, the high proportion of live storage is the key to maintaining these negative impacts at low levels.

The dumps containing high calc and low grade ore will continue to be situated on top of, or adjacent to, the waste rock dumps around the periphery of the open pit. The areas of these dumps and their possible future impacts are dealt with in Section 6.4.

No additional development of the mine offices, gardens and security are expected to take place. Therefore, the impacts due to these features are expected to remain virtually unchanged. A possible exception to this could be the introduction of a noxious weed species or the arrival of additional alien bird and insect species.

The environmental surveillance and monitoring procedures currently undertaken at the Rössing Uranium Mine will continue to be conducted in the future. These activities have had, and will continue to have, extremely important positive impacts through the control and reduction of noise, dust and radiation levels over the entire mine works. These activities will continue to have important positive impacts for the health and social values of all mine personnel.

6.3 Processing Operations

The facilities and processes used to process uranium ore are unlikely to cover a significantly larger area than at present (Table 6.1), except if a heap leach process is incorporated.

Once again, the most important negative impacts are those due to elevated dust, noise and radiation levels, together with the emission of harmful gasses such as SO_2 from the acid plant. These impacts will be particularly acute close to the source and will diminish with distance. Training of personnel and the use of appropriate safety equipment will reduce these impacts. The visual impact of the facilities and the loss of scenic diversity will continue to have moderately important negative impacts.

The minor negative impact caused by the loss of habitat for indigenous plant, bird and animal species will tend to be accentuated by the further development of gardens containing alien plant species.

6.4 Waste Disposal

6.4.1 Waste Rock

During the remaining life of the Rössing Uranium Mine, it is anticipated that an additional 690 million tonnes of waste rock and approximately 156 million tonnes of high calc and low grade

uranium ore will be removed from the open pit. (Table 5.1). Table 6.3 shows the cumulative total areas that will be covered by the different dumps during this period (1990 - 2018). A substantial amount of waste rock will be used to back-fill the mined-out north-western sections of the open pit.

TABLE 6.2: Predicted cumulative total areas covered by dumps of waste rock and different ore grades at the Rössing Uranium Mine. (All areas are given in hectares; data provided by A. Knowles, Rössing Uranium Mine).

Year	Waste Rock	Low Grade	High Calc	Ore	Total
1990	455,96	41,83	37,33	11,57	546,69
1995	515,56	70,42	48,76	11,57	646,31
2000	499,99	111,16	61,08	11,57	683,80
2005	537,73	106,11	71,30	11,57	726,71
2010	573975	106,11	78,95	11,57	770,38
2015	618,09	110,26	111,72	11,57	851,64
2018	625,84	116,76	111,72	0	854,32

Once again, the most severe negative impacts associated with the waste rock dumps will be due to increased dust and noise levels, loss of scenic diversity and loss of plant, bird and animal habitats. Where the waste rock dump in the Dome Gorge approaches the Khan River confluence, it has a severe negative impact on aesthetic values.

The dumping technique currently employed will continue to cause elevated noise levels in the vicinity of the waste rock dumps, accompanied by higher dust and radionuclide levels. These dust and radiation levels will continue to pose a serious threat to plant and animal life in the area. Seepage of rainwater through the waste rock dumps will lead to higher levels of salts and radionuclides entering the groundwater. It will therefore be important to institute appropriate remedial or preventative measures at the down-slope sides of the waste rock dumps in Dome and Pinnacle Gorges, to prevent or reduce contamination of local groundwater.

6.4.2 Tailings

The Rössing tailings dam is expected to increase in area from 585 hectares to approximately 700 hectares by the end of the mine's lifespan (Table 6.1). This represents a relatively small increase over its current basal area and is the result of proposed changes to the tailings discharge practice (Kesler, 1987; Robertson & McPhail, 1989). During the same time, however, the height of the tailings dam is expected to increase to between 620 and 660 m.a.s.l., approximately double its present height. Again, the most severe negative impacts associated with the tailings dam are expected to be due to elevated dust and radiation levels, contamination of groundwater, the loss of scenic diversity and the loss of plant, animal and bird habitats.

