# ANNEXURE E:
# FINAL MCDM LAND USE REPORT 2008

Report No: 4691/402239

# APPLICATION OF A MULTIPLE CRITERIA DECISION-MAKING MODEL TO ASSIST WITH FUTURE LAND USE PLANNING AT RÖSSING URANIUM MINE ~ HEAP LEACH, RIPIOS, TAILINGS AND WASTE DUMPS

## *REPORT ON SELECTED MODEL, APPLICATION AND FINDINGS*

August 2008

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## PROJECT DETAILS

| | |
|---|---|
| **TITLE** | Application of a Multiple Criteria Decision-Making Model to Assist with Future Land Use Planning at Rössing Uranium Mine ~ Heap Leach, Ripios, Tailings and Waste Dumps |
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My colleague, Brett Lawson, for facilitation of the workshop.

Thanks also to Katharina Dierkes for assistance with mapping and providing GIS support during and after the workshop.

# ABBREVIATIONS

| | |
|---|---|
| **AHP** | Analytical Hierarchy Process |
| **CR** | Consistency Ratio |
| **MCDM** | Multiple Criteria Decision-Making |
| **MET** | Ministry of Environment and Tourism (national environmental authority) |
| **MET:DEA** | Ministry of Environment and Tourism's Directorate of Environmental Affairs |
| **RU** | Rössing Uranium |
| **SEIA** | Social and Environmental Impact Assessment |

# NON-TECHNICAL EXECUTIVE SUMMARY

## Application of a Multiple Criteria Decision-Making Model to Assist with Future Land Use Planning at Rössing Uranium Mine ~ Heap Leach, Ripios, Tailings and Waste Dumps

Rössing Uranium has operated an open pit uranium mine in the Erongo Region of Namibia since 1976. Rössing Uranium is now looking at extending the life of the mine and consequently the associated social and environmental issues are being reviewed. The proposed expansion project would comprise nine individual components and is divided into two main phases. The Ministry of Environment and Tourism: Department of Environmental Affairs has issued a clearance for the Phase 1 Social and Environmental Impact Assessment project components and the Phase 2 Social and Environmental Impact Assessment for the remaining expansion project components will follow this land use optimisation exercise.

Engineers and scientists often face decisions whereby priority is to be assigned to various options based on a set of multiple criteria. This decision-making process is referred to as Multiple Criteria Decision-Making. It is structured using sets of pairwise comparisons in matrices, using a numerical scale to assign preference to alternatives.

Four of the Phase 2 Social and Environmental Impact Assessment project components, *viz.* increased waste rock disposal capacity, increased tailings disposal capacity, establishing an acid heap leaching facility and associated ripios or spent ore waste site, have associated long term spatial planning implications and has to be located within the mining licence area or accessory works area. Rössing Uranium appointed Ninham Shand (Pty) Ltd to assist with the strategic planning of the future land use, through the application of a Multiple Criteria Decision-Making Model, specifically aimed at the optimisation of the layout of these four expansion project components.

Advantages of this specific model in an application such as land use optimisation at Rössing mine are the following:

- It can tolerate a degree of inaccuracy due to rating or level of detail of base data, and as such allows for the application of this model early in the project life cycle, prior to detailed engineering designs being available;
- It allows for testing of the consistency of rating;
- It allows for a degree of difference of interpretation of rating scale by the various team members / specialists looking at the various aspects, as the results are normalised in the process as the model expresses the results as unit-less numerical values indicating relative preference only;
- Its ease of use and transparency;
- A sensitivity analysis can be done easily; and

- If required, it allows for the ranking of the criteria to determine the weighting that would apply to these criteria in the calculation of the relative preference in the optimisation process.

Rössing Uranium determined the draft list of criteria and the various facility site options for the heap leach, ripios, waste rock dumps and tailings facilities prior to the scheduled optimisation workshop and these were accepted as process inputs. The main purpose of the list of criteria is to ensure consistency in the evaluation process by clearly defining aspects to be considered.

The optimisation workshop was scheduled from 20 to 21 May at the Rössmund Conference Centre outside Swakopmund. The attendants represented the technical, environmental, socio-economic and strategic fields of expertise and included technical project managers for the expansion project components and a suite of Rössing Uranium in-house and contracted scientists and specialists. The diverse group that participated in the workshop stimulated considered debate, resulting in consensus on the rankings in the applications of the model. Mutual agreement on the outcome of the optimisation process was successfully realised.

The overall premise of the workshop, proposed by Rössing Uranium and adopted by all present, was:

*"Given the shortage of space, we need to find the optimum arrangement to limit impact on undisturbed ground."*

The purpose of this workshop was to consider the allocation of land to four identified land uses through allowing for the potential maximum expansion scenario. Specific objectives agreed upon at the outset of the workshop included:

- To minimise the physical footprint of the proposed expansion;
- To prioritise the sites for different applications (or facilities) in areas where the sustainable development impacts are minimised;
- To find the best practical site for each land use;
- To make best use of newly impacted sites; and
- To ensure that the expansion follows a strategic life of mine approach.

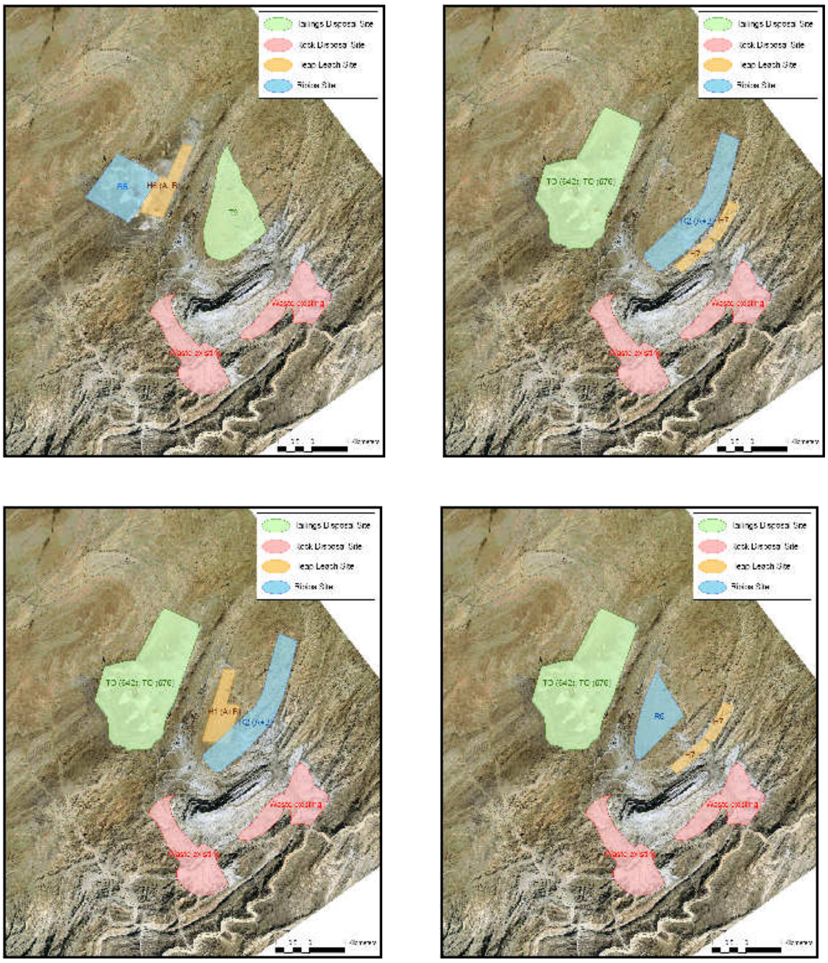
The model was applied in the optimisation to meet the objectives listed above. The need for the optimisation stemmed from the spatial constraints, the need to identify the optimum layout of the proposed facilities against the pre-determined criteria, and Rössing Uranium's commitment to sustainable development and the undertaking to limit the impact on undisturbed ground.

The strategy for optimisation applied at the workshop allowed for the preference ranking of the four individual facilities (in isolation) through application of the selected model, followed by development of possible and feasible layout combinations of the top-ranked facility sites. Each such combined layout comprised a single heap leach, ripios, waste rock dump and tailings site. The conclusion to this process was the optimisation of these combined layouts through a second application of the model, which indicated the relative order of preference of these combined layouts.

It was decided to consider the first three criteria categories, being technical, environmental and socio-economic, in the first application of model to determine the preferred siting of the individual facilities, whilst the strategic criteria category was added in the second application to rank combined layouts.

The individual facility sites were ranked against the criteria using the determined weightings and the top sites were used to determine a list of 81 potential combined layouts for further consideration by looking at combinations of the top three sites for each individual facility. Further to the strategic decision to exclude all in-pit facility sites, mutually exclusive facility site combinations and impractical layouts were excluded from further consideration.  Since none of the top ranked waste sites overlapped with any other potential facility sites, the waste sites could be excluded from further assessment as it did not influence the optimisation of the remaining combined layouts.

The four top-ranked combined layouts that emerged from this process are illustrated below.



**Top Four Combined Layouts in Order of Preference**

A sensitivity analysis was undertaken to test the outcome, with seven different criteria category weighting scenarios considered. The sensitivity analysis confirmed the preference of the top four ranked layouts and thus no need exists to investigate any of the other layouts further.

The top four layouts could broadly be grouped into two categories, since three of the four layouts are minor variations of each other. As such, the main alternatives would be to:

- Establish the heap leach and ripios facilities on the existing tailings, with a new tailings facility to be established on the Dome; or
- Establish the heap leach and ripios facilities on the Dome, with increased capacity provided at the existing tailings facility by elevating it.

The recommendations for the way forward are to:

- Study the top four ranked layouts and to prepare financial models for each, based on preliminary engineering design work for each of the sites;
- Commission any specialist studies that would be required to underpin such engineering design work;
- Where required, consider ways of providing additional capacity where the specific sites considered could prove to have insufficient capacity, either by enlarging them, or adding the next ranked site to the layout; and
- Recommend a final selected layout for consideration in the Phase 2 Social and Environmental Impact Assessment.

The findings and recommendations of this optimisation of combined layouts would need to feed into the Phase 2 Social and Environmental Impact Assessment process, which would seek environmental clearance for these and other expansion project components.

**August 2008**

# 1 BACKGROUND AND INTRODUCTION

The purpose of this chapter is to provide background information on the proposed expansion project and to contextualise the need for the application of the Multiple Criteria Decision-Making (MCDM) model and to provide limited background information on the model used. This chapter ends with a brief section on the context and structure of the remaining chapters of the report.

## 1.1 BACKGROUND AND INTRODUCTION

Rössing Uranium (RU) has operated an open pit uranium mine in the Erongo Region of Namibia since 1976. Figure 1 overleaf provides a locality map for the mine. As a result of an increase in uranium prices on the international market in recent years, RU is able to consider the possible financial benefit from an expansion of its operations. The previous mine plan predicted an operational period ending in the year 2016. According to this plan, a sustainability assessment was undertaken and approved in 2005. RU is now looking at a mine plan beyond 2016 and consequently, the associated social and environmental issues are being reviewed.

A Social and Environmental Impact Assessment (SEIA)[1] has thus been commissioned by RU for their proposed expansion project, as required by the Environmental Assessment Policy (1994) but also informed by the principles of Namibia's Environmental Management Act (Act No 7 of 2007), as well as the internal standards and guidelines prescribed by Rio Tinto, RU's parent company. The proposed expansion project would comprise, in summary, nine individual components and the SEIA being undertaken is divided into two main phases, as per the list below:

Phase 1:

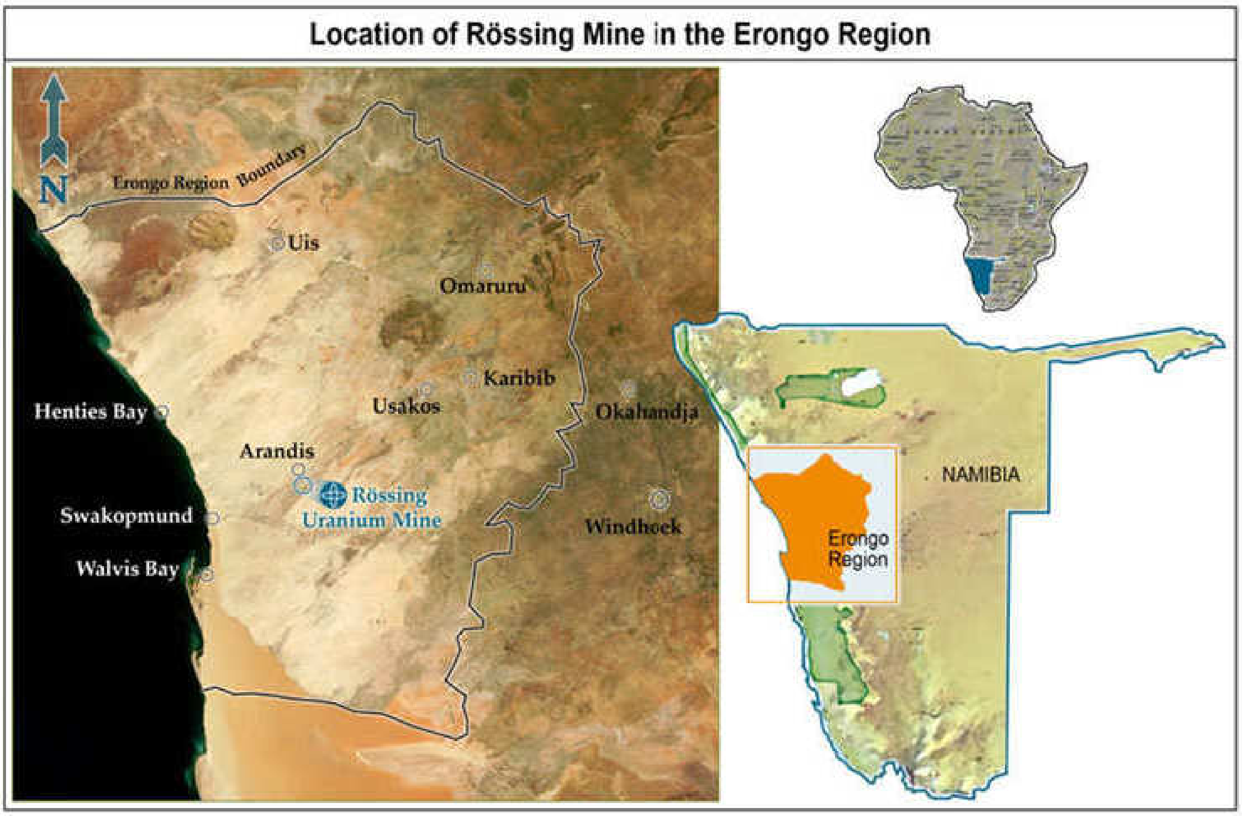
- A sulphuric acid manufacturing plant with associated sulphur storage on the mine, and the transport of sulphur from the Port of Walvis Bay;
- A radiometric ore sorter plant;
- Mining of an ore body known as SK4;

Phase 2:

- Extension of the current mining activities in the existing SJ pit;
- New mining activity in the larger SK area;
- *Increased waste rock disposal capacity*;
- *Increased tailings disposal capacity*;
- *Establishing an acid heap leaching facility and ripios site*; and
- Sulphur handling in the Port of Walvis Bay.

[1] It is recognised that the term "environment" when applied in the context of an environmental impact assessment refers to the total environment, i.e. encompassing both the socio-economic and biophysical environments. Notwithstanding this recognition, however, RU prefers to retain the term "social" in the title of the present environmental impact assessment, as a clear indication of their commitment to the human element in the affected environment and in keeping with their Sustainable Development Frameworks.

The Ministry of Environment and Tourism's Directorate of Environmental Affairs (MET:DEA) has issued a clearance for the Phase 1 SEIA project components and the Phase 2 SEIA will follow this land use optimisation exercise.




**Locality Map** (source: RU)

Four of the Phase 2 project components, *viz.* increased waste rock disposal capacity, increased tailings disposal capacity, establishing an acid heap leaching facility, and associated ripios or spent ore waste site, have associated long term spatial planning implications and have to be located somewhere within the mining licence area or the accessory works area. The locations of the other components are fixed, in that they are either linked to a specific ore body location, or the existing Port of Walvis Bay. As such, RU appointed Ninham Shand (Pty) Ltd to assist with the strategic planning of the future land use, through the application of a Multiple Criteria Decision-Making (MCDM) Model, specifically aimed at the optimisation of the layout of these four project components.

The purpose of this report is to document the process followed, record inputs prior to the MCDM model application workshop, the ranking and outcomes of the MCDM application workshop, and to summarise the results and recommendations.

## 1.2 THE MCDM MODEL

The process of MCDM prioritises options against a set of criteria, rather than a single criterion. This process is well-suited to address complex technical strategic planning challenges, as is often the case in engineering and mining applications. In MCDM, options could typically include project, technology and sequencing alternatives. Although several MCDM models are available internationally, not all are ideal for this specific category of application.

The model used in this process is the Ideal Mode Analytical Hierarchy Process (AHP) Pairwise Comparison Model. A detailed description of this model, including an historical overview, matrix structure, mathematical formulae and a numerical example is included as Annexure E to this report for reference purposes. These aspects are not repeated in this report.

It has to be said that MCDM using structured pairwise comparisons in a matrix has a long history of development and is known to have been used, albeit in a simplified form, since the 1700s. Various developments and improvements to these earlier models were introduced by mathematicians and researchers through the ages. Specific refinements that led to the development of the Ideal Mode AHP Pairwise Comparison Model followed in the 1980s when the original AHP Pairwise Comparison Model was proven unstable. The recommended model is widely accepted as the most reliable and has inspired the development of various other MCDM tools and software packages. It is recommended due to the ease of application in a spreadsheet format using simple matrix mathematics.

Advantages of this specific model in an application such as land use optimisation at Rössing mine are the following:

- It can tolerate a degree of inaccuracy due to rating or level of detail of base data, and as such allows for the application of this model early in the project life cycle, prior to detailed engineering designs being available;
- It allows for testing of the consistency of rating;
- It allows for a degree of difference of interpretation of rating scale by the various team members / specialists looking at the various aspects, as the results are normalised in the process as the model expresses the results as unit-less numerical values indicating relative preference only;
- Its ease of use and transparency;
- A sensitivity analysis can be done easily; and
- If required, it allows for the ranking of the criteria to determine the weighting that would apply to these criteria in the calculation of the relative preference in the optimisation process.

The specific rating scale used throughout this application is summarised in the table below:

| RATING SCALE TABLE | |
|---|---|
| **Rating** | **Description of Relative Rating** |
| 1 | Equal |
| 3 | Weak preference |
| 5 | Essential or strong preference |
| 7 | Demonstrated preference |
| 9 | Absolute preference |
| 2, 4, 6, 8 | Intermediate values |
| Reciprocals of the above | If for criterion x, option A has a rating of one of the above when compared to option B ($R_{xAB}$), then option B has the reciprocal rating when compared to option A ($R_{xBA} = 1 / R_{xAB}$) |

## 1.3 CONTEXT AND STRUCTURE OF THIS REPORT

This report on the application of the MCDM model at RU is structured as follows:

| | |
|---|---|
| Chapter One | *Provides the background and introduction, and summarises advantages of the recommended MCDM model;* |
| Chapter Two | *Describes the inputs to the MCDM workshop, i.e. the list of criteria and the various facility site options as determined by RU;* |
| Chapter Three | *Describes the application of the MCDM model to rank individual facilities, describes the process followed to define combined layouts and filtering thereof, followed by the second round of MCDM model application to determine optimum layouts;* |
| Chapter Four | *Describes the sensitivity analysis completed after the workshop; and* |
| Chapter Five | *Summarises the final ranking results, describes advantages of the top-ranked layouts and lists the recommendations.* |

# 2 MCDM WORKSHOP INPUTS

The purpose of this chapter is to briefly describe the inputs to the MCDM workshop, specifically the list of criteria and the various facility site options for the heap leach, ripios, waste rock dumps and tailings facilities, as determined by RU prior to the workshop. The main purpose of the list of criteria is to ensure consistency in the MCDM evaluation process by clearly defining aspects to be considered.

## 2.1 CRITERIA

The main purpose of the criteria list is to define which aspects need to be considered in the evaluation of the facility site options, and later in the evaluation of the combined layouts, thus ensuring consistency in the evaluation process.

RU determined a list of criteria comprising four main categories for use in the MCDM workshop. This list is repeated here, for ease of reference, with limited additions thereto recommended by the specialists that attended the two day workshop indicated in *italics text*. Note that the three main pillars of sustainable development, being economic viability, environmental sustainability and social acceptability, form the basis from which these criteria categories were developed. Economic criteria are built into the technical (or engineering) category, since engineering solutions has budget implications. The fourth criteria category, being Strategic Criteria, applied only tho the evaluation of combined layouts.

### 2.1.1 Technical Criteria

Technical criteria and sub-criteria for consideration included:

- Height and distance from plant, heap leach or pit,
  - Conveyor/haul routes and cycle times,
  - Power consumption, diesel consumption and general equipment wear-and-tear;
- Topography and elevation,
  - Terrain preparation;
- Cut off grade *and pit size* (will affect volumes/leach recovery),
  - Volume and area footprint,
  - Material profile (final);
- Settlement;
- Sufficient buffer for fly rock;
- Deposition method (conveyors, pipelines, paddies, thickened, dry stacking, race track, on-off);
- Geohydrology,
  - Subsurface stability,
  - Lining requirements,
  - Leachate management,
  - Storm water permeability; and
- Closure,
  - Cover requirements,
  - Long term stability.