The increased height of the tailings dam will increase the hydraulic pressure exerted on the local groundwater and could accelerate the rates of movement of seepage fronts and accentuate groundwater contamination. To some extent, this process will be countered by the proposed paddock system which will recycle larger quantities of water from the tailings dam and lower the hydraulic head.

An extremely important feature is that the underlying geological formations effectively neutralize the acidic seepage water, precipitating heavy metals and some of the salts. This neutralization capacity is finite and, as yet, unquantified. Therefore, it is very possible that continued seepage of acidic water will exhaust this neutralization capacity and increase the extent of groundwater contamination, with severe negative impacts on any plant life growing in the path of the seepage fronts.

In addition to its effect on groundwater, the increased height of the tailings dam will also lead to an increase in the quantity of dust and radionuclides dispersed by winds. This will have to be countered by progressively covering the exposed tailings dam surfaces with layers of alluvium or waste rock. This increase in the average particle size of surface layers will considerably reduce the erosive power of the wind. In turn, this will limit the amount of wind-blown tailings and sand that can be distributed across the surrounding countryside. Any stabilizing cover of alluvium and waste rock will also reduce the quantity of radon exhaled from the tailings dam. Preliminary estimates (Robertson & McPhail, 1989) indicate that radon levels will be reduced to within the Rössing target level of 0.74 Bq m^{-2} sec^{-1}.

6.4.3 Industrial Refuse

Approximately 13 000 m^3 of industrial rubbish will continue to be dumped each year at the Rössing Uranium Mine. The current practice of dumping this material within waste rock dumps will continue (L. Knoetze, personal communication). These dumps are likely to continue to have moderately important negative impacts on local groundwater through the contribution of salts and heavy metals leached out by percolating rainfall.

6.5 Control of Dust and Radiation Emissions

The effective control of dust and radiation emissions will continue to be a vitally important activity at the Rössing Uranium Mine. As before, optimum use of recycled seepage water and effluent will form the basis of dust control techniques in the open pit and on unsurfaced roads. Therefore, this will continue to have minor negative impacts on the local groundwater and microclimate.

Within the mine works, elevated dust and radiation levels will continue to be controlled through the use of covered or shrouded conveyor systems and exhaust ventilation. Protective clothing and respirators will also continue to play a central role in reducing the health risks of dust and radiation to mine employees.

At the tailings dam, the proposed paddock discharge system and the use of alluvium and/or waste rock layers will reduce the dispersion of dust and radionuclides. These practices will, however, not reduce the existing impacts of dust and radionuclides that have already been dispersed prior to covering and stabilization of the tailings dam.

6.6 Ground and Surface Water Protection Measures

Several counter measures are currently employed at the Rössing Uranium Mine to protect the local ground and surface water resources. These counter measures will continue to play a vital role in reducing the impact of seepage from the mine.

It is anticipated that seepage from the tailings dam could increase due to the increased hydraulic

pressure; this would be countered to a certain extent by improved recycling of return dam solution (Section 6.4.2). Nevertheless, the seepage dam is expected to continue to collect over 300 m^3 of tailings seepage per day, plus water extracted from the de-watering wells at the head of Panner Gorge. Plans to reduce or eliminate the Phragmites reedbeds will reduce evapotranspiration losses and provide additional water for dust control measures. This will reduce the negative impact of these reedbeds.

The cutoff trenches and de-watering wells will also continue to be important in preventing contamination of the Khan River groundwater, an important positive impact.

The groundwater monitoring programme will also continue to provide information essential to understanding the groundwater characteristics of the area and evaluating the effect of remedial actions. The negative impacts associated with disturbance, noise and dust levels during travel to, and sampling of, these wells is considered to be negligible. Vegetation monitoring in the bed of the Khan River will continue to provide useful ecological information on the condition of the perennial vegetation.

6.7 Infrastructure

Should the existing water supplies to the Rössing Uranium Mine continue unchanged, the impacts are envisaged to remain the same as those detailed in Section 4.7.1. However, if the water supplied by the CNSWS from the Kuiseb Delta becomes insufficient to meet Rössing's demands, an additional source will have to be developed. It is probable that an additional well field and possibly a sand dam will be constructed in the Omaruru Delta, several kilometres inland from the small town of Henties Bay, to provide an alternate supply of water for the mine. In addition, it may become necessary for Rössing to construct either a single sand dam or series of smaller dams in the bed of the Khan River. These structures would have the distinct advantage of reducing supply costs, but would also lead to a drastic reduction in flow in the Khan River. This would have severe negative impacts on perennial vegetation in the river bed, but would also have a positive impact in reducing the quantity of saline water reaching the Swakop River.

No additional impacts are anticipated in regard to the supply of electrical power to Rössing; the electricity pylons will continue to be visually intrusive and reduce the scenic diversity of the area. It is anticipated that no additional roads will be constructed at the Rössing Uranium Mine. Therefore, no additional impacts are foreseen. Visual intrusion and elevated dust levels will remain the most important negative impacts.

Many of the borrow pits that were dug during the earlier phases of mining at Rössing have been covered by waste rock and the tailings dam. However, the continued need for road surfacing material and the construction of seepage dam walls will require the development of approximately the same area of new borrow pits. Towards the end of mining activities, very large volumes of alluvium (> 1 million cubic metres) and waste rock will be required for covering and stabilizing the surface of the tailings dam (Robertson & McPhail, 1989). The necessary borrow pits will probably be dug in the upper reaches of Dome and Pinnacle Gorges and the area to the west of the tailings dam. If the proposed paddock system of tailings discharge is implemented, portions of the tailings dam can be covered and stabilized with alluvium at an earlier stage.

Important negative impacts associated with borrow pits will be elevated dust levels, with minor negative impacts caused by periodic engine noise, loss of available habitat, disturbance to indigenous species and minor loss of visual diversity. Many of the additional borrow pits will eventually be covered by waste rock dumps.

6.8 Housing and Recreational Facilities

The town of Arandis presently (1990) covers an area of approximately 135 hectares (Table 6.1). It is anticipated that very little expansion in the area of Arandis will occur during the life of the Rössing Uranium Mine. Any expansion is likely to consist primarily of improved sports facilities and recreational areas and has been estimated to amount to less that 10 % of the existing area of the town (Table 6.1). The development of gardens and sports fields using alien vegetation will continue to pose a minor negative impact which will remain localized in the immediate area of the town.

It is anticipated that the Swakopmund suburbs of Tamariskia and Vineta will undergo minor expansions of up to five hectares in extent with the gradual upgrading of senior staff at Rössing. This will continue to exert a strong positive impact on the regional and national economy, land values and demographic patterns.

Temporary contract workers at the Rössing Uranium Mine will continue to be housed at Namib Lodge and Rossec Lodge. No expansion to these facilities or their recreational amenities is envisaged and their moderately positive impact on regional income levels and the job satisfaction of personnel will continue. Minor negative impacts due to noise disturbance, elevated dust levels and the disruption of vegetation patterns will also continue.

There are no significant expansions envisaged for the Rössing Country Club and these facilities will continue to play an important role in the social life of all mine personnel. The impacts associated with the layout and management of the facilities will continue as described in Section 4.8.4.

6.9 Overall Impressions of Possible Future Impacts

Previous sections of this chapter have detailed the extent and possible significance of environmental impacts resulting from the projected future activities at the Rössing Uranium Mine. Clearly, the enormous scale of operations at Rössing will continue to dictate the extent and severity of impacts. However, as mentioned in Section 4.9, a wide variety of activities and processes at the mine contribute to, and complicate, the impacts on any one component of the environment. It is therefore once again appropriate to draw together those contributors to items of concern and evaluate their overall impact on the environment. In order to avoid excessive repetition, frequent reference will be made to Section 4.9 where the major items of concern in relation to the current mining activities were highlighted.