### 2.1.2 Environmental Criteria

Environmental criteria and sub-criteria for consideration comprised:

- Ecology,
  - Biodiversity,
  - Flora and fauna (including red listed species),
  - Ecological services,
  - Impact on habitat;
- Land use, footprint extension;
- Dust emissions due to wind erosion;
- Resource use (water, energy),
  - Water losses due to wind,
  - Power consumption;
- Seepage impact and control options;
- Geohydrology *and seepage,*
  - Water quality; and
- Closure,
  - Rehabilitation,
  - Long term leachate.

### 2.1.3 Socio-Economic Criteria

The Socio-Economic criteria and sub-criteria included:

- Dust impact and control options;
- Distance from Arandis (potential health impact on inhabitants);
- Surface area exposed (radon emissions);
- Visual impact, both with respect to colour and height;
- Archaeology;
- Geohydrology,
  - Resource use; and
- Closure,
  - Long term emissions (i.e. water, air).

### 2.1.4 Strategic Criteria

Strategic criteria and sub-criteria for consideration in the evaluation of combined layouts included:

- Sterilisation of ore reserves and future drilling areas;
- Co-disposal with waste rock;
- Potential reuse of material;
- Surrounding land uses;
- Sequencing;
- Phased use of separate sites for the same process options e.g. ripios placed in a number of sites;
- Reputation,
  - Bad and good practice,

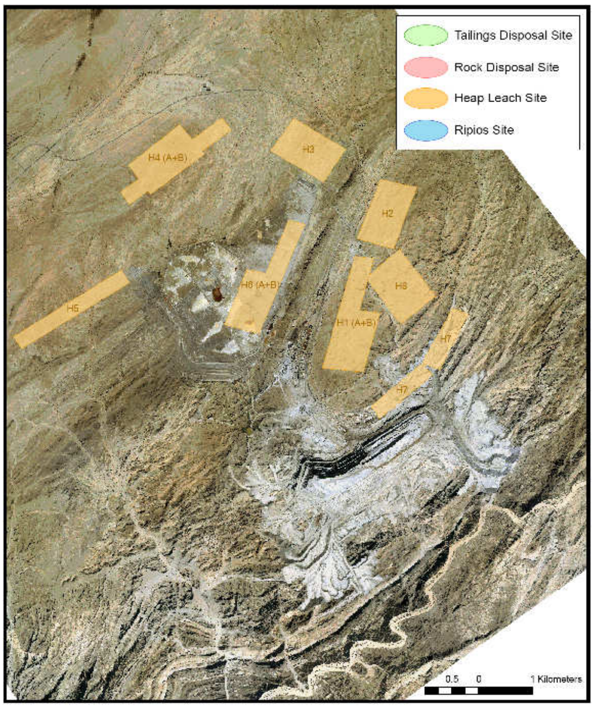
  - o Extension of operational footprint into undisturbed areas,
  - o Impact on habitat (possible loss of Red Data species);
- *Closure,*
  - o *Sequencing*; and
- *Water storage on site*.

## 2.2 FACITLITY SITE OPTIONS

RU identified different potential site options for consideration in this land use optimisation exercise, based on land availability and technical considerations associated with each of the facilities. Note that an overlap of sites was allowed for this purpose, as the outcome of the land use optimisation process would indicate preference in cases of mutual exclusivity. Maps indicating the potential facility sites are included in Annexure B.

### 2.2.1 Heap Leach

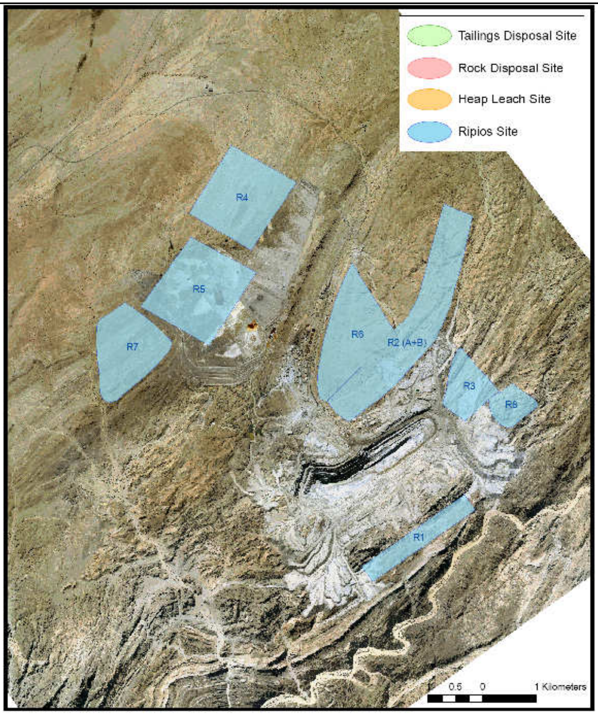
Eight different heap leach site options were identified by RU for consideration in the MCDM land use optimisation process. These included sites on the Dome, on the existing tailings facility and north and west of the existing tailings facility. The figure below indicates the potential sites in orange.




**Heap Leach Site Options**

### 2.2.2 Ripios

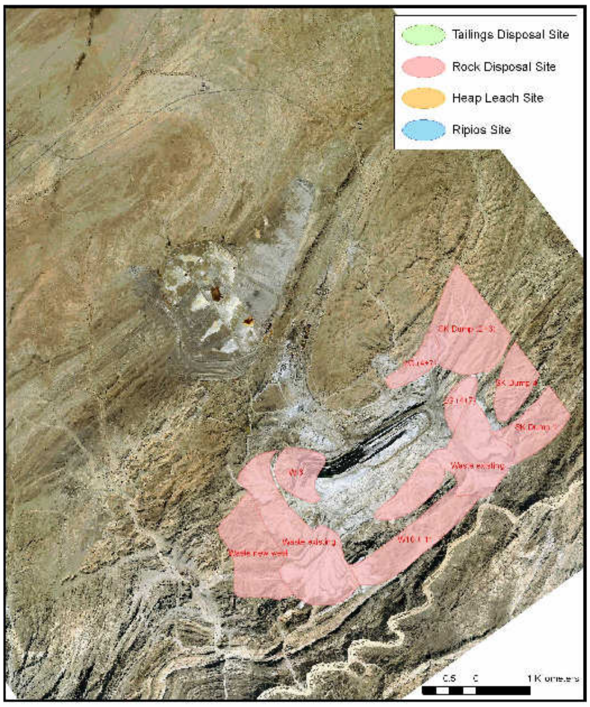
Similarly, eight different ripios site options were identified. These included sites on the Dome, on the existing tailings facility, north and west of the existing tailings facility, but also included areas between the existing waste rock dumps and the Khan River and north east of the existing pit. The potential sites are indicated in blue on the figure below.




**Ripios Site Options**

### 2.2.3 Waste Rock Dumps

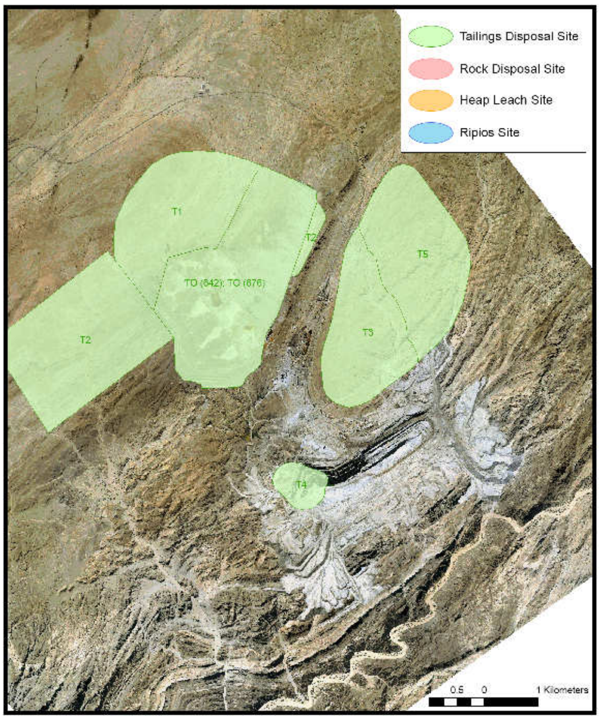
RU identified eight different waste rock dump site options. These included sites around the existing pit, an option that leads onto the Dome and in-pit options. The figure below indicates the potential sites in pink.




**Waste Rock Dump Site Options**

### 2.2.4 Tailings

Six potential tailings site options were identified, including sites on the Dome, on the existing tailings facility, north and west of the existing tailings facility, and an in-pit option. Refer to the figure below that illustrates the potential site areas in green.




**Tailings Site Options**

# 3 APPLICATION OF THE MODEL

This chapter summarises the proceedings of the MCDM workshop held on 20 and 21 May 2008 at the Rössmund Conference Centre outside Swakopmund. It describes the application of the MCDM model to rank individual facilities, describes the process followed to define combined layouts and filtering thereof, followed by the second round of MCDM model application to determine optimum layouts.

## 3.1 STRATEGY FOR OPTIMISATION

A MCDM workshop was scheduled from 20 to 21 May at the Rössmund Conference Centre outside Swakopmund. Workshop attendance lists for the two days are included as Annexure A.

The workshop attendants represented the technical, environmental, socio-economic and strategic fields of expertise and included technical project managers for the expansion project components and a suite of RU in-house and contracted scientists and specialists. The diverse group that participated in the workshop stimulated considered debate, resulting in consensus on the rankings in the applications of the MCDM model. Mutual agreement on the outcome of the optimisation process was successfully realised.

The purpose of this workshop was to consider the allocation of land to four identified land uses through allowing for the potential maximum expansion scenario. Specific objectives agreed upon at the outset of the workshop included:

- To minimise the physical footprint of the proposed expansion;
- To prioritise the sites for different applications (or facilities) in areas where the sustainable development impacts are minimised;
- To find the best practical site for each land use;
- To make best use of newly impacted sites; and
- To ensure that the expansion follows a strategic life of mine approach.

The overall premise of the workshop, proposed by RU and adopted by all present, was:

*"Given the shortage of space, we need to find the optimum arrangement to limit impact on undisturbed ground."*

The MCDM model was applied in the optimisation to meet the objectives listed above. The need for the optimisation stemmed from the spatial constraints, the need to identify the optimum layout of the proposed facilities against the pre-determined criteria, and RU's commitment to sustainable development and the undertaking to limit the impact on undisturbed ground.

The strategy for optimisation applied at the workshop allowed for the preference ranking of the potential sites for each of the four individual facilities (in isolation) through application of the selected MCDM model, followed by development of possible and feasible layout combinations of the top-ranked facility sites and culminating in the preference ranking of these layouts through a second application of the MCDM model.

It was decided to consider the first three categories of criteria, being technical, environmental and socio-economic, in the first application of MCDM model application to determine the preference of the individual facility sites, whilst the strategic category was added in the second application to rank combined layouts.

## 3.2 RANKING OF SITES FOR INDIVIDUAL FACILITIES

### 3.2.1 Criteria and Weighting

RU decided to adapt the typical matrix pairwise comparison to determine the weighting of the different criteria categories to allow a more focused process to determine the overall criteria category weighting, by selecting three key criteria from each category and populating the matrix with these, rather than just the three main categories. The relative weight of each category was then calculated by adding the priority vectors (or priorities) of the three criteria selected from that specific category. This approach is defendable and allowed for focused debate to determine the weighting.

The specific criteria selected were in some cases adapted slightly from the original list, or in some instances combinations were specified, and included the following:

| Criteria Category | Key Selected Criteria |
|---|---|
| Technical | Height, distance & topography |
| | Deposition |
| | Grade & pit size |
| Environmental | Ecology & footprint |
| | Resource use |
| | Geohydrology & seepage |
| Socio-Economic | Archaeology |
| | Air quality |
| | Visual |

As per the method proposed, a pairwise comparison matrix was populated with the nine key selected criteria (three each from the technical, environmental and socio-economic criteria categories), and the ranking done using the prescribed method and scale, as shown below.

**RÖSSING URANIUM ~Criteria~**

| CRITERIA | HEIGHT, DISTANCE & TOPO | DEPOSITION | GRADE & PIT SIZE | ECOLOGY & FOOTPRINT | RESOURCE USE | GEOHYDROLOGY & SEEPAGE | ARCHAEOLOGY | AIR QUALITY | VISUAL | PRIORITY |
|---|---|---|---|---|---|---|---|---|---|---|
| HEIGHT, DISTANCE & TOPO | 1 | 5 | 1/5 | 1 | 1 | 3 | 1 | 1/5 | 4 | 8.9% |
| DEPOSITION | 1/5 | 1 | 1/5 | 1/5 | 1/5 | 1/3 | 1/5 | 1/7 | 1 | 2.4% |
| GRADE & PIT SIZE | 5 | 5 | 1 | 5 | 5 | 5 | 3 | 1/3 | 4 | 23.1% |
| ECOLOGY & FOOTPRINT | 1 | 5 | 1/5 | 1 | 1 | 3 | 1 | 1/3 | 5 | 9.7% |
| RESOURCE USE | 1 | 5 | 1/5 | 1 | 1 | 4 | 3 | 1/3 | 5 | 11.3% |
| GEOHYDROLOGY & SEEPAGE | 1/3 | 3 | 1/5 | 1/3 | 1/4 | 1 | 1/3 | 1/5 | 3 | 4.3% |
| ARCHAEOLOGY | 1 | 5 | 1/3 | 1 | 1/3 | 3 | 1 | 1/5 | 2 | 7.7% |
| AIR QUALITY | 5 | 7 | 3 | 3 | 3 | 5 | 5 | 1 | 5 | 29.7% |
| VISUAL | 1/4 | 1 | 1/4 | 1/5 | 1/5 | 1/3 | 1/2 | 1/5 | 1 | 2.9% |

| | |
|---|---|
| Emax | 10.03 |
| CI | 0.13 |
| CR | 8.89% |

The resultant weighting of the criteria, as per the “Priority” column in the matrix, allowed for the calculation of the total weight of each criteria category by adding these values of the three criteria from each category. The weight of the technical criteria category, for example, was calculated by adding these values of the first three criteria in the matrix. This resulted in the following overall weighting for the three criteria categories and was applied in the individual facility preference ranking that followed:

- Technical = 34,4%
- Environmental = 25,3%
- Socio-Economic = 40,3%

Note that a consistency ratio (CR) value was calculated. This value confirms the consistency of rating within the matrix, with regard to both the preference in each pairwise comparison cell and the application of the rating scale. As per this model, CR values of 10% and less are deemed acceptable, confirming the validity of the outcome.

Although only nine key criteria were used to determine the overall criteria category weighting as described here, <u>all criteria were considered in the MCDM model application described in the next sections</u>.

### 3.2.2 Heap Leach

The heap leach facility was considered against the three criteria categories of technical, environmental and socio-economic, as shown below. Refer to Section 2.2.1 for detail on the exact location of the sites considered.

RÖSSING URANIUM ~Heap Leach~

| TECHNICAL | H5 | H4(A+B) | H3 | H6(A+B) | H2 | H1(A+B) | H8 | H7 | PRIORITY |
|---|---|---|---|---|---|---|---|---|---|
| H5 | 1 | 5 | 1 | 1/3 | 3 | 1/5 | 1/3 | 1/7 | 0.058 |
| H4(A+B) | 1/5 | 1 | 1/3 | 1/7 | 1/3 | 1/7 | 1/5 | 1/9 | 0.020 |
| H3 | 1 | 3 | 1 | 1/5 | 1 | 1/3 | 1/3 | 1/3 | 0.053 |
| H6(A+B) | 3 | 7 | 5 | 1 | 5 | 3 | 4 | 1 | 0.254 |
| H2 | 1/3 | 3 | 1 | 1/5 | 1 | 1/5 | 1/3 | 1/9 | 0.038 |
| H1(A+B) | 5 | 7 | 3 | 1/3 | 5 | 1 | 3 | 1/5 | 0.152 |
| H8 | 3 | 5 | 3 | 1/4 | 3 | 1/3 | 1 | 1/7 | 0.090 |
| H7 | 7 | 9 | 3 | 1 | 9 | 5 | 7 | 1 | 0.336 |

| | |
|---|---|
| Emax | 8.85 |
| CI | 0.12 |
| CR | 8.63% |

RÖSSING URANIUM ~Heap Leach~

| ENVIRONMENTAL | H5 | H4(A+B) | H3 | H6(A+B) | H2 | H1(A+B) | H8 | H7 | PRIORITY |
|---|---|---|---|---|---|---|---|---|---|
| H5 | 1 | 3 | 3 | 1/7 | 1/5 | 1/6 | 1/6 | 1/9 | 0.032 |
| H4(A+B) | 1/3 | 1 | 1 | 1/7 | 1/5 | 1/6 | 1/6 | 1/9 | 0.021 |
| H3 | 1/3 | 1 | 1 | 1/7 | 1/5 | 1/7 | 1/6 | 1/9 | 0.021 |
| H6(A+B) | 7 | 7 | 7 | 1 | 5 | 4 | 4 | 1/3 | 0.243 |
| H2 | 5 | 5 | 5 | 1/5 | 1 | 1/3 | 1 | 1/5 | 0.083 |
| H1(A+B) | 6 | 6 | 7 | 1/4 | 3 | 1 | 2 | 1/5 | 0.133 |
| H8 | 6 | 6 | 6 | 1/4 | 1 | 1/2 | 1 | 1/5 | 0.096 |
| H7 | 9 | 9 | 9 | 3 | 5 | 5 | 5 | 1 | 0.371 |

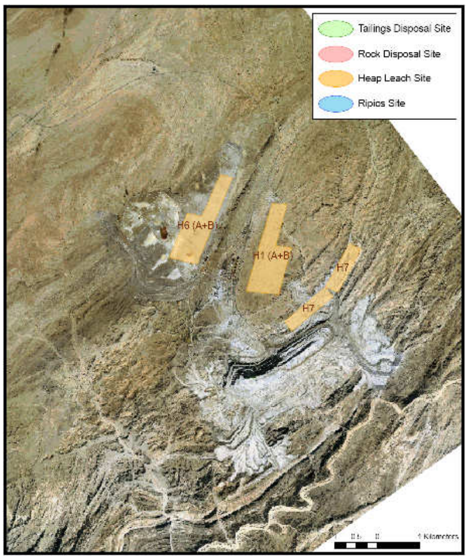
| | |
|---|---|
| Emax | 8.89 |
| CI | 0.13 |
| CR | 9.05% |

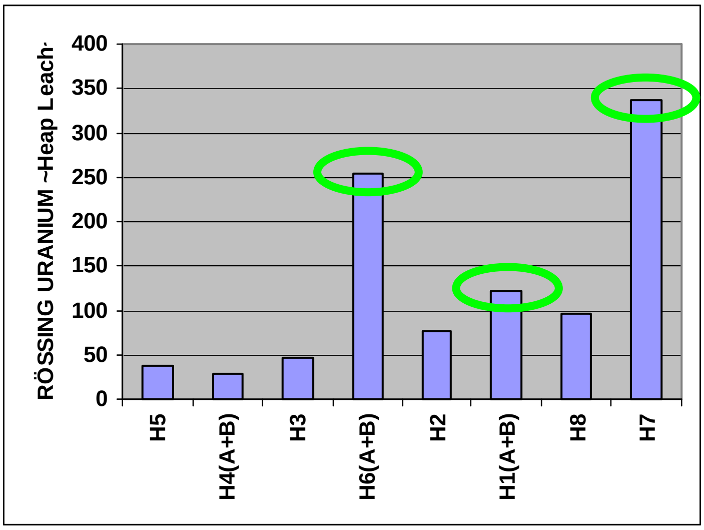
RÖSSING URANIUM ~Heap Leach~

| SOCIO-ECONOMIC | H5 | H4(A+B) | H3 | H6(A+B) | H2 | H1(A+B) | H8 | H7 | PRIORITY |
|---|---|---|---|---|---|---|---|---|---|
| H5 | 1 | 1/3 | 1/5 | 1/5 | 1/3 | 1/3 | 1/3 | 1/7 | 0.028 |
| H4(A+B) | 3 | 1 | 1/3 | 1/5 | 1/3 | 1/3 | 1/3 | 1/7 | 0.039 |
| H3 | 5 | 3 | 1 | 1/5 | 1/3 | 1/3 | 1/3 | 1/6 | 0.055 |
| H6(A+B) | 5 | 5 | 5 | 1 | 5 | 5 | 4 | 1/3 | 0.259 |
| H2 | 3 | 3 | 3 | 1/5 | 1 | 1 | 2 | 1/3 | 0.107 |
| H1(A+B) | 3 | 3 | 3 | 1/5 | 1 | 1 | 1/2 | 1/3 | 0.090 |
| H8 | 3 | 3 | 3 | 1/4 | 1/2 | 2 | 1 | 1/3 | 0.101 |
| H7 | 7 | 7 | 6 | 3 | 3 | 3 | 3 | 1 | 0.322 |

| | |
|---|---|
| Emax | 8.82 |
| CI | 0.12 |
| CR | 8.30% |

This resulted in the following relative preference of facility sites, with the top three ranked sites to be taken forward indicated on the map insert below.




**Heap Leach Ranking Results**

It should be noted that the graph represents total calculated priority values in a unit-less scale, normalised three times during the process. As such, it does not allow for direct numerical comparison and serves the purpose of indicating a relative preference, rather that an absolute preference or priority value.

### 3.2.3 Ripios

Similarly, the ripios facility was considered against each of the three criteria categories as shown below. Refer to Section 2.2.2 for the location of these sites.

**RÖSSING URANIUM ~Ripios~**

| TECHNICAL | R7 | R5 | R4 | R6 | R2(A+B) | R3 | R1 | R8 | PRIORITY |
|---|---|---|---|---|---|---|---|---|---|
| R7 | 1 | 3 | 5 | 1/3 | 1/3 | 1 | 9 | 1 | 0.122 |
| R5 | 1/3 | 1 | 3 | 1/5 | 1/3 | 3 | 9 | 3 | 0.107 |
| R4 | 1/5 | 1/3 | 1 | 1/5 | 1/5 | 1 | 5 | 1 | 0.051 |
| R6 | 3 | 5 | 5 | 1 | 1 | 5 | 9 | 7 | 0.306 |
| R2(A+B) | 3 | 3 | 5 | 1 | 1 | 5 | 9 | 5 | 0.275 |
| R3 | 1 | 1/3 | 1 | 1/5 | 1/5 | 1 | 5 | 3 | 0.071 |
| R1 | 1/9 | 1/9 | 1/5 | 1/9 | 1/9 | 1/5 | 1 | 1/7 | 0.015 |
| R8 | 1 | 1/3 | 1 | 1/7 | 1/5 | 1/3 | 7 | 1 | 0.054 |

| | |
|---|---|
| Emax | 8.69 |
| CI | 0.10 |
| CR | 6.96% |

**RÖSSING URANIUM ~Ripios~**

| ENVIRONMENTAL | R7 | R5 | R4 | R6 | R2(A+B) | R3 | R1 | R8 | PRIORITY |
|---|---|---|---|---|---|---|---|---|---|
| R7 | 1 | 1/7 | 1 | 1/5 | 1/5 | 1/5 | 1 | 1/7 | 0.028 |
| R5 | 7 | 1 | 7 | 5 | 5 | 4 | 5 | 1 | 0.294 |
| R4 | 1 | 1/7 | 1 | 1/6 | 1/6 | 1/4 | 1 | 1/7 | 0.027 |
| R6 | 5 | 1/5 | 6 | 1 | 2 | 1/3 | 4 | 1/5 | 0.096 |
| R2(A+B) | 5 | 1/5 | 6 | 1/2 | 1 | 1/3 | 4 | 1/5 | 0.081 |
| R3 | 5 | 1/4 | 4 | 3 | 3 | 1 | 3 | 1/5 | 0.125 |
| R1 | 1 | 1/5 | 1 | 1/4 | 1/4 | 1/3 | 1 | 1/7 | 0.033 |
| R8 | 7 | 1 | 7 | 5 | 5 | 5 | 7 | 1 | 0.315 |

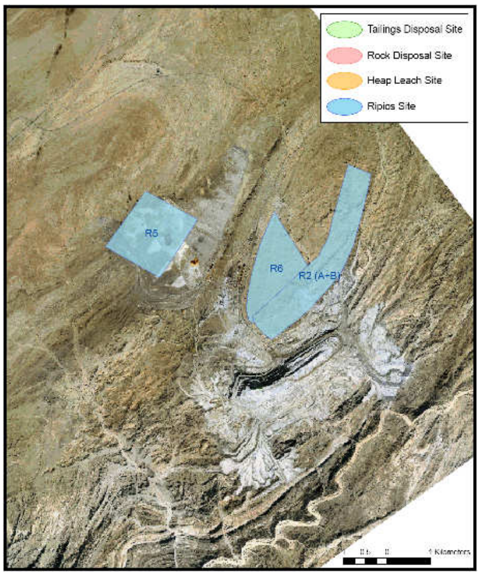
| | |
|---|---|
| Emax | 8.76 |
| CI | 0.11 |
| CR | 7.74% |

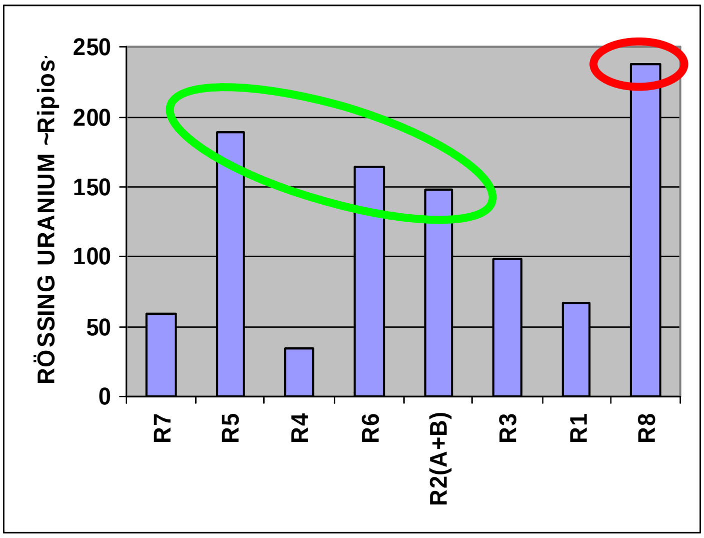
RÖSSING URANIUM ~Ripios~

| SOCIO-ECONOMIC | R7 | R5 | R4 | R6 | R2(A+B) | R3 | R1 | R8 | PRIORITY |
|---|---|---|---|---|---|---|---|---|---|
| R7 | 1 | 1/7 | 1/3 | 1/5 | 1/5 | 1/5 | 1/7 | 1/9 | 0.019 |
| R5 | 7 | 1 | 5 | 3 | 3 | 3 | 3 | 1/3 | 0.197 |
| R4 | 3 | 1/5 | 1 | 1/5 | 1/5 | 1/7 | 1/7 | 1/9 | 0.025 |
| R6 | 5 | 1/3 | 5 | 1 | 1 | 1/3 | 1/3 | 1/5 | 0.068 |
| R2(A+B) | 5 | 1/3 | 5 | 1 | 1 | 1/3 | 1/3 | 1/5 | 0.068 |
| R3 | 5 | 1/3 | 7 | 3 | 3 | 1 | 1/3 | 1/5 | 0.107 |
| R1 | 7 | 1/3 | 7 | 3 | 3 | 3 | 1 | 1/5 | 0.146 |
| R8 | 9 | 3 | 9 | 5 | 5 | 5 | 5 | 1 | 0.372 |

| | |
|---|---|
| Emax | 8.85 |
| CI | 0.12 |
| CR | 8.64% |

This resulted in the following relative preference of facility sites, with the top three ranked sites to be taken forward indicated on the map insert. Note that the site R8, as indicated by the red circle, was not taken forward, since it represents an in-pit option and the strategic decision was taken to exclude all in-pit options from current planning as these could potentially sterilise ore resources at depth that may in future be considered feasible to mine.




**Ripios Ranking Results**

### 3.2.4 Waste Rock Dumps

The identified waste rock dump site options (refer to Section 2.2.3) were considered against the three criteria categories as shown in the matrices below.

RÖSSING URANIUM ~Waste~

| TECHNICAL | W (New West) | W (Existing) | W8 | W10+W11 | W (LG4+LG7) | W (SK1) | W (SKDump4) | W (SKDump2+3) | PRIORITY |
|---|---|---|---|---|---|---|---|---|---|
| W (New West) | 1 | 1/5 | 1/7 | 5 | 1/5 | 2 | 1/3 | 3 | 0.058 |
| W (Existing) | 5 | 1 | 1/3 | 7 | 1 | 5 | 1/2 | 6 | 0.157 |
| W8 | 7 | 3 | 1 | 7 | 3 | 7 | 2 | 7 | 0.314 |
| W10+W11 | 1/5 | 1/7 | 1/7 | 1 | 1/5 | 1/3 | 1/7 | 1 | 0.023 |
| W (LG4+LG7) | 5 | 1 | 1/3 | 5 | 1 | 7 | 1/5 | 7 | 0.143 |
| W (SK1) | 1/2 | 1/5 | 1/7 | 3 | 1/7 | 1 | 1/7 | 5 | 0.042 |
| W (SKDump4) | 3 | 2 | 1/2 | 7 | 5 | 7 | 1 | 7 | 0.240 |
| W (SKDump2+3) | 1/3 | 1/6 | 1/7 | 1 | 1/7 | 1/5 | 1/7 | 1 | 0.023 |

| | |
|---|---|
| Emax | 8.86 |
| CI | 0.12 |
| CR | 8.69% |

RÖSSING URANIUM ~Waste~

| ENVIRONMENTAL | W (New West) | W (Existing) | W8 | W10+W11 | W (LG4+LG7) | W (SK1) | W (SKDump4) | W (SKDump2+3) | PRIORITY |
|---|---|---|---|---|---|---|---|---|---|
| W (New West) | 1 | 1/7 | 1/8 | 1/3 | 1/7 | 1 | 1/7 | 3 | 0.030 |
| W (Existing) | 7 | 1 | 1/3 | 5 | 1 | 5 | 1/3 | 6 | 0.148 |
| W8 | 8 | 3 | 1 | 7 | 3 | 7 | 2 | 8 | 0.319 |
| W10+W11 | 3 | 1/5 | 1/7 | 1 | 1/5 | 2 | 1/5 | 3 | 0.050 |
| W (LG4+LG7) | 7 | 1 | 1/3 | 5 | 1 | 5 | 1/3 | 6 | 0.148 |
| W (SK1) | 1 | 1/5 | 1/7 | 1/2 | 1/5 | 1 | 1/7 | 3 | 0.035 |
| W (SKDump4) | 7 | 3 | 1/2 | 5 | 3 | 7 | 1 | 7 | 0.249 |
| W (SKDump2+3) | 1/3 | 1/6 | 1/8 | 1/3 | 1/6 | 1/3 | 1/7 | 1 | 0.021 |

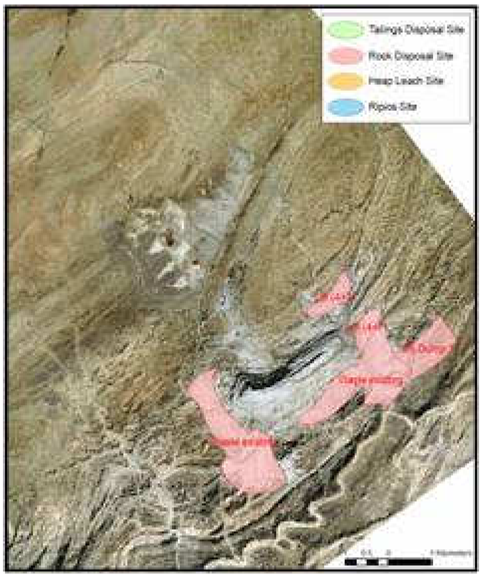
| | |
|---|---|
| Emax | 8.52 |
| CI | 0.07 |
| CR | 5.26% |

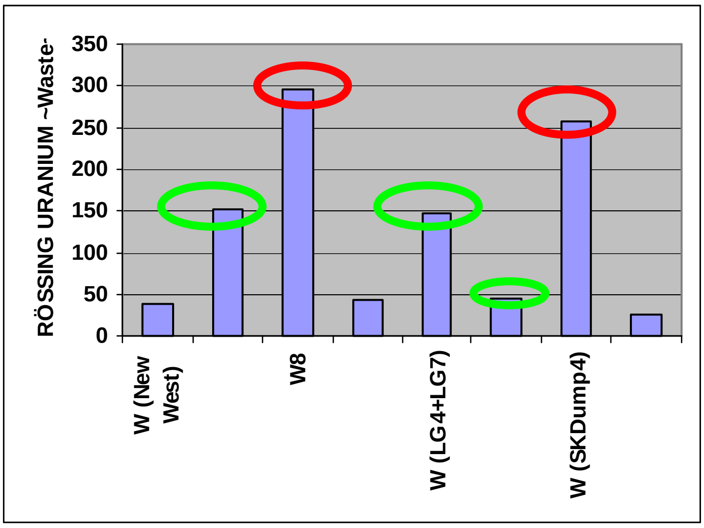
RÖSSING URANIUM ~Waste~

| SOCIO-ECONOMIC | W (New West) | W (Existing) | W8 | W10+W11 | W (LG4+LG7) | W (SK1) | W (SKDump4) | W (SKDump2+3) | PRIORITY |
|---|---|---|---|---|---|---|---|---|---|
| W (New West) | 1 | 1/5 | 1/7 | 1/3 | 1/5 | 1/3 | 1/7 | 1/2 | 0.025 |
| W (Existing) | 5 | 1 | 1/3 | 5 | 1 | 5 | 1/3 | 5 | 0.149 |
| W8 | 7 | 3 | 1 | 5 | 3 | 5 | 1 | 5 | 0.268 |
| W10+W11 | 3 | 1/5 | 1/5 | 1 | 1/5 | 1 | 1/5 | 3 | 0.051 |
| W (LG4+LG7) | 5 | 1 | 1/3 | 5 | 1 | 5 | 1/3 | 5 | 0.149 |
| W (SK1) | 3 | 1/5 | 1/5 | 1 | 1/5 | 1 | 1/5 | 3 | 0.051 |
| W (SKDump4) | 7 | 3 | 1 | 5 | 3 | 5 | 1 | 6 | 0.275 |
| W (SKDump2+3) | 2 | 1/5 | 1/5 | 1/3 | 1/5 | 1/3 | 1/6 | 1 | 0.032 |

| | |
|---|---|
| Emax | 8.52 |
| CI | 0.07 |
| CR | 5.28% |

Similarly, this application of the MCDM model resulted in the following relative preference of waste rock dump sites. The top three ranked sites to be taken forward are indicated on the map insert. Note that the sites W8 and W(SKDump4), indicated by the red circles, were not taken forward, since both are in-pit options.




**Waste Rock Dump Ranking Results**

### 3.2.5 Tailings

Applying the same methodology, the tailings facility was considered against the three criteria categories as shown below. Refer to Section 2.2.4 for the location of these sites.

RÖSSING URANIUM ~Tailings~

| TECHNICAL | T0(642) | T0(676) | T1 | T2 | T5 | T3 | T4 | PRIORITY |
|---|---|---|---|---|---|---|---|---|
| T0(642) | 1 | 3 | 3 | 5 | 7 | 6 | 9 | 0.385 |
| T0(676) | 1/3 | 1 | 3 | 3 | 5 | 4 | 6 | 0.222 |
| T1 | 1/3 | 1/3 | 1 | 5 | 7 | 6 | 5 | 0.189 |
| T2 | 1/5 | 1/3 | 1/5 | 1 | 2 | 1 | 5 | 0.072 |
| T5 | 1/7 | 1/5 | 1/7 | 1/2 | 1 | 1/3 | 4 | 0.041 |
| T3 | 1/6 | 1/4 | 1/6 | 1 | 3 | 1 | 5 | 0.069 |
| T4 | 1/9 | 1/6 | 1/5 | 1/5 | 1/4 | 1/5 | 1 | 0.022 |

| | |
|---|---|
| Emax | 7.74 |
| CI | 0.12 |
| CR | 9.31% |

RÖSSING URANIUM ~Tailings~

| ENVIRONMENTAL | T0(642) | T0(676) | T1 | T2 | T5 | T3 | T4 | PRIORITY |
|---|---|---|---|---|---|---|---|---|
| T0(642) | 1 | 5 | 7 | 7 | 5 | 3 | 1/3 | 0.240 |
| T0(676) | 1/5 | 1 | 5 | 5 | 3 | 2 | 1/5 | 0.112 |
| T1 | 1/7 | 1/5 | 1 | 1 | 1/3 | 1/5 | 1/9 | 0.026 |
| T2 | 1/7 | 1/5 | 1 | 1 | 1/5 | 1/6 | 1/9 | 0.024 |
| T5 | 1/5 | 1/3 | 3 | 5 | 1 | 1/3 | 1/9 | 0.054 |
| T3 | 1/3 | 1/2 | 5 | 6 | 3 | 1 | 1/9 | 0.094 |
| T4 | 3 | 5 | 9 | 9 | 9 | 9 | 1 | 0.450 |

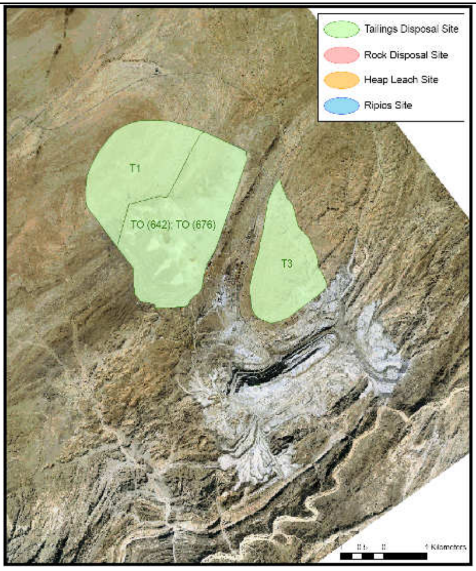
| | |
|---|---|
| Emax | 7.72 |
| CI | 0.12 |
| CR | 9.05% |

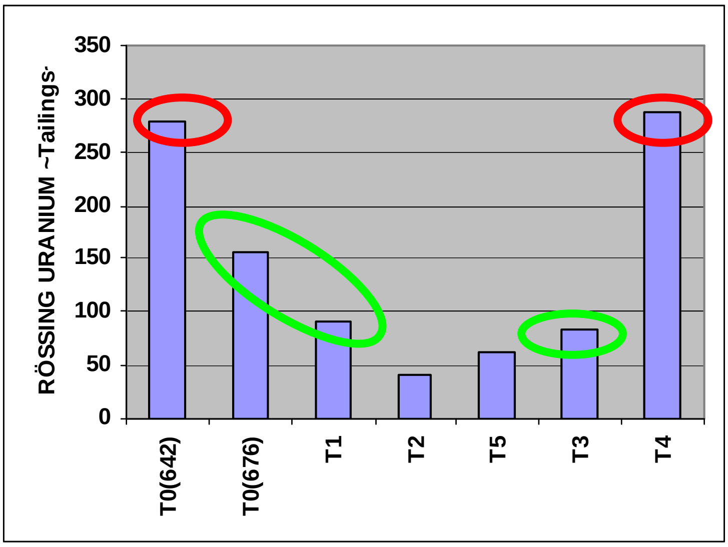
RÖSSING URANIUM ~Tailings~

| SOCIO-ECONOMIC | T0(642) | T0(676) | T1 | T2 | T5 | T3 | T4 | PRIORITY |
|---|---|---|---|---|---|---|---|---|
| T0(642) | 1 | 3 | 5 | 6 | 3 | 3 | 1/5 | 0.194 |
| T0(676) | 1/3 | 1 | 4 | 5 | 2 | 2 | 1/5 | 0.119 |
| T1 | 1/5 | 1/4 | 1 | 3 | 1/5 | 1/5 | 1/7 | 0.034 |
| T2 | 1/6 | 1/5 | 1/3 | 1 | 1/6 | 1/6 | 1/7 | 0.022 |
| T5 | 1/3 | 1/2 | 5 | 6 | 1 | 1 | 1/7 | 0.089 |
| T3 | 1/3 | 1/2 | 5 | 6 | 1 | 1 | 1/7 | 0.089 |
| T4 | 5 | 5 | 7 | 7 | 7 | 7 | 1 | 0.452 |

| | |
|---|---|
| Emax | 7.83 |
| CI | 0.14 |
| CR | 10.45% |

The outcome in terms of relative preference of facility sites, with the top three ranked sites to be taken forward, are indicated on the map insert. Note that the site T0(642) and site T4, as indicated by the red circles, were not taken forward. Site T0(642) represents the existing tailings facility and could have been excluded from the assessment, whilst site T4 is an in-pit option.




**Tailings Ranking Results**

## 3.3 EVALUATION OF POTENTIAL COMBINED LAYOUTS

The next step towards finding the optimum layout was to define potential combined layouts based on the three top-ranked sites as determined in the optimisation of the sites for the individual facilities, as described in the previous section. By limiting possibilities to the top three ranked sites of each facility, a total of 81 layouts were defined. This list of initial layouts is included as Annexure C.

### 3.3.1 Strategic Decisions and Filters Applied

Further to the strategic decisions taken earlier, which resulted in the exclusion of all in-pit facility site options and the exclusion of the existing tailings facility, filters were applied to eliminate non-feasible layouts from the list of 81, to reduce it to practical and feasible potential layouts for consideration in the application of the MCDM to optimise combined layouts. Through this filtering process, mutually exclusive facility site combinations and impractical layouts (based on energy costs associated with the increased distances between facilities) were excluded.