6.9.1 Noise and Vibration

Noise and vibration are inescapable features of any mining operation, with the extent and severity of any impacts diminishing with distance from the source. Clearly, the major impacts of noise and vibration will continue to be experienced by mine personnel though their effects are controllable through the use of appropriate protective equipment (Section 4.9.1).

In the case of the natural environment around the mine, noise and vibration will continue to disturb animals and birds for a radius of a few kilometres. Earlier observations that some small game animals and birds might be "acclimatized" to moderate noise levels suggests that these species will continue to tolerate the noise generated during mining operations.

6.9.2 Dispersion of Particulates

The dispersion of particulate material by air and water will continue to be a prime concern at the Rössing Uranium Mine. In particular, respirable dust dispersed from the tailings dam, open pit, ore crushers and conveyers, and the processing plant will continue to pose health hazards to mine employees. Once again, thorough watering down procedures and the use of protective equipment and clothing will reduce these health risks to acceptable levels.

Runoff generated during the infrequent and episodic rainfalls experienced at Rössing will continue to be regarded as an important erosive process for the dispersion of dust and radionuclides (Section 4.9.2). The anticipated increase in the height of the tailings dam will increase the importance of runoff, though its impacts will be concentrated in the shallow water courses at the head of Panner and Pinnacle Gorges.

Wind erosion of dust and radionuclides from the tailings dam will increase in importance as the height of the tailings dam increases. The strong east winds that are so characteristic of the winter months will continue to disperse tailings dust over a large area of the surrounding desert. The development of improved tailings discharge techniques will, however, allow more attention to be paid to stabilization of the tailings dam surface and walls. Tests with sand fences and layers of waste rock and alluvium have demonstrated that wind erosion can be reduced to acceptable levels. The appropriate combinations of materials and techniques should be installed progressively with the aim of minimizing erosion loss and radon exhalations. This will greatly reduce the area of surrounding desert requiring clean-up actions when the mine is finally decommissioned.

6.9.3 Radiation

Radon exhalations from the tailings dam, ore stockpiles and waste rock dumps, together with the dispersion of radionuclides in wind-blown tailings and ore will continue to pose a serious problem. While the consequences of this radiation for plant and animal life are not known, they are considered to be harmful (Section 4.9.3). The remote location of the mine, together with the short half-life of radon and its rapid dilution in air, will continue to be mitigating factors. The implementation of improved dust control techniques at the tailings dam would contribute substantially to reducing ambient radon levels. While continued use of appropriate safety procedures and protective equipment are expected to be sufficient for the protection of mine personnel, continued monitoring is required to verify this.

6.9.4 Seepage and Groundwater Contamination

Seepage from the tailings dam at the Rössing Uranium Mine has the potential to cause very serious environmental impacts, particularly through contamination of local groundwater (Section 4.9.4). The present rates of seepage from the tailings dam are likely to increase gradually as the height of the tailings dam is increased in the future. The existing de-watering wells and cut-off trenches provide an efficient means of controlling the spread of contaminant plumes into the Khan River. It is anticipated that this system will continue to prevent the ingress of seepage plumes from Dome, Pinnacle and Panner Gorges into the Khan River. However, geological evidence suggests strongly that there is considerable additional major groundwater movement through fractures in the bedrock. Additional studies will be required to ascertain whether or not seepage through the bedrock poses a significant threat to water quality in the lower Khan River.