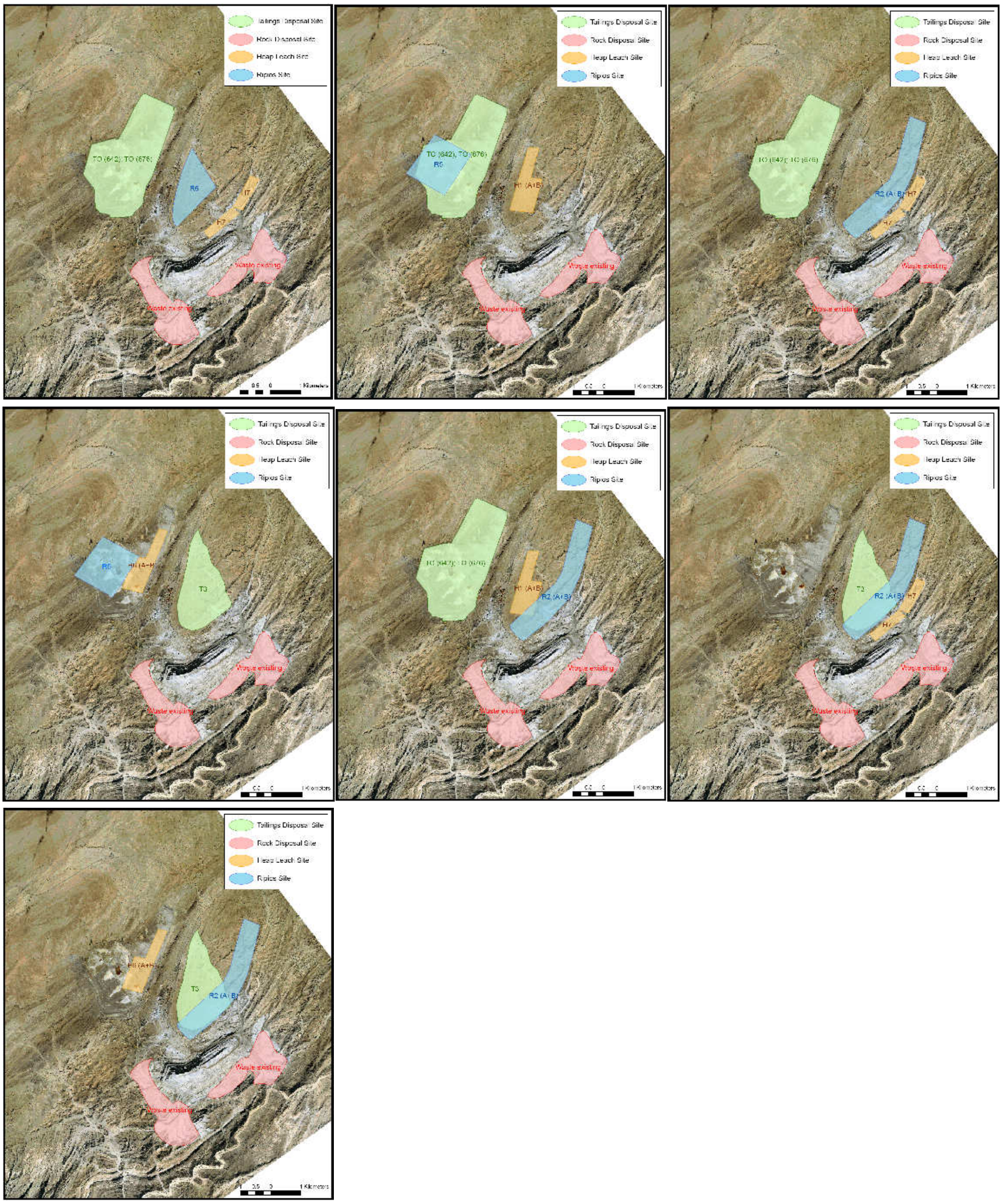
The following filters were applied:

- Mutually exclusive combinations of heap leach, ripios and tailings facility options;
- Mutually exclusive combinations of waste rock dump and heap leach facility options; and
- Heap leach and ripios sites too remote from one another.

These filters resulted in a significant decrease in the number of potential combined layouts. Further, it was noted that the waste site selection could be excluded from the assessment, since none of the final potential waste sites overlapped with any other potential facility sites. This resulted in seven potential combined layouts that effectively could be implemented with any of the top three waste site options. In addition, since the existing waste rock dumps have sufficient capacity for the extended life of mine operations, it was decided to limit the waste rock dump options to the existing, for the purposes of optimisation of potential combined layouts.

### 3.3.2 Potential Combined Layouts for Ranking

The potential combined layouts that would feed into the next application of the MCDM model to rank combined layouts were Layout 3 (H7, R6, TO(672) & W existing), Layout 12 (H1(A&B), R5, TO(672) & W existing), Layout 13 (H7, R2(A&B), TO(672) & W existing), Layout 25 (H6(A&B), R5, T3 & W existing), Layout 33 (H1(A&B), R2(A&B), TO(672) & W existing), Layout 37 (H7, R2(A&B), T3 & W existing) and Layout 52 (H6(A&B), R2(A&B), T3 & W existing) respectively, as per the illustrations below. Larger scale layout maps are included as Annexure D.




**Potential Combined Layouts for Ranking**

# 3.4 RANKING OF COMBINED LAYOUTS

## 3.4.1 Criteria and Weighting

Similar to the approach adopted in the MCDM application to rank individual facility sites, the weighting of the criteria categories were determined by selecting key criteria from each criteria category and populating the matrix with these. In this instance, all four criteria categories, being technical, environmental, socio-economic and strategic were considered, and two key criteria were selected per criteria category. As per the methodology developed, the relative weight of each category was calculated by adding the priority vectors (or priorities) of the two criteria selected from that particular category.

The specific key criteria selected included the following:

| Criteria Category | Key Selected Criteria |
|---|---|
| Technical | Height, distance & topography |
| | Grade & pit size |
| Environmental | Ecology & footprint |
| | Resource use |
| Socio-Economic | Archaeology |
| | Air quality |
| Strategic | Sterilisation & sequence |
| | Reputation & closure |

The pairwise comparison matrix with rating values, as shown below, resulted in the following overall weighting for the four criteria categories, using the same method as described in Section 3.2.1, with the only difference being that two key criteria each from the four criteria categories, were considered. This could now be applied in the preference ranking of combined layouts:

- Technical = 21,44%
- Environmental = 14,53%
- Socio-Economic = 26,40%
- Strategic = 37,63%

RÖSSING URANIUM ~Criteria~

| CRITERIA | HEIGHT, DISTANCE & TOPO | GRADE & PIT SIZE | ECOLOGY & FOOTPRINT | RESOURCE USE | ARCHAEOLOGY | AIR QUALITY | STERILISATION & SEQUENCE | REPUTATION & CLOSURE | PRIORITY |
|---|---|---|---|---|---|---|---|---|---|
| HEIGHT, DISTANCE & TOPO | 1 | 1/5 | 1 | 1 | 1 | 1/5 | 1/7 | 1/5 | 4.5% |
| GRADE & PIT SIZE | 5 | 1 | 3 | 3 | 3 | 1/3 | 1 | 1 | 16.9% |
| ECOLOGY & FOOTPRINT | 1 | 1/3 | 1 | 1 | 1 | 1/3 | 1 | 1 | 8.0% |
| RESOURCE USE | 1 | 1/3 | 1 | 1 | 3 | 1/3 | 1/5 | 1/3 | 6.5% |
| ARCHAEOLOGY | 1 | 1/3 | 1 | 1/3 | 1 | 1/5 | 1/3 | 1 | 5.7% |
| AIR QUALITY | 5 | 3 | 3 | 3 | 5 | 1 | 1/3 | 1 | 20.7% |
| STERILISATION & SEQUENCE | 7 | 1 | 1 | 5 | 3 | 3 | 1 | 3 | 24.8% |
| REPUTATION & CLOSURE | 5 | 1 | 1 | 3 | 1 | 1 | 1/3 | 1 | 12.9% |

| | |
|---|---|
| Emax | 9.01 |
| CI | 0.14 |
| CR | 10.21% |

Note that although only eight key criteria were used to determine the overall criteria category weighting, all criteria on the list as per Section 2.1 were considered in the MCDM model application to rank combined layouts, as described in the following sections.

### 3.4.2 Ranking Results

The combined layouts were considered against the four criteria categories being technical, environmental, socio-economic and strategic, as shown below. Once again, the CR values were calculated for each matrix to confirm the consistency of the results.

RÖSSING URANIUM ~Layouts~

| TECHNICAL | L3:H7/R6/T0 | L12:H1/R5/T0 | L13:H7/R2/T0 | L25:H6/R5/T3 | L33:H1/R2/T0 | L37:H7/R2/T3 | L52:H6/R2/T3 | PRIORITY |
|---|---|---|---|---|---|---|---|---|
| L3:H7/R6/T0 | 1 | 3 | 1/3 | 1/3 | 1/5 | 9 | 9 | 0.112 |
| L12:H1/R5/T0 | 1/3 | 1 | 1/5 | 1/5 | 1/7 | 3 | 3 | 0.049 |
| L13:H7/R2/T0 | 3 | 5 | 1 | 3 | 1/3 | 7 | 9 | 0.234 |
| L25:H6/R5/T3 | 3 | 5 | 1/3 | 1 | 1/5 | 7 | 9 | 0.159 |
| L33:H1/R2/T0 | 5 | 7 | 3 | 5 | 1 | 9 | 9 | 0.402 |
| L37:H7/R2/T3 | 1/9 | 1/3 | 1/7 | 1/7 | 1/9 | 1 | 1 | 0.023 |
| L52:H6/R2/T3 | 1/9 | 1/3 | 1/9 | 1/9 | 1/9 | 1 | 1 | 0.021 |

| | |
|---|---|
| Emax | 7.79 |
| CI | 0.13 |
| CR | 9.95% |

RÖSSING URANIUM ~Layouts~

| ENVIRONMENTAL | L3:H7/R6/T0 | L12:H1/R5/T0 | L13:H7/R2/T0 | L25:H6/R5/T3 | L33:H1/R2/T0 | L37:H7/R2/T3 | L52:H6/R2/T3 | PRIORITY |
|---|---|---|---|---|---|---|---|---|
| L3:H7/R6/T0 | 1 | 3 | 1 | 1/3 | 3 | 5 | 5 | 0.193 |
| L12:H1/R5/T0 | 1/3 | 1 | 1/3 | 1/5 | 1 | 3 | 3 | 0.083 |
| L13:H7/R2/T0 | 1 | 3 | 1 | 1/5 | 5 | 7 | 5 | 0.202 |
| L25:H6/R5/T3 | 3 | 5 | 5 | 1 | 3 | 5 | 5 | 0.357 |
| L33:H1/R2/T0 | 1/3 | 1 | 1/5 | 1/3 | 1 | 5 | 5 | 0.096 |
| L37:H7/R2/T3 | 1/5 | 1/3 | 1/7 | 1/5 | 1/5 | 1 | 1 | 0.034 |
| L52:H6/R2/T3 | 1/5 | 1/3 | 1/5 | 1/5 | 1/5 | 1 | 1 | 0.035 |

| | |
|---|---|
| Emax | 7.86 |
| CI | 0.14 |
| CR | 10.80% |

RÖSSING URANIUM ~Layouts~

| SOCIO-ECONOMIC | L3:H7/R6/T0 | L12:H1/R5/T0 | L13:H7/R2/T0 | L25:H6/R5/T3 | L33:H1/R2/T0 | L37:H7/R2/T3 | L52:H6/R2/T3 | PRIORITY |
|---|---|---|---|---|---|---|---|---|
| L3:H7/R6/T0 | 1 | 3 | 1 | 3 | 3 | 5 | 7 | 0.280 |
| L12:H1/R5/T0 | 1/3 | 1 | 1 | 4 | 3 | 7 | 6 | 0.219 |
| L13:H7/R2/T0 | 1 | 1 | 1 | 3 | 3 | 7 | 6 | 0.246 |
| L25:H6/R5/T3 | 1/3 | 1/4 | 1/3 | 1 | 1/3 | 5 | 5 | 0.085 |
| L33:H1/R2/T0 | 1/3 | 1/3 | 1/3 | 3 | 1 | 3 | 3 | 0.105 |
| L37:H7/R2/T3 | 1/5 | 1/7 | 1/7 | 1/5 | 1/3 | 1 | 1 | 0.033 |
| L52:H6/R2/T3 | 1/7 | 1/6 | 1/6 | 1/5 | 1/3 | 1 | 1 | 0.032 |

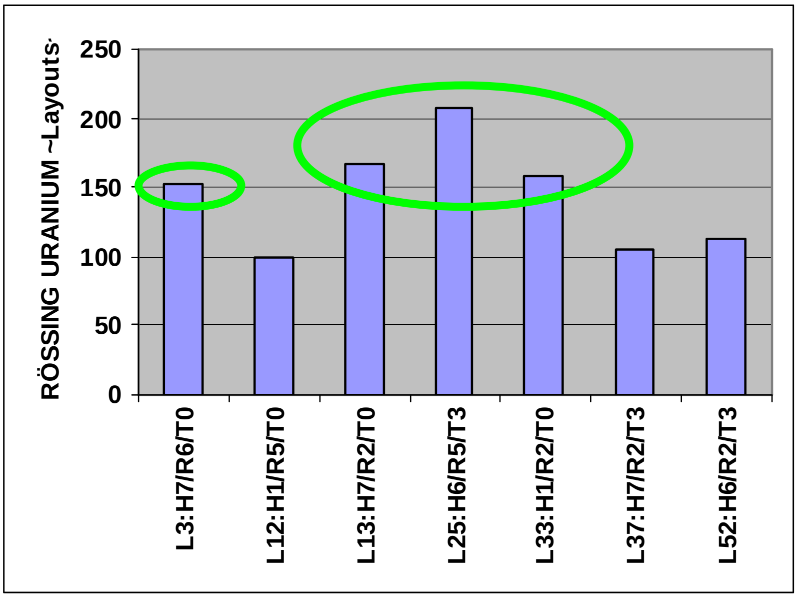
| | |
|---|---|
| Emax | 7.47 |
| CI | 0.08 |
| CR | 5.98% |

RÖSSING URANIUM ~Layouts~

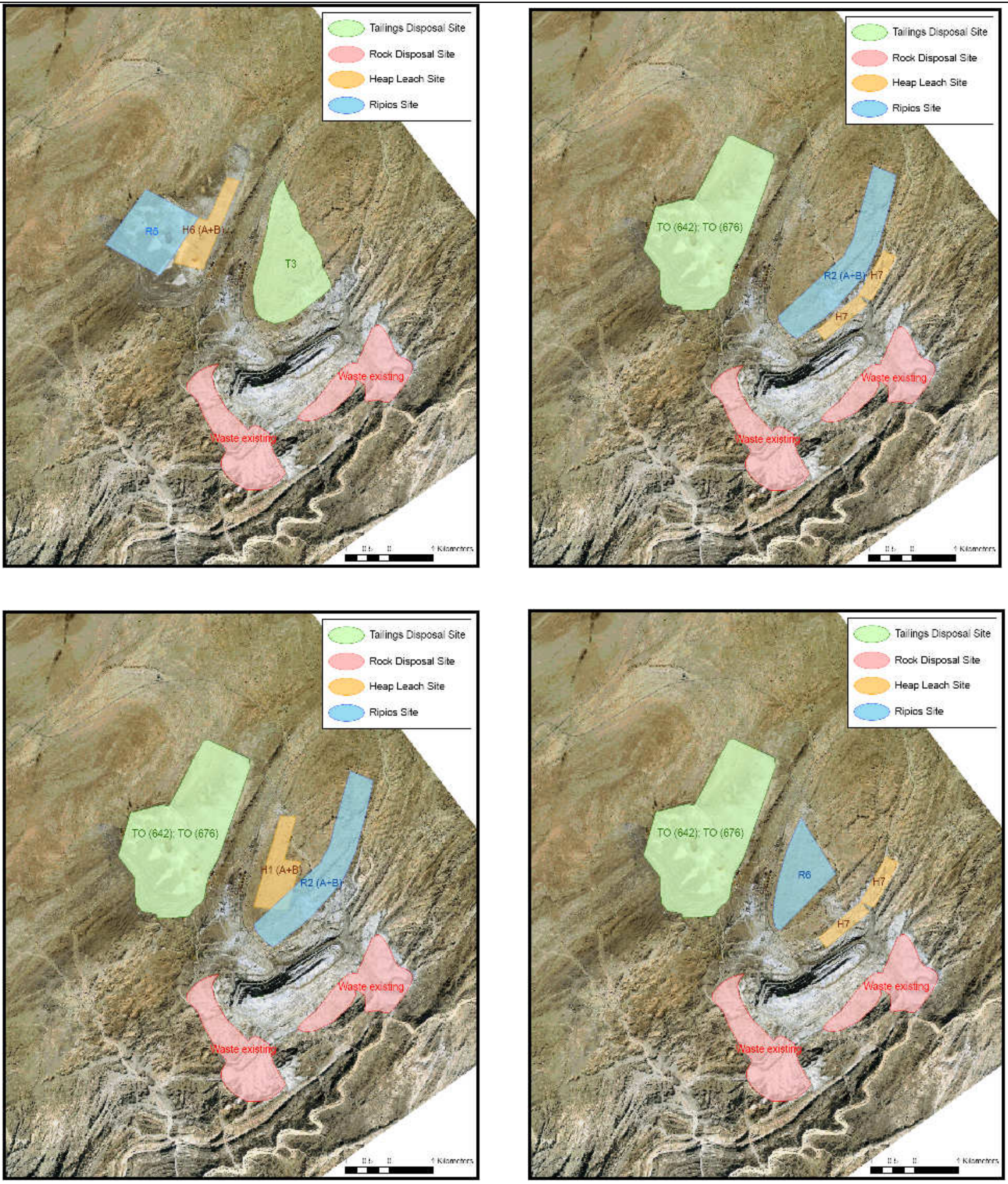
| STRATEGIC | L3:H7/R6/T0 | L12:H1/R5/T0 | L13:H7/R2/T0 | L25:H6/R5/T3 | L33:H1/R2/T0 | L37:H7/R2/T3 | L52:H6/R2/T3 | PRIORITY |
|---|---|---|---|---|---|---|---|---|
| L3:H7/R6/T0 | 1 | 3 | 1 | 1/3 | 1/3 | 1/5 | 1/3 | 0.069 |
| L12:H1/R5/T0 | 1/3 | 1 | 1/3 | 1/3 | 1/5 | 1/3 | 1/3 | 0.043 |
| L13:H7/R2/T0 | 1 | 3 | 1 | 1/3 | 1/3 | 1/2 | 1/3 | 0.079 |
| L25:H6/R5/T3 | 3 | 3 | 3 | 1 | 5 | 2 | 1 | 0.264 |
| L33:H1/R2/T0 | 3 | 5 | 3 | 1/5 | 1 | 1/3 | 1/3 | 0.119 |
| L37:H7/R2/T3 | 5 | 3 | 2 | 1/2 | 3 | 1 | 1 | 0.204 |
| L52:H6/R2/T3 | 3 | 3 | 3 | 1 | 3 | 1 | 1 | 0.222 |

| | |
|---|---|
| Emax | 7.64 |
| CI | 0.11 |
| CR | 8.09% |

This resulted in the following relative preference of combined layouts, with the top four ranked layouts to be taken forward by RU through detailed engineering analysis indicated on the map inserts:




**Relative Preference of Combined Layouts**




**Top Four Combined Layouts in Order of Preference**

Note that enlargements of these layouts are contained in Annexure D, together with the other three considered in this final application of the MCDM model.

# 4 SENSITIVITY ANALYSIS

The purpose of this chapter is to describe the sensitivity analysis undertaken after the MCDM application to rank combined layouts, to test the findings against various scenarios by changing the weighting applied to the four criteria categories. This was achieved by evaluating the outcomes with seven different weighting scenarios.

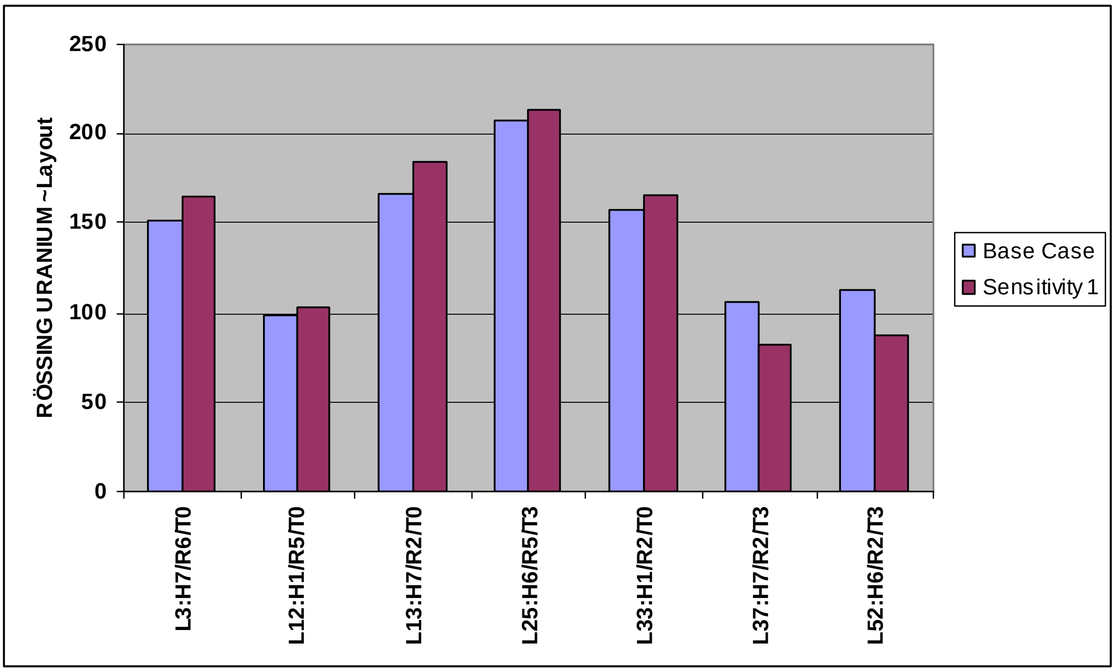
A sensitivity analysis was undertaken to test the outcome of the application of the MCDM model to rank combined layouts, with seven different weighting scenarios, as described in the following sections. The graphs provided for each scenario indicates the outcome of the sensitivity analysis against the base case for comparative purposes.

## 4.1 SENSITIVITY 1: ALL CRITERIA EQUAL

The weighting of the criteria categories were adjusted to the following for this analysis:

- Technical = 25,00%
- Environmental = 25,00%
- Socio-Economic = 25,00%
- Strategic = 25,00%

This resulted in the same top four layouts, with the same order of relative preference.



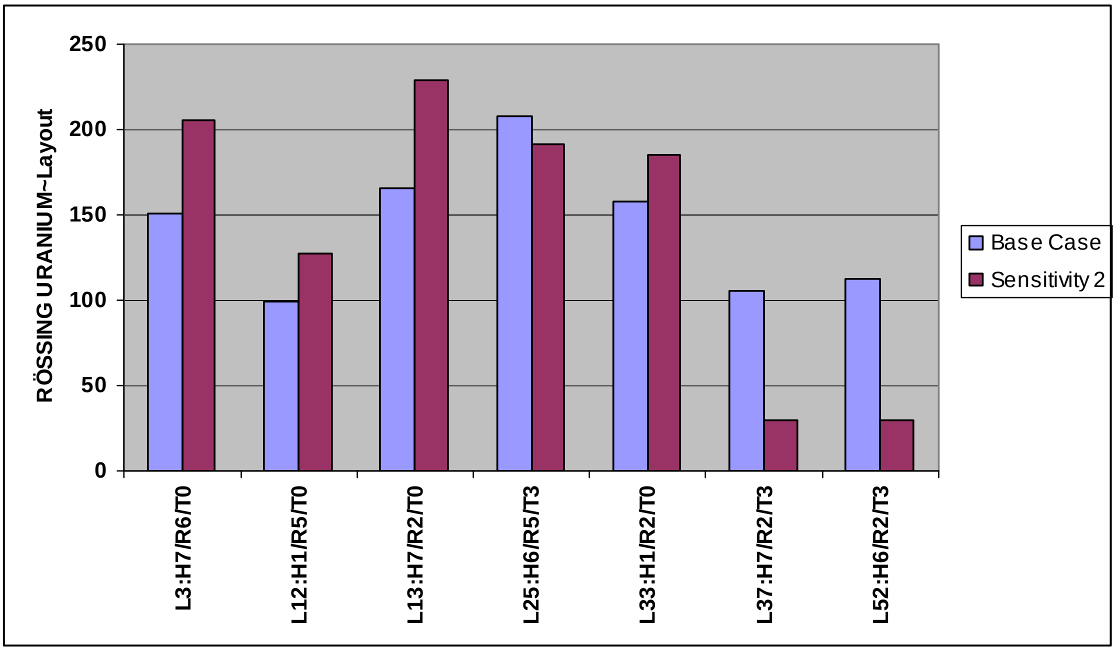

**Results of Sensitivity Analysis 1 against the Base Case**

## 4.2 SENSITIVITY 2: DISCOUNTING STRATEGIC CRITERIA AND REMAINING CRITERIA BEING EQUAL

The weighting of the criteria categories were adjusted to the following:

- Technical = 33,33%
- Environmental = 33,33%
- Socio-Economic = 33,33%
- Strategic = 00,00%

This resulted in the same top four layouts, albeit with a change in the order of relative preference.



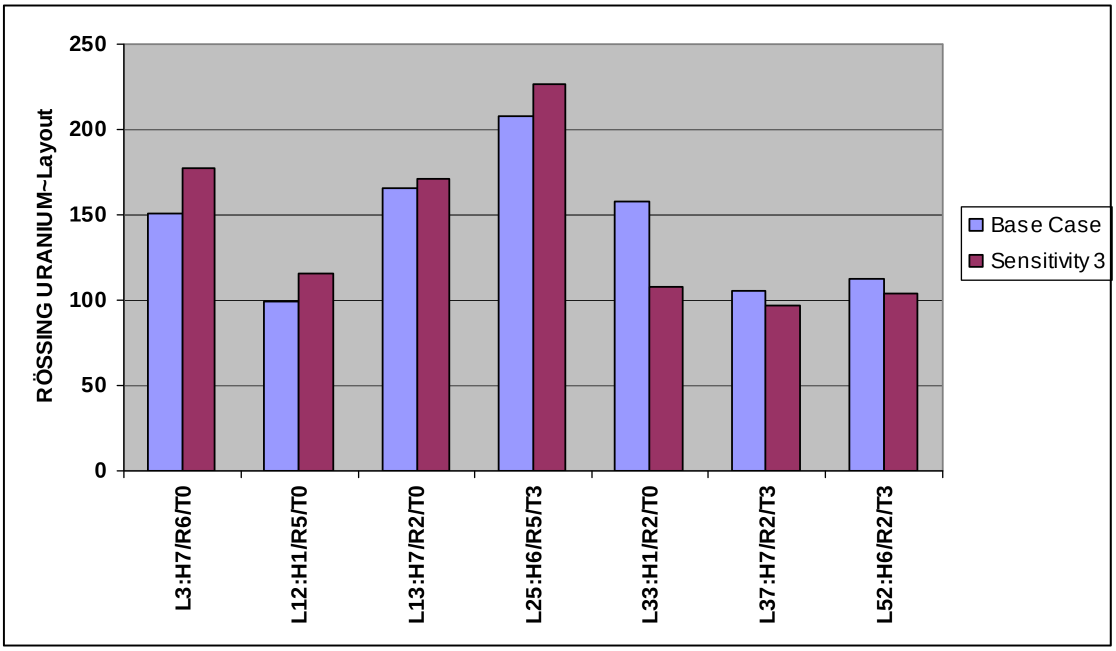

**Results of Sensitivity Analysis 2 against the Base Case**

## 4.3 SENSITIVITY 3: DISCOUNTING TECHNICAL CRITERIA AND REMAINING CRITERIA BEING EQUAL

The following weighting of the criteria categories were used in this analysis:

- Technical = 00,00%
- Environmental = 33,33%
- Socio-Economic = 33,33%
- Strategic = 33,33%

This resulted in a change to the top four layouts, with Layout 12 now replacing Layout 33.



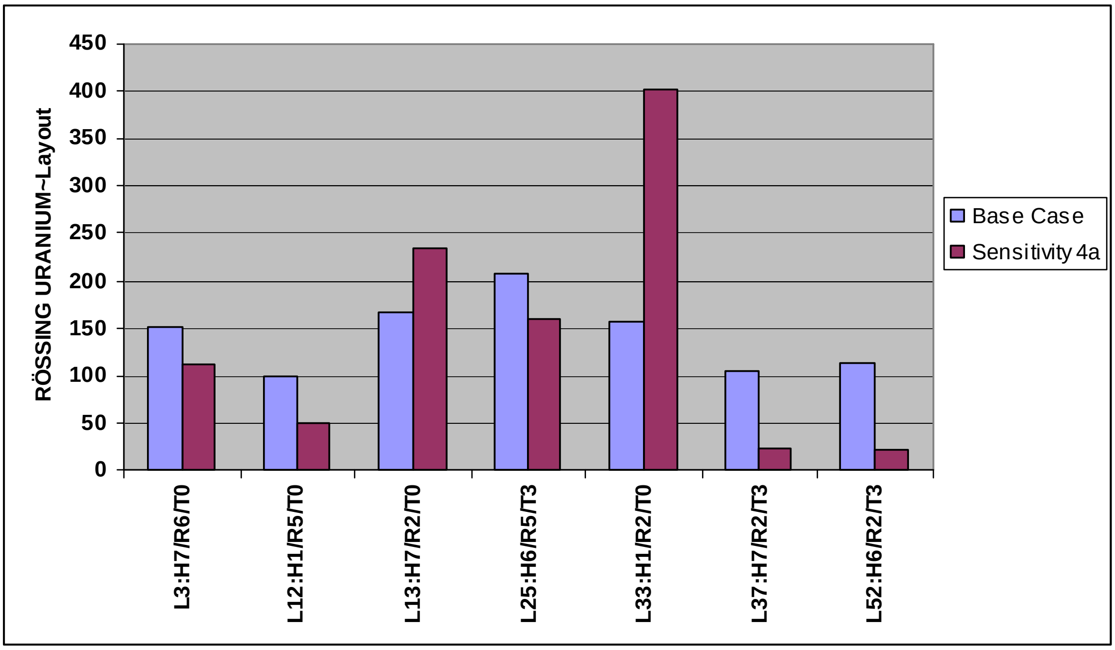

**Results of Sensitivity Analysis 3 against the Base Case**

## 4.4 SENSITIVITY 4: EACH CRITERIA CATEGORY ON ITS OWN

The weighting of the criteria categories were adjusted to the following for this first analysis:

- Technical = 100,00%
- Environmental = 000,00%
- Socio-Economic = 000,00%
- Strategic = 000,00%

This resulted in the same top four layouts, with a change in the order of relative preference.

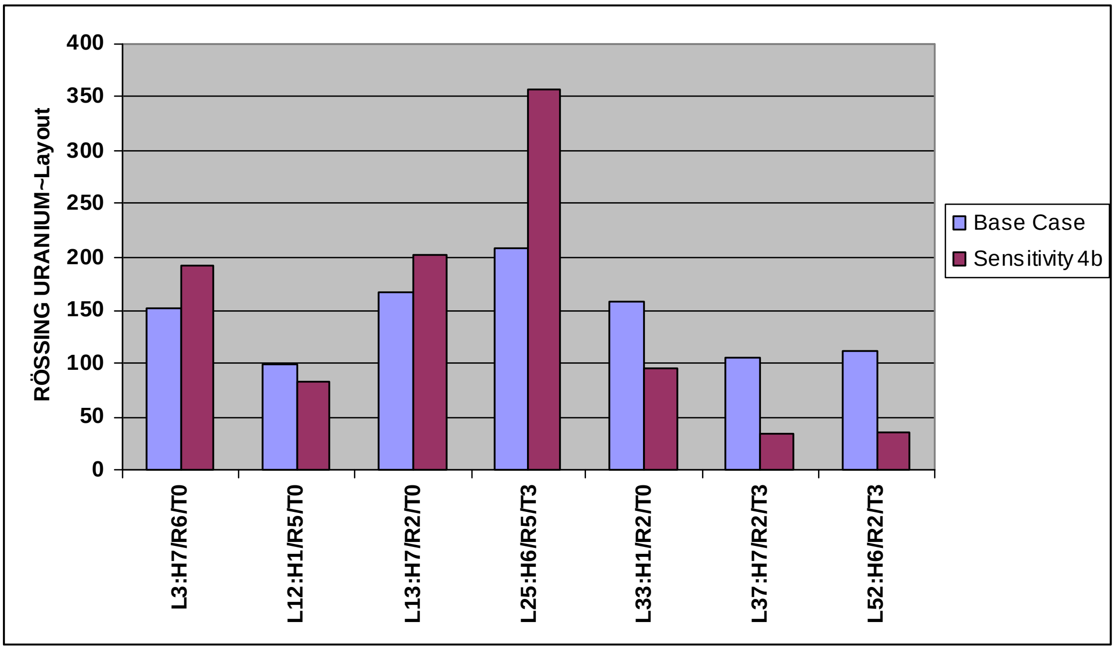



**Results of Sensitivity Analysis 4a against the Base Case**

The weighting of the criteria categories were then adjusted to the following:

- Technical = 000,00%
- Environmental = 100,00%
- Socio-Economic = 000,00%
- Strategic = 000,00%

Similarly, this resulted in the same top four layouts, with a change in the order of relative preference.

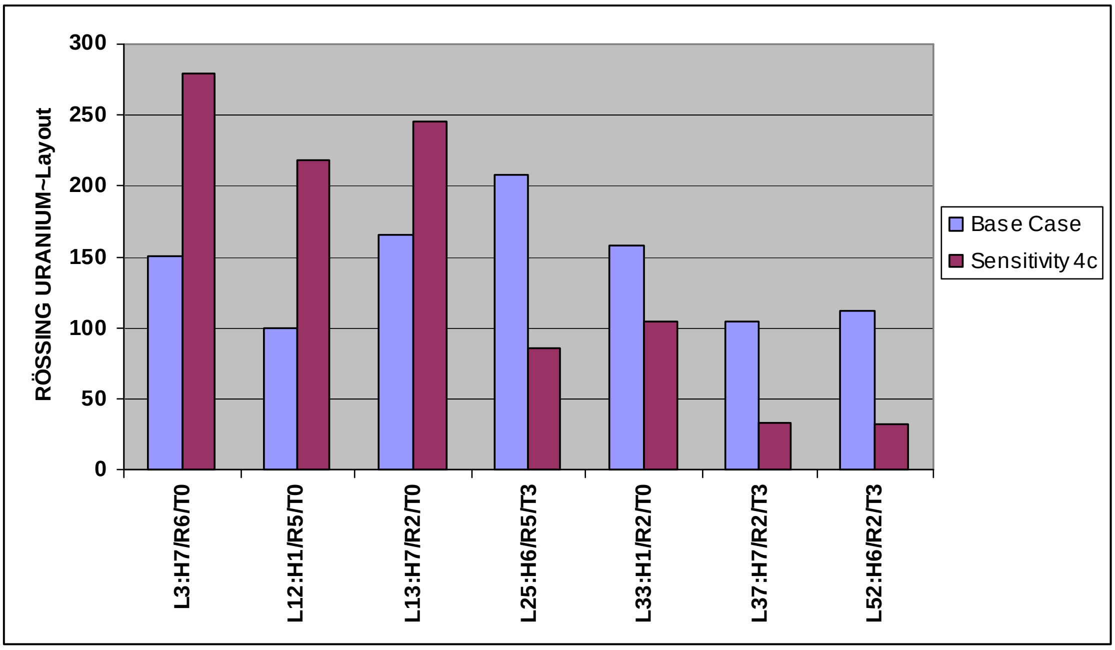



**Results of Sensitivity Analysis 4b against the Base Case**

The weighting of the criteria categories were adjusted to the following for this third analysis:

- Technical = 000,00%
- Environmental = 000,00%
- Socio-Economic = 100,00%
- Strategic = 000,00%

This resulted in a single change to the top four layouts, with a Layout 12 replacing Layout 25.

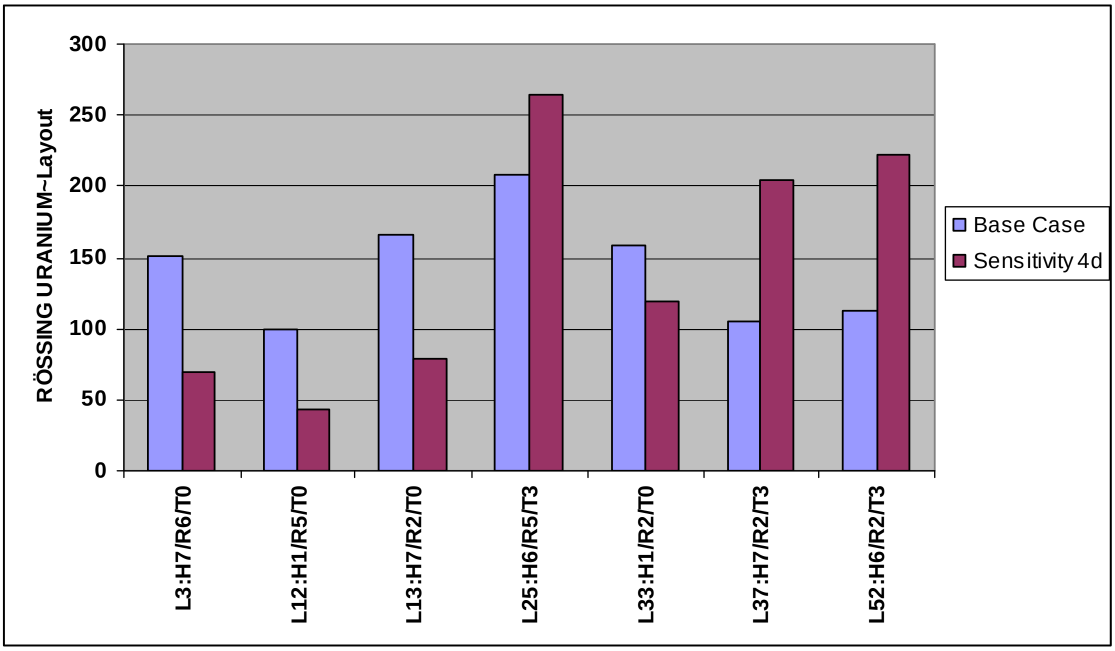



**Results of Sensitivity Analysis 4c against the Base Case**

Ultimately, the weighting of the criteria categories were adjusted to the following:

- Technical = 000,00%
- Environmental = 000,00%
- Socio-Economic = 000,00%
- Strategic = 100,00%

This resulted in two changes to the top four layouts, with Layouts 37 and 52 replacing Layouts 13 and 3.




**Results of Sensitivity Analysis 4d against the Base Case**

## 4.5 CONCLUSION

The first sensitivity analysis considered, being all criteria equal, resulted in the same top four layouts in the same order of preference.

The second sensitivity analysis considered, being discounting strategic criteria and the remaining criteria categories being equal, resulted in the same top four layouts, albeit in a different order of relative priority.

The third sensitivity analysis considered, being discounting technical criteria and the remaining criteria categories being equal, resulted in only one change to the top four layouts, with Layout 25 still ranking the highest.

The first two of the fourth sensitivity analysis, where each of the criteria categories was considered on its own (and in this case technical and environmental criteria), resulted in the same top four layouts, with a different order of relative preference. The last two, with socio-economic and strategic criteria considered on its own, resulted in variations to the top four, with one change in the first case and two changes in the second.

It can be concluded that the top four layouts are the preferred options and should be considered in more detail by RU. Since the sensitivity analysis resulted in different layouts being included in the top four (in the limited cases where there were changes), no need exists to investigate any of the other layouts further. This recommendation would have been different, should the sensitivity analysis consistently prioritised the same layout not included in the top four ranked layouts in the base case scenario.

# 5 RESULTS AND RECOMMENDATIONS

The purpose of this chapter is to summarise the final ranking results, to describe the advantages of the top-ranked layouts and to provide recommendations for the way forward.

## 5.1 FINDINGS

The four top-ranked combined layouts, as determined through this optimisation process using a broad range of criteria categories, namely technical, environmental, socio-economic and strategic, were Layout 25, Layout 13, Layout 33 and Layout 3. Refer to Section 3.4.2 or Annexure D for schematic representations of these layouts.

Layout 25 comprises heap leach site H6(A&B), ripios site R5, tailings site T3 and the existing waste rock dump sites. Layout 13 comprises heap leach site H7, ripios site R2(A&B), the existing tailings site T0(672) and the existing waste rock dumps. Layout 33 comprises heap leach site H1(A&B), ripios site R2(A&B), the existing tailings site T0(672) and the existing waste rock dumps. Layout 3 comprises heap leach site H7, ripios site R6, the existing tailings site T0(672) and the existing waste rock dumps.

The sensitivity analysis confirmed the top four ranked layouts and no need exists to investigate any of the other layouts further.

Shortcomings identified through the process include the potential capacity limitations presented by some of the facility sites considered, specifically the tailings sites used.

## 5.2 ADVANTAGES OF TOP-RANKED LAYOUTS

The top four layouts could broadly be grouped into two categories, since three of the four layouts are minor variations of each other. As such, the main alternatives would be to:

- Establish the heap leach and ripios facilities on the existing tailings, with a new tailings facility to be established on the Dome (Layout 25); or
- Establish the heap leach and ripios facilities on the Dome, with increased capacity provided at the existing tailings facility by elevating it (Layouts 13, 33 and 3).

Both these scenarios would limit potential unnecessary biophysical impact, since the proposed new areas under consideration are limited to the Dome area with all of the above.

Layout 25 has the following advantages:

- The establishment of the heap leach and ripios facilities on the existing tailings will result in the drying out of this facility with added long-term rehabilitation benefits;
- By positioning the heap leach and ripios facilities here, impacts on other undisturbed areas are limited; and

- The new tailings facility on the Dome will drain into the expanded pit, resulting in effective leachate collection.

Layouts 13, 33 and 3 have the following advantages:
- By positioning the heap leach and ripios facilities on the Dome, costs ad resource use associated with transportation of the ore to the heap leach site is limited; and
- The existing tailings facility is enlarged, resulting in limited new impacts since control mechanisms and monitoring infrastructure exists.

## 5.3 RECOMMENDATIONS

The recommendations for the way forward on this MCDM model application for RU are to:

- Study the top four ranked layouts and to prepare financial models for each, based on preliminary engineering design work for each of the sites;
- Commission any specialist studies that would be required to underpin such engineering design work;
- Where required, consider ways of providing additional capacity where the specific sites considered could prove to have insufficient capacity, either by enlarging them, or adding the next ranked site to the layout; and
- Recommend a final selected layout for consideration in the Phase 2 SEIA.

Note that the findings and recommendations of this MCDM model application to optimise combined layouts would need to feed into the Phase 2 SEIA process, which would seek environmental clearance for these and other expansion project components.