The chemical retardation and buffering capacity of the Rössing marbles and soils beneath the tailings dam have played a major role in reducing the movement of contaminants from the tailings dam into the local groundwater. However, this capacity is both finite and non-renewable. Contaminant break-out will take place when the available buffering capacity has been consumed and individual contaminants will then move further away from the tailings dam. Whilst there is presently insufficient evidence available to predict when and where this will take place, it must be regarded as inevitable. At that time, it is vital that the route and speed of groundwater movement is known so that effective control measures can be implemented. Failure to adequately control tailings seepage will cause a rapid increase in the groundwater salt load and the probable elimination of all perennial vegetation in the affected areas.

6.9.5 Habitat Disturbance and Loss

By the year 2018, it is anticipated that the total area covered by mining operations at the Rössing Uranium Mine will amount to approximately 27 km^2, with an additional 3.3 km^2 at Swakopmund, Arandis and the Rössing Country Club (Table 6.1). In the immediate vicinity of the Rössing Uranium Mine, it is conservatively estimated that an additional area of at least 10 km^2 will be directly affected by wind-blown tailings, dust and radionuclides, or by excessive noise levels. These areas represent an increase of some 40-50 % over those affected at present (Section 4.9.5). Most of the affected areas will again consist of rugged hill slopes, steep-sided valleys and ephemeral water courses. These habitat types provide vitally important sources of food and shelter for birds and animals while much of the region's remarkable plant life is concentrated along the dry water courses (Section 4.9.5).

As stated previously (Section 4.9.5), the available evidence suggests strongly that the area around the Rössing Uranium Mine most likely contained several plant and animal communities, many of which must be considered as rare and endangered because of their scarcity. It is also clear that many of the plant communities originally present on the Rössing Uranium Mine site have been eliminated completely, while the increased area of impact will eliminate others. Though the available botanical evidence (Robinson, 1976; Craven, 1986) suggests that most if not all of these species are present in other nearby habitats along the Khan and Swakop Rivers, the scarcity of these habitats indicates increased pressure on habitat availability. Thus, the predicted increase in area of impact must be considered a cause for deep concern.

6.9.6 Visual Intrusion

The enormous scale of mining operations at Rössing is clearly visible, both on ERTS satellite images of the Central Namib Desert and from commercial air flights (Section 4.9.6). The predicted increase in the extent of the mine workings by the year 2018 will accentuate this.

The visual impact of the Rössing Uranium Mine workings depends on the viewer's vantage point. At present, very little can be seen of these workings from those vantage points that are available to the general public (Section 4.9.6), with the possible exception of certain infrastructure components and dust plumes from the open pit and tailings dam. Much of the visual impact is also obscured by the general dust haze so characteristic of the region and which is exacerbated during the strong east winds of winter.

The projected increase in the height of the tailings dam will dramatically increase its visual intrusion though this will be partially offset by the tan coloured tailings tending to blend in with the surrounding countryside.

The waste rock dumps in Dome and Pinnacle Gorges will continue to be extremely intrusive from selected vantage points along the Khan River bed and the range of hills along its south bank.

6.9.7 Socio-Economic Changes

Traditionally, the Namibian economy has relied heavily on exports of primary merchandise and imports of manufactured goods. In the past, minerals and agricultural produce accounted for some 91 % of total exports (Section 4.9.7), with uranium as the major contributor to the country's gross domestic product. This position was precarious and depended largely on world uranium prices and demand. The world market for uranium is still in a state of flux and no clear trend in uranium prices is visible as yet.

Several social and economic changes are expected to take place within Namibia in the years following independence, particularly due to the lack of trade restrictions. Amongst other factors, the country's withdrawal from the Rand monetary area and the anticipated Central Government emphasis on the development of a mixed economy is expected to attract greater participation by foreign investors.

The socio-economic changes brought about by the Rössing Uranium Mine have made enormous contributions at local, regional and national levels (Hartmann, 1987). The development of a labour elite, or middle class, and the strengthening of trade union activities will continue to stabilize the Rössing workforce. This, together with continued indirect income generation through the acquisition of intermediate goods and services, as well as spending by Rössing employees, is expected to increase the "ripple effect" that the Rössing Uranium Mine has had on the National economy.