# ANNEXURE A: WORKSHOP ATTENDANCE LISTS

**RÖSSING URANIUM: PHASE 2 SEIA**

**MULTI-CRITERIA DECISION-MAKING MODEL WORKSHOP: DAY 1** 20/05/2008

**ATTENDANCE LIST**

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**RÖSSING URANIUM: PHASE 2 SEIA**

**MULTI-CRITERIA DECISION-MAKING MODEL WORKSHOP: DAY 2** 21/05/2008

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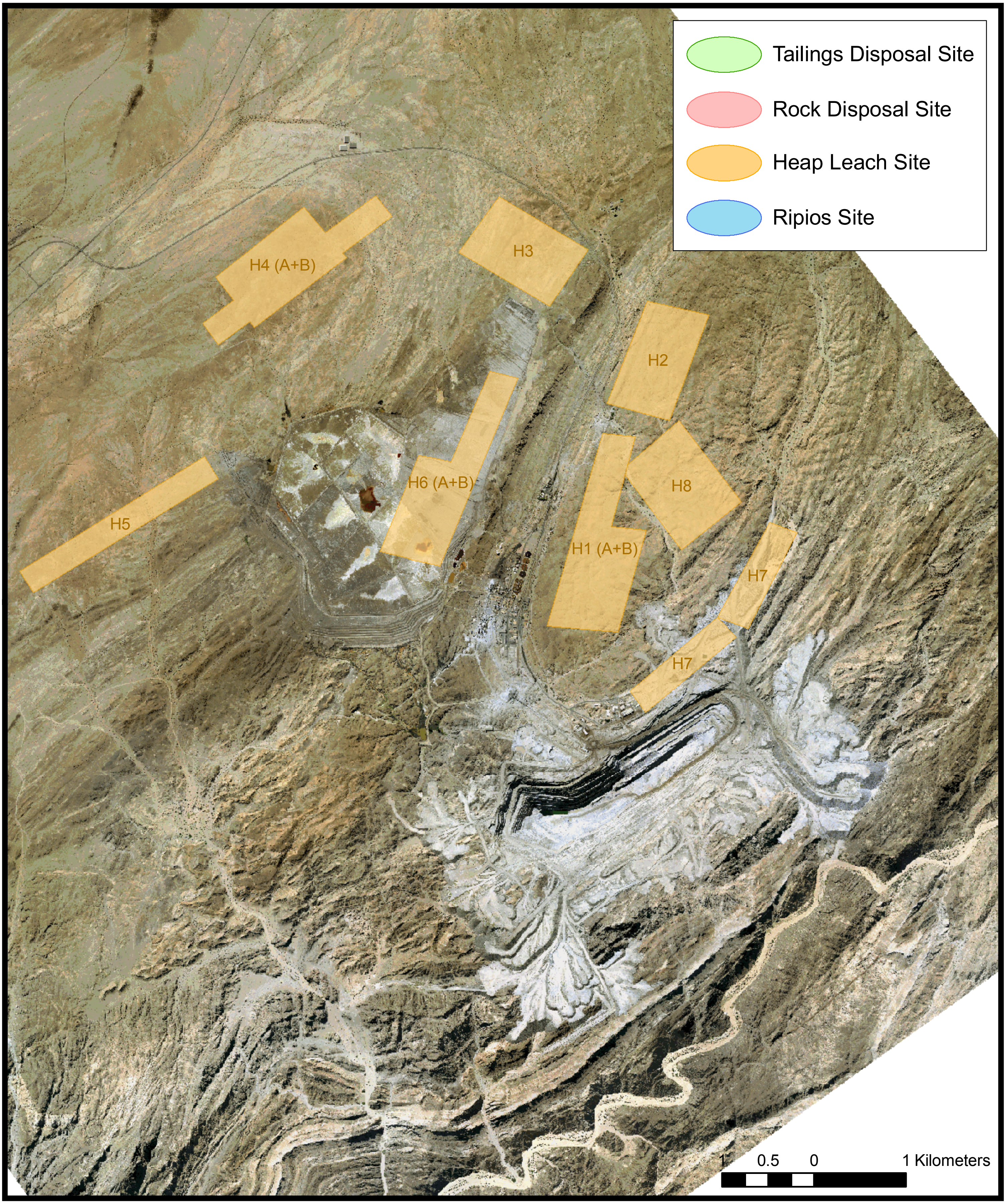
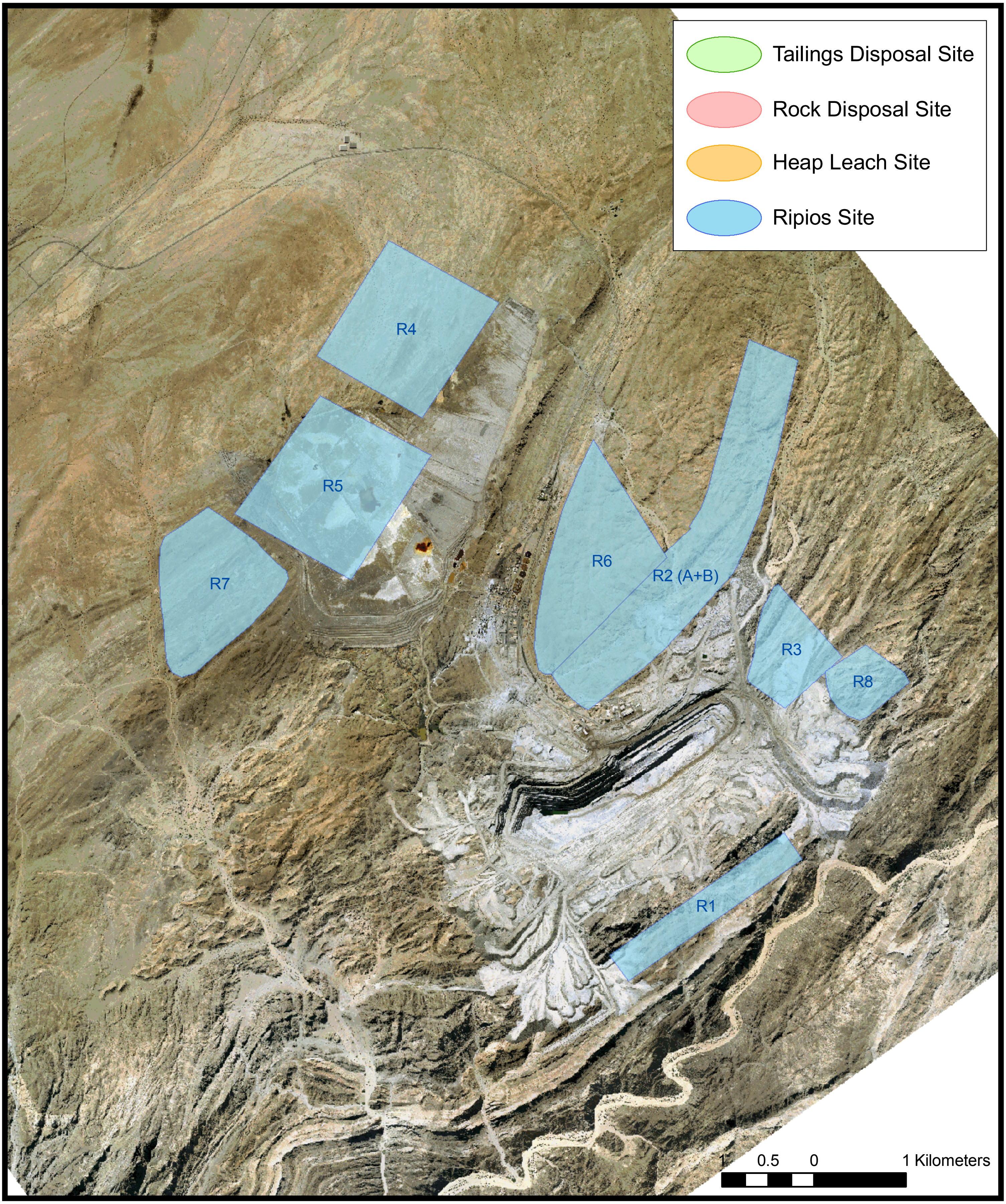
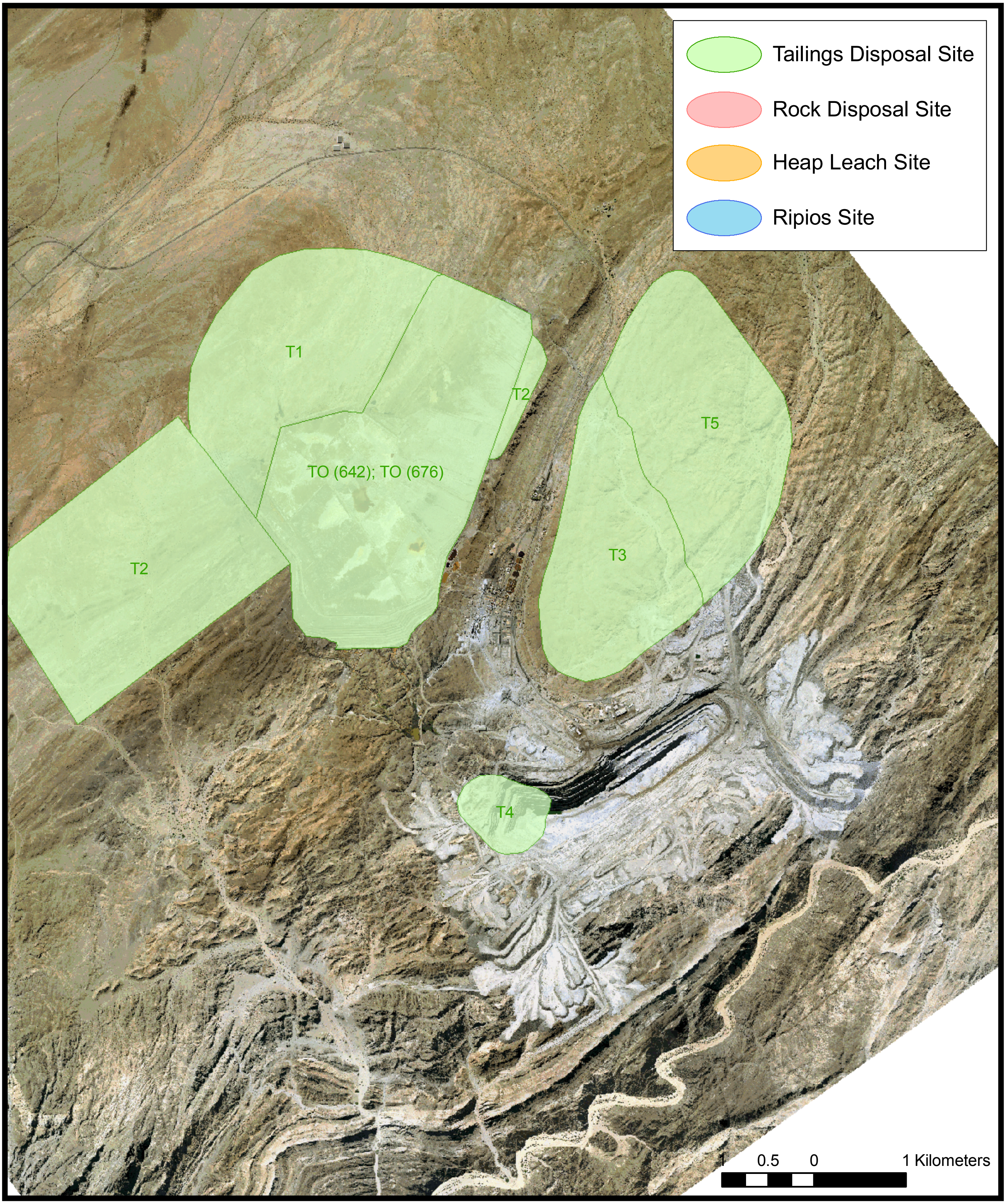
# ANNEXURE B: SITES ALTERNATIVES


Tailings Disposal Site
Rock Disposal Site
Heap Leach Site
Ripios Site
H4 (A+B)
H3
H2
H6 (A+B)
H8
H5
H1 (A+B)
H7
H7
1
0.5
0
1 Kilometers



Tailings Disposal Site
Rock Disposal Site
Heap Leach Site
Ripios Site
R4
R5
R7
R6
R2 (A+B)
R3
R8
R1
1 0.5 0 1 Kilometers


Tailings Disposal Site
Rock Disposal Site
Heap Leach Site
Ripios Site
T1
T2
TO (642); TO (676)
T2
T5
T3
T4
1 0.5 0 1 Kilometers

# ANNEXURE C: INITIAL LIST OF LAYOUTS

RÖSSING URANIUM ~Potential Layouts~

| POTENTIAL LAYOUT | PRIORITY | | | | HEAP LEACH | RIPIOS | WASTE | TAILINGS |
|---|---|---|---|---|---|---|---|---|
| L1 | h1 | r1 | w1 | t1 | H7 | R5 | W(Existing) | T0(676) |
| L2 | h2 | r1 | w1 | t1 | H6(A+B) | R5 | W(Existing) | T0(676) |
| L3 | h1 | r2 | w1 | t1 | H7 | R6 | W(Existing) | T0(676) |
| L4 | h1 | r1 | w2 | t1 | H7 | R5 | W(LG4+LG7) | T0(676) |
| L5 | h1 | r1 | w1 | t2 | H7 | R5 | W(Existing) | T1 |
| L6 | h2 | r2 | w1 | t1 | H6(A+B) | R6 | W(Existing) | T0(676) |
| L7 | h2 | r1 | w2 | t1 | H6(A+B) | R5 | W(LG4+LG7) | T0(676) |
| L8 | h2 | r1 | w1 | t2 | H6(A+B) | R5 | W(Existing) | T1 |
| L9 | h1 | r2 | w2 | t1 | H7 | R6 | W(LG4+LG7) | T0(676) |
| L10 | h1 | r2 | w1 | t2 | H7 | R6 | W(Existing) | T1 |
| L11 | h1 | r1 | w2 | t2 | H7 | R5 | W(LG4+LG7) | T1 |
| L12 | h3 | r1 | w1 | t1 | H1(A+B) | R5 | W(Existing) | T0(676) |
| L13 | h1 | r3 | w1 | t1 | H7 | R2 | W(Existing) | T0(676) |
| L14 | h1 | r1 | w3 | t1 | H7 | R5 | W(SK1) | T0(676) |
| L15 | h1 | r1 | w1 | t3 | H7 | R5 | W(Existing) | T3 |
| L16 | h2 | r2 | w2 | t1 | H6(A+B) | R6 | W(LG4+LG7) | T0(676) |
| L17 | h2 | r2 | w1 | t2 | H6(A+B) | R6 | W(Existing) | T1 |
| L18 | h2 | r1 | w2 | t2 | H6(A+B) | R5 | W(LG4+LG7) | T1 |
| L19 | h1 | r2 | w2 | t2 | H7 | R6 | W(LG4+LG7) | T1 |
| L20 | h3 | r2 | w1 | t1 | H1(A+B) | R6 | W(Existing) | T0(676) |
| L21 | h3 | r1 | w2 | t1 | H1(A+B) | R5 | W(LG4+LG7) | T0(676) |
| L22 | h3 | r1 | w1 | t2 | H1(A+B) | R5 | W(Existing) | T1 |
| L23 | h2 | r3 | w1 | t1 | H6(A+B) | R2 | W(Existing) | T0(676) |
| L24 | h2 | r1 | w3 | t1 | H6(A+B) | R5 | W(SK1) | T0(676) |
| L25 | h2 | r1 | w1 | t3 | H6(A+B) | R5 | W(Existing) | T3 |
| L26 | h1 | r2 | w3 | t1 | H7 | R6 | W(SK1) | T0(676) |
| L27 | h1 | r2 | w1 | t3 | H7 | R6 | W(Existing) | T3 |
| L28 | h1 | r1 | w2 | t3 | H7 | R5 | W(LG4+LG7) | T3 |
| L29 | h1 | r3 | w2 | t1 | H7 | R2 | W(LG4+LG7) | T0(676) |
| L30 | h1 | r1 | w3 | t2 | H7 | R5 | W(SK1) | T1 |
| L31 | h1 | r3 | w1 | t2 | H7 | R2 | W(Existing) | T1 |
| L32 | h2 | r2 | w2 | t2 | H6(A+B) | R6 | W(LG4+LG7) | T1 |
| L33 | h3 | r3 | w1 | t1 | H1(A+B) | R2 | W(Existing) | T0(676) |
| L34 | h3 | r1 | w3 | t1 | H1(A+B) | R5 | W(SK1) | T0(676) |

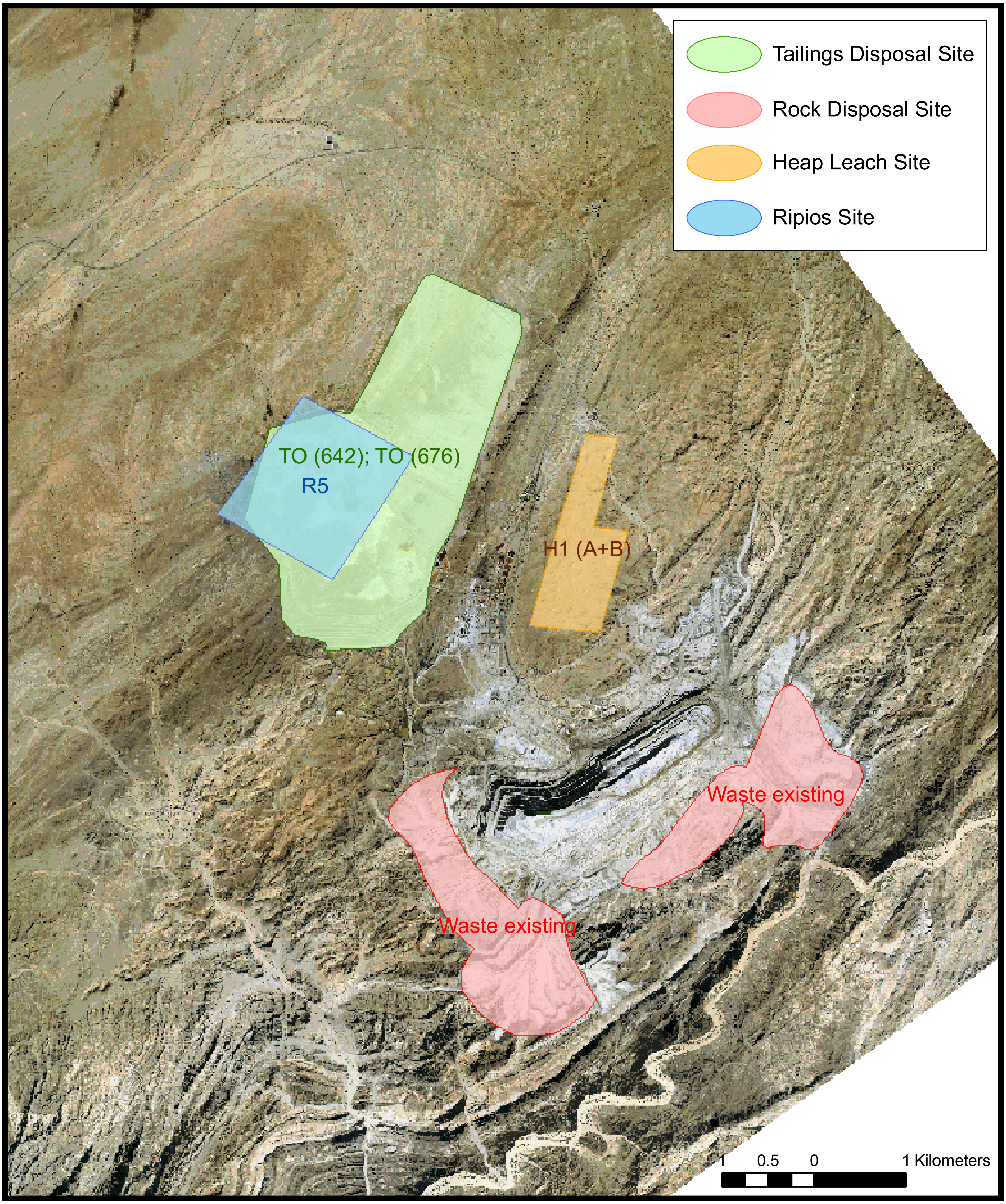
RÖSSING URANIUM ~Potential Layouts~

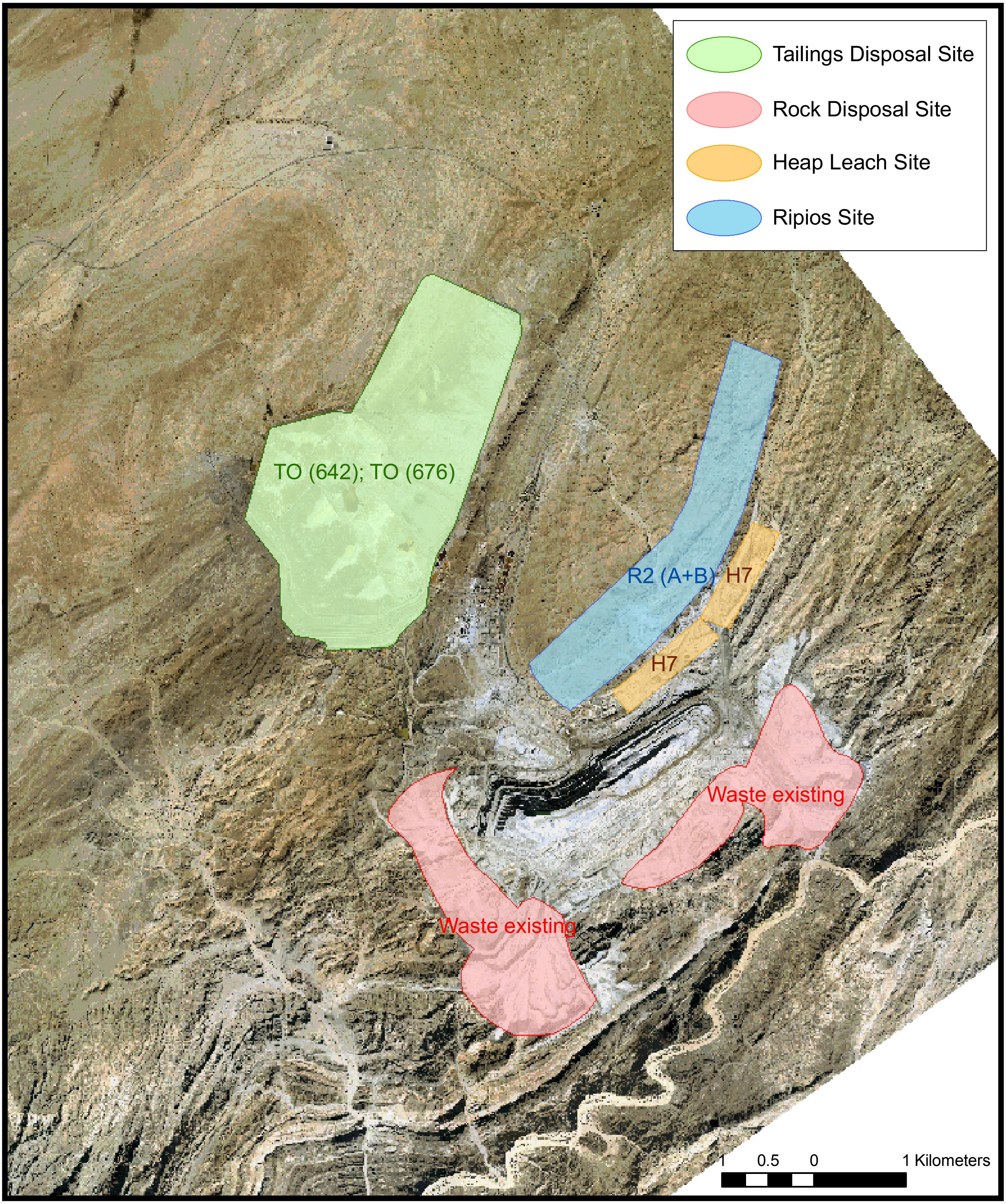
| POTENTIAL LAYOUT | PRIORITY | | | | HEAP LEACH | RIPIOS | WASTE | TAILINGS |
|---|---|---|---|---|---|---|---|---|
| L35 | h3 | r1 | w1 | t3 | H1(A+B) | R5 | W(Existing) | T3 |
| L36 | h1 | r3 | w3 | t1 | H7 | R2 | W(SK1) | T0(676) |
| L37 | h1 | r3 | w1 | t3 | H7 | R2 | W(Existing) | T3 |
| L38 | h1 | r1 | w3 | t3 | H7 | R5 | W(SK1) | T3 |
| L39 | h3 | r1 | w2 | t2 | H1(A+B) | R5 | W(LG4+LG7) | T1 |
| L40 | h3 | r2 | w1 | t2 | H1(A+B) | R6 | W(Existing) | T1 |
| L41 | h3 | r2 | w2 | t1 | H1(A+B) | R6 | W(LG4+LG7) | T0(676) |
| L42 | h1 | r3 | w2 | t2 | H7 | R2 | W(LG4+LG7) | T1 |
| L43 | h1 | r2 | w3 | t2 | H7 | R6 | W(SK1) | T1 |
| L44 | h1 | r2 | w2 | t3 | H7 | R6 | W(LG4+LG7) | T3 |
| L45 | h2 | r1 | w3 | t2 | H6(A+B) | R5 | W(SK1) | T1 |
| L46 | h2 | r1 | w2 | t3 | H6(A+B) | R5 | W(LG4+LG7) | T3 |
| L47 | h2 | r2 | w1 | t3 | H6(A+B) | R6 | W(Existing) | T3 |
| L48 | h2 | r3 | w1 | t2 | H6(A+B) | R2 | W(Existing) | T1 |
| L49 | h2 | r2 | w3 | t1 | H6(A+B) | R6 | W(SK1) | T0(676) |
| L50 | h2 | r3 | w2 | t1 | H6(A+B) | R2 | W(LG4+LG7) | T0(676) |
| L51 | h2 | r1 | w3 | t3 | H6(A+B) | R5 | W(SK1) | T3 |
| L52 | h2 | r3 | w1 | t3 | H6(A+B) | R2 | W(Existing) | T3 |
| L53 | h2 | r3 | w3 | t1 | H6(A+B) | R2 | W(SK1) | T0(676) |
| L54 | h1 | r2 | w3 | t3 | H7 | R6 | W(SK1) | T3 |
| L55 | h1 | r3 | w2 | t3 | H7 | R2 | W(LG4+LG7) | T3 |
| L56 | h1 | r3 | w3 | t2 | H7 | R2 | W(SK1) | T1 |
| L57 | h3 | r1 | w2 | t3 | H1(A+B) | R5 | W(LG4+LG7) | T3 |
| L58 | h3 | r1 | w3 | t2 | H1(A+B) | R5 | W(SK1) | T1 |
| L59 | h3 | r3 | w1 | t2 | H1(A+B) | R2 | W(Existing) | T1 |
| L60 | h3 | r2 | w1 | t3 | H1(A+B) | R6 | W(Existing) | T3 |
| L61 | h3 | r3 | w2 | t1 | H1(A+B) | R2 | W(LG4+LG7) | T0(676) |
| L62 | h3 | r2 | w3 | t1 | H1(A+B) | R6 | W(SK1) | T0(676) |
| L63 | h3 | r2 | w2 | t2 | H1(A+B) | R6 | W(LG4+LG7) | T1 |
| L64 | h2 | r3 | w2 | t2 | H6(A+B) | R2 | W(LG4+LG7) | T1 |
| L65 | h2 | r2 | w3 | t2 | H6(A+B) | R6 | W(SK1) | T1 |
| L66 | h2 | r2 | w2 | t3 | H6(A+B) | R6 | W(LG4+LG7) | T3 |
| L67 | h3 | r3 | w2 | t2 | H1(A+B) | R2 | W(LG4+LG7) | T1 |
| L68 | h3 | r2 | w3 | t2 | H1(A+B) | R6 | W(SK1) | T1 |

RÖSSING URANIUM ~Potential Layouts~

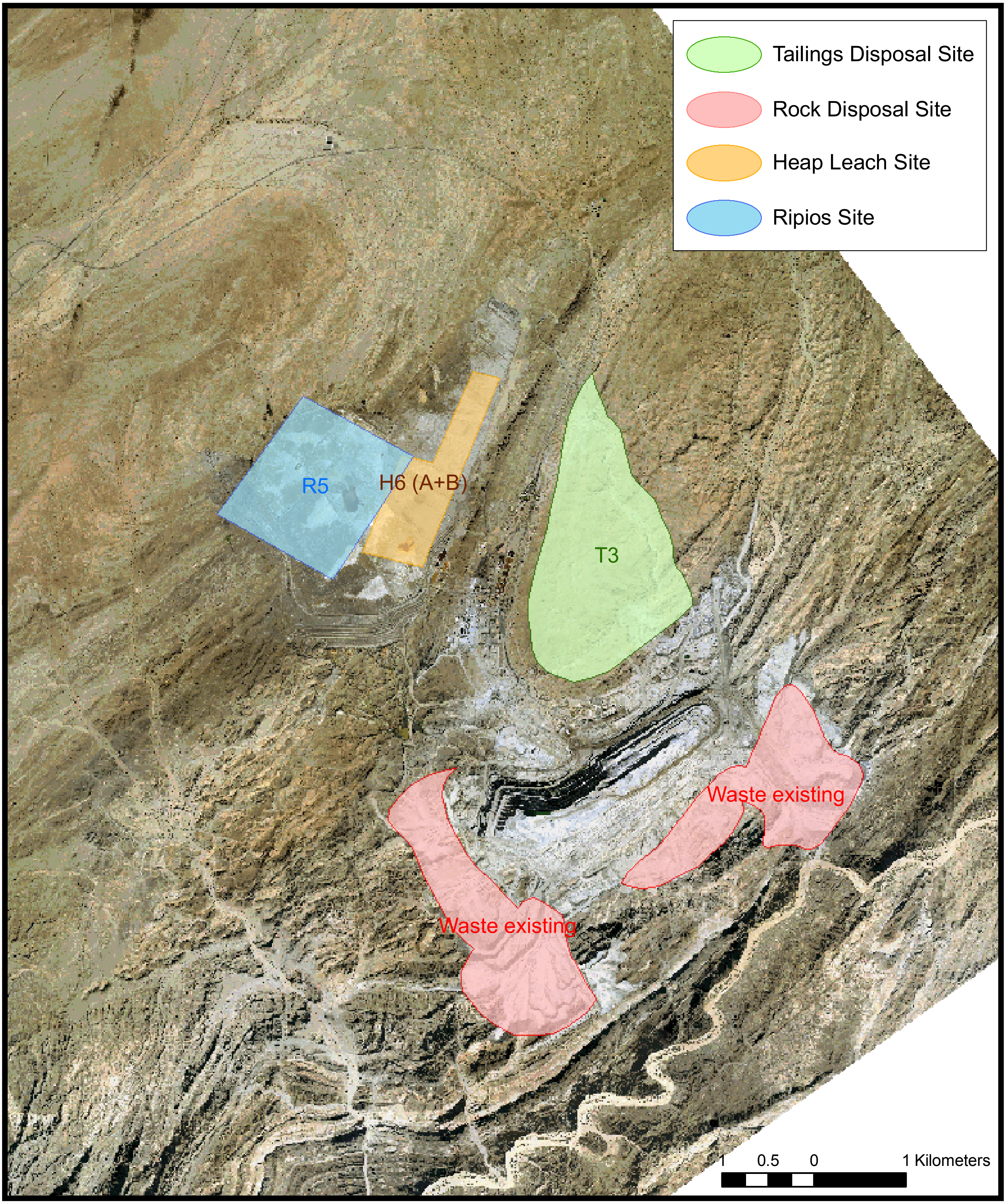
| POTENTIAL LAYOUT | PRIORITY | | | | HEAP LEACH | RIPIOS | WASTE | TAILINGS |
|---|---|---|---|---|---|---|---|---|
| L69 | h3 | r2 | w2 | t3 | H1(A+B) | R6 | W(LG4+LG7) | T3 |
| L70 | h2 | r3 | w3 | t2 | H6(A+B) | R2 | W(SK1) | T1 |
| L71 | h2 | r3 | w2 | t3 | H6(A+B) | R2 | W(LG4+LG7) | T3 |
| L72 | h2 | r2 | w3 | t3 | H6(A+B) | R6 | W(SK1) | T3 |
| L73 | h3 | r3 | w3 | t1 | H1(A+B) | R2 | W(SK1) | T0(676) |
| L74 | h3 | r3 | w1 | t3 | H1(A+B) | R2 | W(Existing) | T3 |
| L75 | h3 | r1 | w3 | t3 | H1(A+B) | R5 | W(SK1) | T3 |
| L76 | h1 | r3 | w3 | t3 | H7 | R2 | W(SK1) | T3 |
| L77 | h3 | r3 | w3 | t2 | H1(A+B) | R2 | W(SK1) | T1 |
| L78 | h3 | r3 | w2 | t3 | H1(A+B) | R2 | W(LG4+LG7) | T3 |
| L79 | h3 | r2 | w3 | t3 | H1(A+B) | R6 | W(SK1) | T3 |
| L80 | h2 | r3 | w3 | t3 | H6(A+B) | R2 | W(SK1) | T3 |
| L81 | h3 | r3 | w3 | t3 | H1(A+B) | R2 | W(SK1) | T3 |

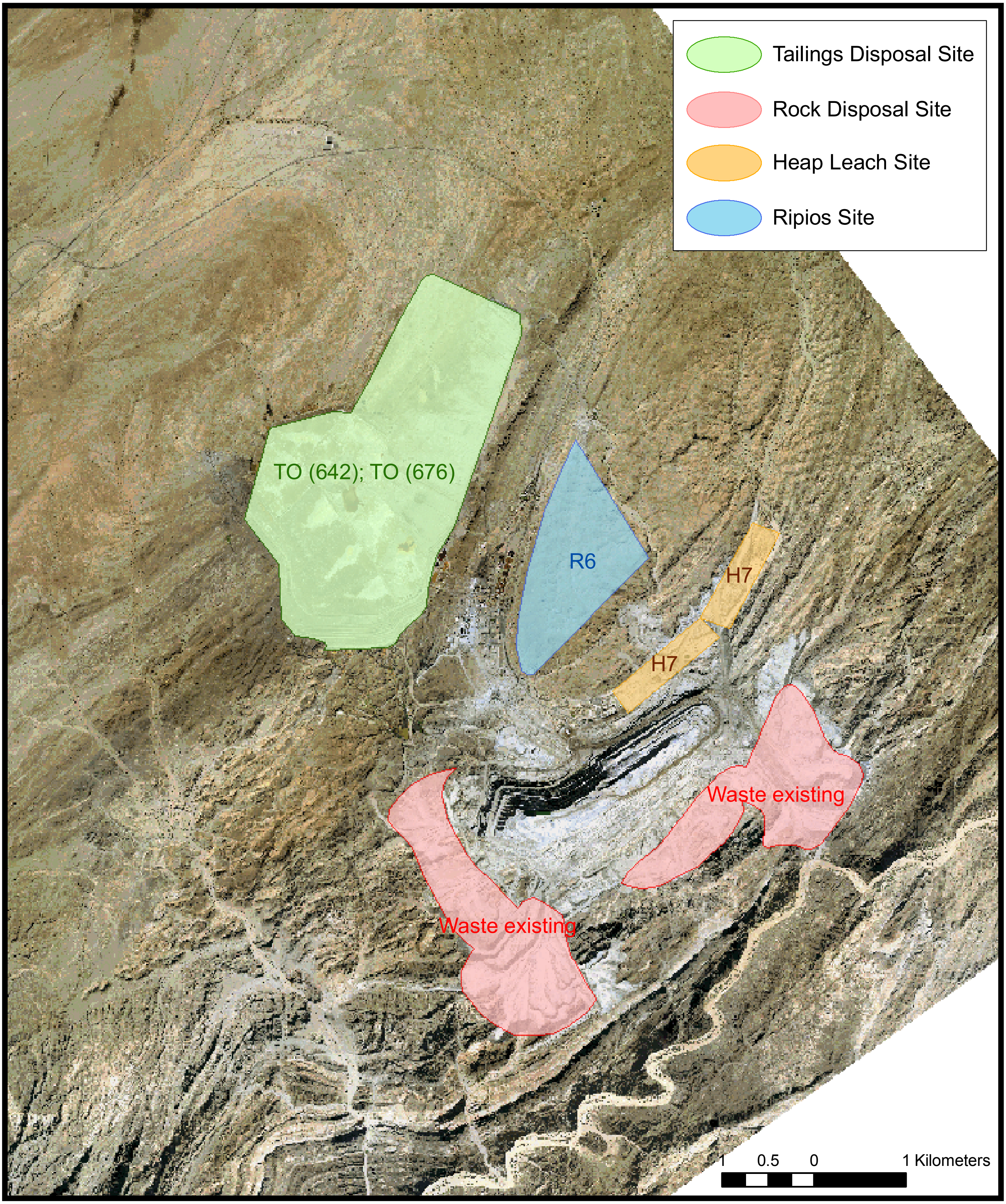
# ANNEXURE D: FEASIBLE LAYOUTS

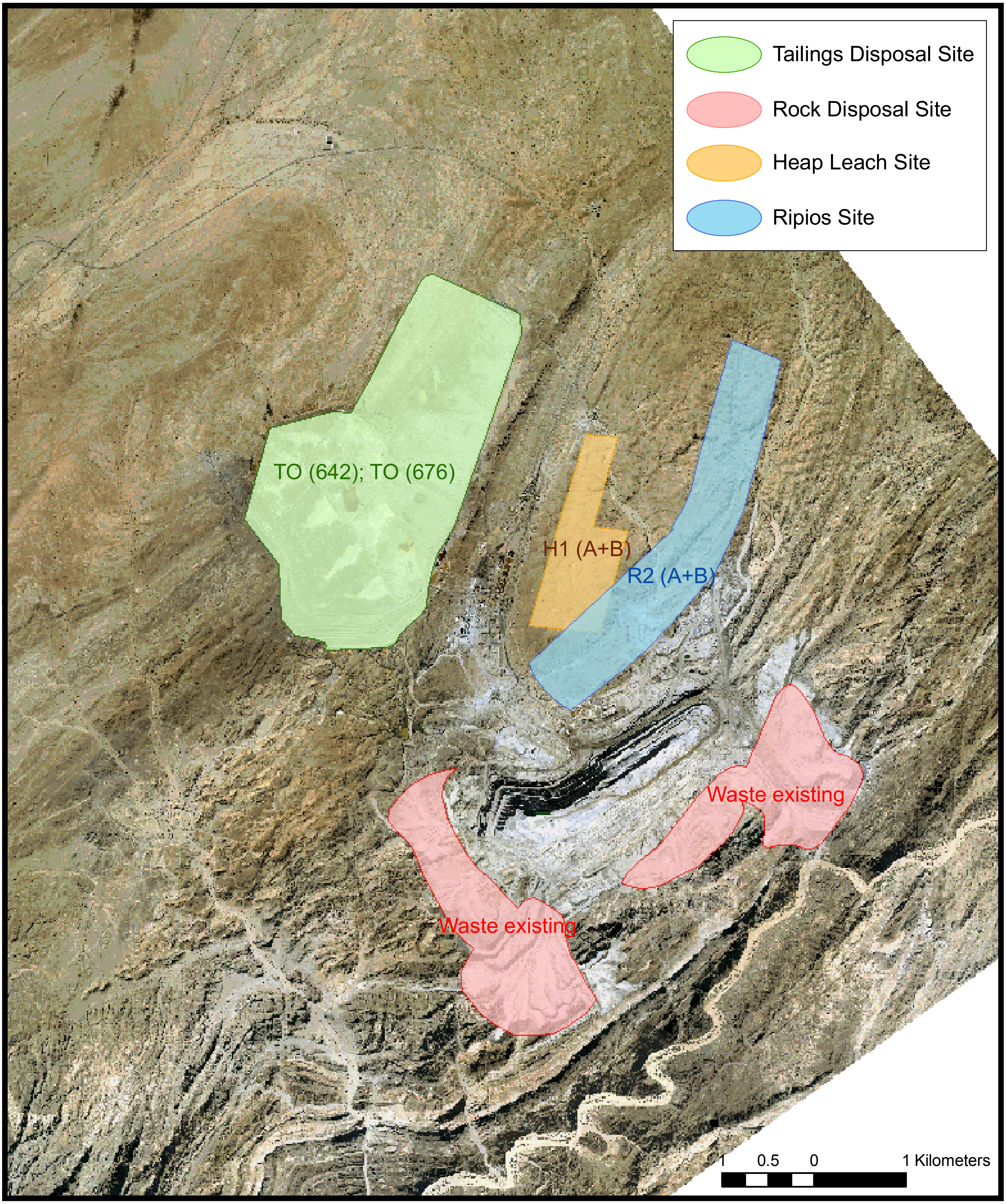

Tailings Disposal Site
Rock Disposal Site
Heap Leach Site
Ripios Site
TO (642); TO (676)
R5
H1 (A+B)
Waste existing
Waste existing
1 0.5 0 1 Kilometers

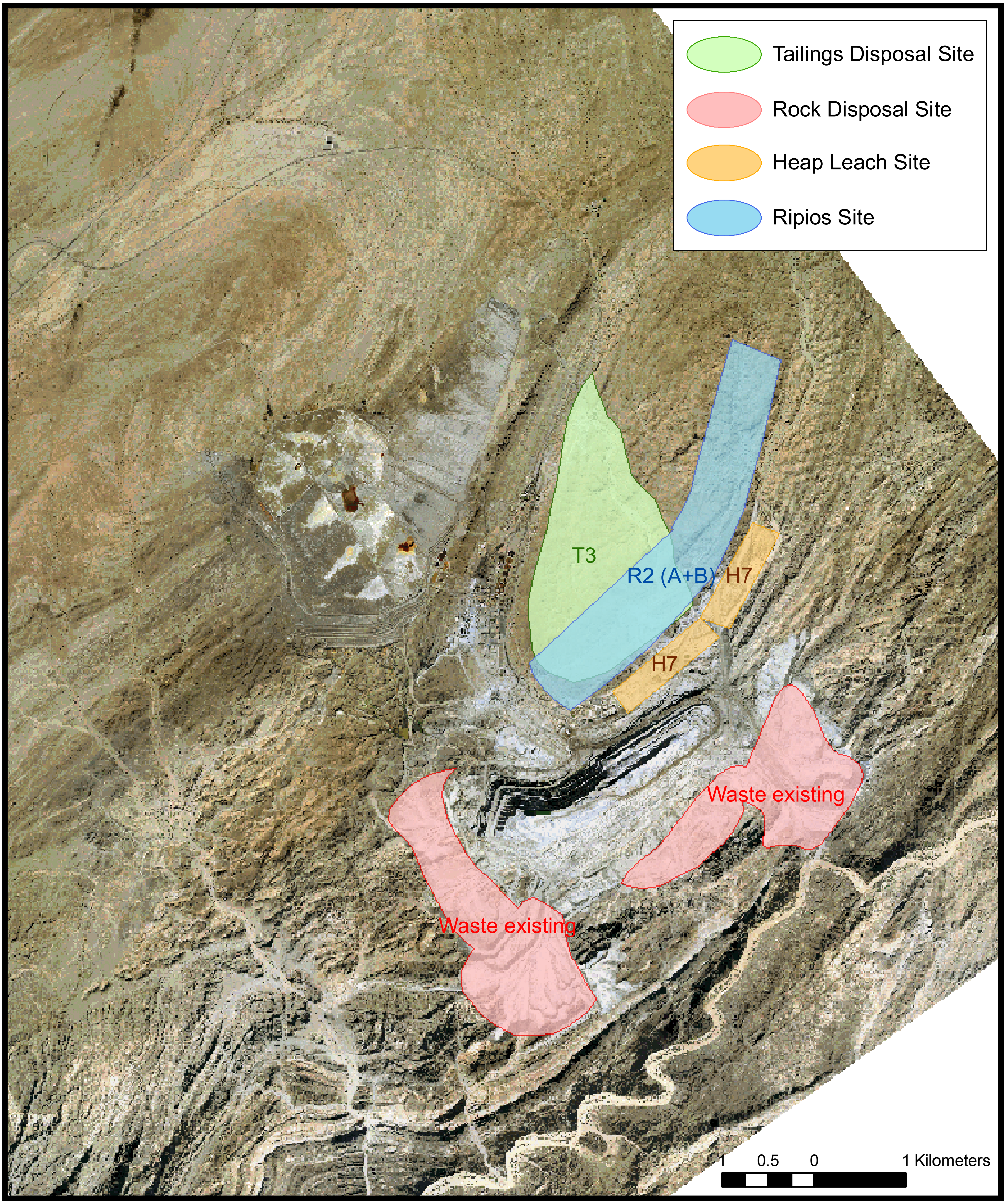


Tailings Disposal Site
Rock Disposal Site
Heap Leach Site
Ripios Site
TO (642); TO (676)
R2 (A+B)
H7
H7
Waste existing
Waste existing
1 0.5 0 1 Kilometers

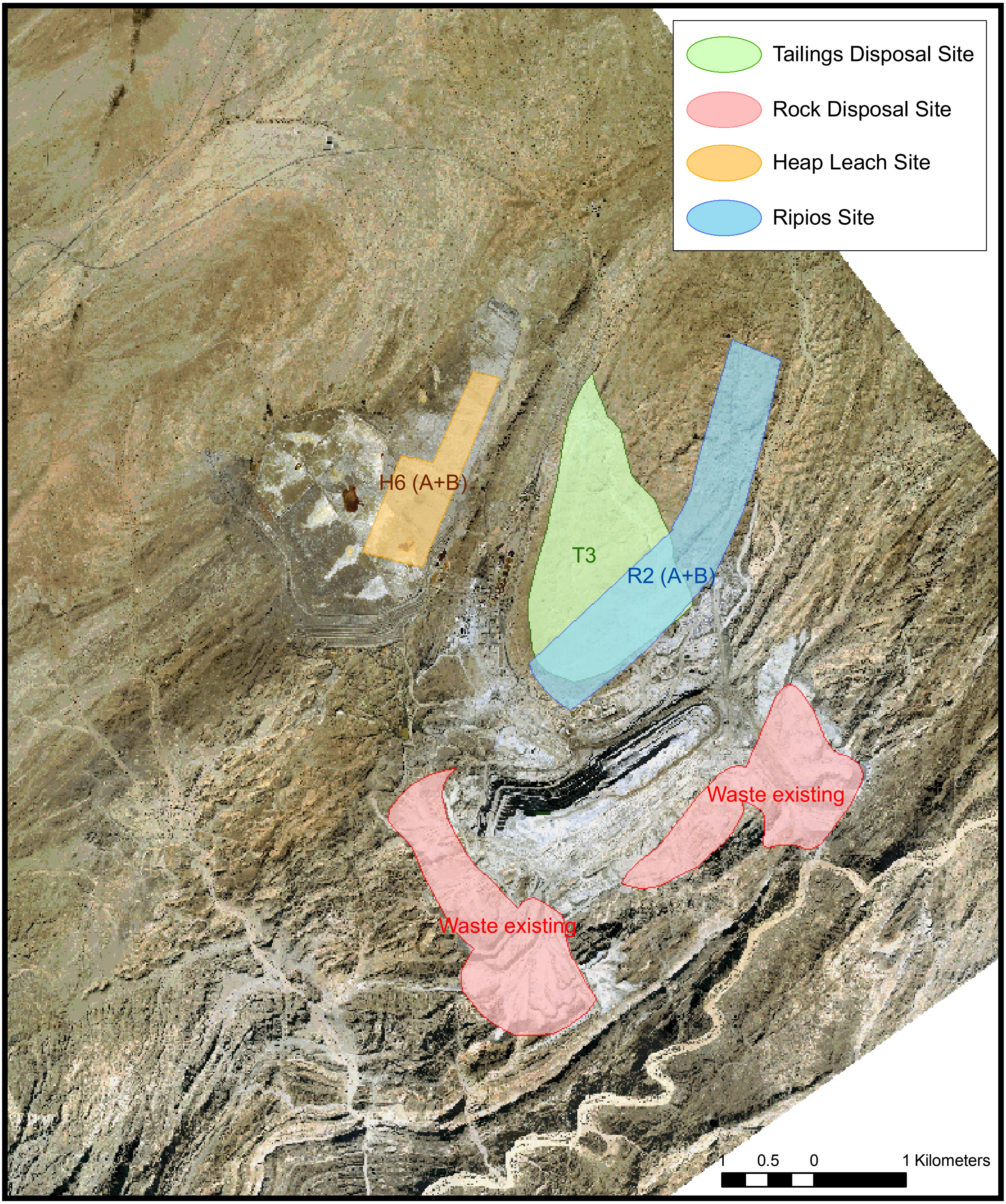

Tailings Disposal Site
Rock Disposal Site
Heap Leach Site
Ripios Site
R5
H6 (A+B)
T3
Waste existing
Waste existing
1 0.5 0 1 Kilometers


Tailings Disposal Site
Rock Disposal Site
Heap Leach Site
Ripios Site
TO (642); TO (676)
R6
H7
H7
Waste existing
Waste existing
1 0.5 0 1 Kilometers


Tailings Disposal Site
Rock Disposal Site
Heap Leach Site
Ripios Site
TO (642); TO (676)
H1 (A+B)
R2 (A+B)
Waste existing
Waste existing
1 0.5 0 1 Kilometers



Tailings Disposal Site
Rock Disposal Site
Heap Leach Site
Ripios Site
T3
R2 (A+B)
H7
H7
Waste existing
Waste existing
1 0.5 0 1 Kilometers



Tailings Disposal Site
Rock Disposal Site
Heap Leach Site
Ripios Site
H6 (A+B)
T3
R2 (A+B)
Waste existing
Waste existing
1 0.5 0 1 Kilometers

# ANNEXURE E: MODEL DESCRIPTION

# IDEAL MODE ANALYTIC HIERARCHY PROCESS PAIRWISE COMPARISON MODEL

**Andries van der Merwe**
**Ninham Shand (Pty) Ltd**

**Contents**



## 1. Introduction

Engineers and scientists often face decisions whereby priority is to be assigned to various options based on a set of multiple criteria. This decision-making process is referred to as Multiple-Criteria Decision-Making (MCDM). Options could include both project alternatives and technology alternatives within projects. The Analytic Hierarchy Process (AHP) is a MCDM approach introduced by Saaty (1977) that has increased in popularity amongst other MCDM support tools, mainly as a result of its simple mathematical structure, ease of use and the fact that a number of popular MCDM software packages adopted this approach increasing the user base. In addition, it has inspired the development of a number of other decision-making support tools.

It is structured using sets of pairwise comparisons to derive both the relative weights of the individual decision criterion and the rating of options in terms of each of the criterion. The pairwise comparison approach was introduced independently by both Ramon Llull and the eighteenth century mathematician and philosopher Marie Jean Antoine Nicolas Cariat, the Marquis de Condorcet, after which the Condorcet Method of voting using pairwise comparisons is named.

The AHP Pairwise Comparison model was proven to be unstable by Belton and Gear (1983), based on the finding that it may reverse the ranking of options with the introduction of an option that is similar than or identical to one of the existing options. They then developed the Ideal Mode AHP as a variant of the Original AHP that proved to address this deficiency by adding a normalisation process to the priority values as described in the next section. This Ideal Mode AHP was later accepted by Saaty (1994) and is widely considered to be the most reliable MCDM method and is described below. (Triantaphyllou and Mann (1995)).

It should be noted that this model, as with many other MCDM models, is used to rate the relative importance or ranking rather than the absolute importance or ranking, as engineers and scientists often have to base decisions on incomplete information, rather than totally quantifiable information. This implies that the model should be able to tolerate a degree of inaccuracy (as a result of the level of detail of the base information) with regard to the rating, which is true for this model. (Triantaphyllou and Mann (1995)). The numerical values of the results should not be interpreted directly, other than for the purposes of indicating relative importance. In addition, this model allows for the testing or confirmation of the consistency of the rating. The calculations to test the consistency of the rating are discussed and explained, but not shown in the numerical example. The model yields acceptable results based on rating consistencies less then 0.10 (or 10%), effectively allowing for this degree of inconsistency in the rating itself.

## 2. Model Description

The Ideal Mode AHP Pairwise Comparison model and application methodology is described below. Firstly the structure is presented, using the relevant matrices facilitating AHP pairwise comparisons, followed by the process methodology.

### Structure

The structure of the model is best explained by looking at an example. When comparing options in a pairwise comparison using this model, as would be done for each of the criterion, the following scale of rating introduced by Saaty (1980) is used:

| RATING SCALE TABLE | |
|---|---|
| **Rating (R)** | **Description of Relative Rating** |
| 1 | Equal |
| 3 | Weak preference |
| 5 | Essential or strong preference |
| 7 | Demonstrated preference |
| 9 | Absolute preference |
| 2, 4, 6, 8 | Intermediate values |
| Reciprocals of the above | If for criterion x, option A has a rating of one of the above when compared to option B ($R_{xAB}$), then option B has the reciprocal rating when compared to option A ($R_{xBA}$) |

When applying this scale, it is useful to first consider whether an option is better or worse than the option it is being compared to in respect of the criterion under consideration. This will then indicate whether the relative rating should be an integer value (when it is better) or a fraction value (when it is worse), using the principle of reciprocal rating as per the scale.  The significance or severity of this preference is then expressed through the application of the numerical values in the scale, unless it is equal in which case a rating of 1 is used.

The first step would be to define the number of options and the number of criterion. To simplify the example, let us assume four options (A, B, C and D) and four criterion ($C_1$, $C_2$, $C_3$ and $C_4$), resulting in the following pairwise comparison matrix for each of the criterion, that could be expanded based on the required number of options, where $R_{xAB}$ represents the rating of option A compared to option B for criterion x (or answering the questions “is A better or worse than B?” and “what is the significance or severity of this preference?”):

| OPTIONS MATRIX FOR CRITERION x | | | | |
|---|---|---|---|---|
| **Pairwise Comparison of Options Against Criterion $C_X$** | **A** | **B** | **C** | **D** |
| **A** | $R_{xAA}$ | $R_{xAB}$ | $R_{xAC}$ | $R_{xAD}$ |
| **B** | $R_{xBA}$ | $R_{xBB}$ | $R_{xBC}$ | $R_{xBD}$ |
| **C** | $R_{xCA}$ | $R_{xCB}$ | $R_{xCC}$ | $R_{xCD}$ |
| **D** | $R_{xDA}$ | $R_{xDB}$ | $R_{xDC}$ | $R_{xDD}$ |

Since $R_{xAA} = R_{xBB} = R_{xCC} = R_{xDD} = R_{xnn} = 1$ per definition, as it represents the rating of an option compared to itself, and $R_{xBA} = 1 / R_{xAB}$ and $R_{xAC} = 1 / R_{xCA}$ etc. per definition, as one is the reciprocal of the other, the matrix is reduced to the following, effectively requiring the rating of the non-shaded cells only per each of the criterion:

| **OPTIONS MATRIX FOR CRITERION 1** | | | | |
|---|---|---|---|---|
| **Pairwise Comparison of Options Against Criterion $C_1$** | **A** | **B** | **C** | **D** |
| **A** | 1 | $R_{1AB}$ | $R_{1AC}$ | $R_{1AD}$ |
| **B** | $1 / R_{1AB}$ | 1 | $R_{1BC}$ | $R_{1BD}$ |
| **C** | $1 / R_{1AC}$ | $1 / R_{1BC}$ | 1 | $R_{1CD}$ |
| **D** | $1 / R_{1AD}$ | $1 / R_{1BD}$ | $1 / R_{1CD}$ | 1 |

For the chosen example, similar matrices would be created for $C_2$, $C_3$ and $C_4$. The same methodology is then used to determine the relative weighting of the criterion in relation to each other that would later be applied to arrive at the overall ranking of options, where $R_{C1C2}$ represents the rating of criterion $C_1$ compared to criterion $C_2$ in the criterion matrix, sometimes referred to as the judgment matrix:

| **CRITERION MATRIX** | | | | |
|---|---|---|---|---|
| **Pairwise Comparison of Criterion** | **$C_1$** | **$C_2$** | **$C_3$** | **$C_4$** |
| **$C_1$** | 1 | $R_{C1C2}$ | $R_{C1C3}$ | $R_{C1C4}$ |
| **$C_2$** | $1 / R_{C1C2}$ | 1 | $R_{C2C3}$ | $R_{C2C4}$ |
| **$C_3$** | $1 / R_{C1C3}$ | $1 / R_{C2C3}$ | 1 | $R_{C3C4}$ |
| **$C_4$** | $1 / R_{C1C4}$ | $1 / R_{C2C4}$ | $1 / R_{C3C4}$ | 1 |

**Process**

The process followed to determine the relative preference rating of the options is then completed in three main steps: the relative priority (or weighting) of the individual criterion is determined; an original AHP decision matrix is calculated; followed by the conversion to the ideal mode decision matrix that results in the final priorities that is usually normalised to express it in easily comparable (relative to each other only) numbers. The process is described below.

The first step to determine the relative priority of the individual criterion is to calculate the geometric mean value of the rating results per criterion. The following formula is applied to the relative ratings in the criterion rating matrix, where $MC_x$ represents the geometric mean of the rating results of criterion $C_X$ of n criteria:

$$MC_x = (R_{CxC1} \text{ x } R_{CxC2} \text{ x } R_{CxC3} \text{ x } R_{CxC4} \text{ x} \ldots\ldots\ldots\ldots R_{CxCn})^{1/n}$$

This calculation is done for each of the criterion. For the chosen example using four criterion, the resultant formula to calculate $MC_1$ representing the geometric mean of the rating results of criterion $C_1$, and noting that $R_{C1C1} = 1$ per definition, is:

$$MC_1 = (1 \times R_{C1C2} \times R_{C1C3} \times R_{C1C4})^{1/4}$$

A column can be added to the criterion rating matrix to show this calculation result, producing the following matrix:

| CRITERION MATRIX | | | | | |
|---|---|---|---|---|---|
| **Pairwise Comparison of Criterion** | **$C_1$** | **$C_2$** | **$C_3$** | **$C_4$** | **Geometric Mean of Rating** |
| **$C_1$** | 1 | $R_{C1C2}$ | $R_{C1C3}$ | $R_{C1C4}$ | $M_{C1}$ |
| **$C_2$** | $1 / R_{C1C2}$ | 1 | $R_{C2C3}$ | $R_{C2C4}$ | $M_{C2}$ |
| **$C_3$** | $1 / R_{C1C3}$ | $1 / R_{C2C3}$ | 1 | $R_{C3C4}$ | $M_{C3}$ |
| **$C_4$** | $1 / R_{C1C4}$ | $1 / R_{C2C4}$ | $1 / R_{C3C4}$ | 1 | $M_{C4}$ |

The relative priority of each criterion is then calculated by normalising this column by dividing each of the values by the total of the column (or the sum of the geometric mean values):

$$PC_x = M_{Cx} / (M_{C1} + M_{C2} + M_{C3} + M_{C4} + \ldots\ldots M_{Cn})$$

The resultant formula for the calculation of the relative priority of criterion 1 for the given example is:

$$PC_1 = M_{C1} / (M_{C1} + M_{C2} + M_{C3} + M_{C4})$$

A second column can be added to the criterion rating matrix to show this calculation result, producing the following criterion priority matrix:

| CRITERION PRIORITY MATRIX | | | | | | |
|---|---|---|---|---|---|---|
| **Pairwise Comparison of Criterion** | **$C_1$** | **$C_2$** | **$C_3$** | **$C_4$** | **Geometric Mean** | **Criterion Priority Vector** |
| **$C_1$** | 1 | $R_{C1C2}$ | $R_{C1C3}$ | $R_{C1C4}$ | $M_{C1}$ | $P_{C1}$ |
| **$C_2$** | $1 / R_{C1C2}$ | 1 | $R_{C2C3}$ | $R_{C2C4}$ | $M_{C2}$ | $P_{C2}$ |
| **$C_3$** | $1 / R_{C1C3}$ | $1 / R_{C2C3}$ | 1 | $R_{C3C4}$ | $M_{C3}$ | $P_{C3}$ |
| **$C_4$** | $1 / R_{C1C4}$ | $1 / R_{C2C4}$ | $1 / R_{C3C4}$ | 1 | $M_{C4}$ | $P_{C4}$ |

A similar calculation is done to determine the relative priorities of each of the options per criteria, by first calculating the geometric mean values of the rating results, using the formula below for the given example, where $M_xA$ represents the geometric mean of the rating results of option A for criterion x where 4 options were evaluated:

$$M_xA = (R_{xAA} \times R_{xAB} \times R_{xAC} \times R_{xAD})^{1/4}$$

Applying the definitions and methodology described above, this calculation of the geometric mean of the rating results of each of the options is done for every criterion. As an example, the calculation of $M_1A$ represents the geometric mean of rating results of option A for criterion 1, where 4 options are evaluated, is done using:

$$M_1A = (1 \times R_{1AB} \times R_{1AC} \times R_{1AD})^{1/4}$$

Similar to the calculation of the relative priority of each of the criterion, the relative priority of each option is then calculated per criterion by normalising the values:

$$P_xA = M_{xA} / (M_{1A} + M_{2A} + M_{3A} + M_{4A} + \dots\dots\dots M_{nA})$$

The resultant formula for the calculation of the relative priority of option A for criterion 1 for the given example is:

$$P_1A = M_{1A} / (M_{1A} + M_{2A} + M_{3A} + M_{4A})$$

Similar to what was done to determine the criterion priority matrix, two columns are added to the options matrix per criterion, resulting in the following set of matrices for the given example:

| OPTIONS PRIORITY MATRIX FOR CRITERION 1 | | | | | | |
|---|---|---|---|---|---|---|
| **Pairwise Comparison of Options Against Criterion $C_1$** | **A** | **B** | **C** | **D** | **Geometric Mean of Rating Against Criterion $C_1$** | **Option Priority Vector for Criterion $C_1$** |
| **A** | 1 | $R_{1AB}$ | $R_{1AC}$ | $R_{1AD}$ | $M_{1A}$ | $P_{1A}$ |
| **B** | $1 / R_{1AB}$ | 1 | $R_{1BC}$ | $R_{1BD}$ | $M_{1B}$ | $P_{1B}$ |
| **C** | $1 / R_{1AC}$ | $1 / R_{1BC}$ | 1 | $R_{1CD}$ | $M_{1C}$ | $P_{1C}$ |
| **D** | $1 / R_{1AD}$ | $1 / R_{1BD}$ | $1 / R_{1CD}$ | 1 | $M_{1D}$ | $P_{1D}$ |

| OPTIONS PRIORITY MATRIX FOR CRITERION 2 | | | | | | |
|---|---|---|---|---|---|---|
| **Pairwise Comparison of Options Against Criterion $C_2$** | **A** | **B** | **C** | **D** | **Geometric Mean of Rating Against Criterion $C_2$** | **Option Priority Vector for Criterion $C_2$** |
| **A** | 1 | $R_{2AB}$ | $R_{2AC}$ | $R_{2AD}$ | $M_{2A}$ | $P_{2A}$ |
| **B** | $1 / R_{2AB}$ | 1 | $R_{2BC}$ | $R_{2BD}$ | $M_{2B}$ | $P_{2B}$ |
| **C** | $1 / R_{2AC}$ | $1 / R_{2BC}$ | 1 | $R_{2CD}$ | $M_{2C}$ | $P_{2C}$ |
| **D** | $1 / R_{2AD}$ | $1 / R_{2BD}$ | $1 / R_{2CD}$ | 1 | $M_{2D}$ | $P_{2D}$ |

| OPTIONS PRIORITY MATRIX FOR CRITERION 3 | | | | | | |
|---|---|---|---|---|---|---|
| **Pairwise Comparison of Options Against Criterion $C_3$** | **A** | **B** | **C** | **D** | **Geometric Mean of Rating Against Criterion $C_3$** | **Option Priority Vector for Criterion $C_3$** |
| **A** | 1 | $R_{3AB}$ | $R_{3AC}$ | $R_{3AD}$ | $M_{3A}$ | $P_{3A}$ |
| **B** | 1 / $R_{3AB}$ | 1 | $R_{3BC}$ | $R_{3BD}$ | $M_{3B}$ | $P_{3B}$ |
| **C** | 1 / $R_{3AC}$ | 1 / $R_{3BC}$ | 1 | $R_{3CD}$ | $M_{3C}$ | $P_{3C}$ |
| **D** | 1 / $R_{3AD}$ | 1 / $R_{3BD}$ | 1 / $R_{3CD}$ | 1 | $M_{3D}$ | $P_{3D}$ |

| OPTIONS PRIORITY MATRIX FOR CRITERION 4 | | | | | | |
|---|---|---|---|---|---|---|
| **Pairwise Comparison of Options Against Criterion $C_4$** | **A** | **B** | **C** | **D** | **Geometric Mean of Rating Against Criterion $C_4$** | **Option Priority Vector for Criterion $C_4$** |
| **A** | 1 | $R_{4AB}$ | $R_{4AC}$ | $R_{4AD}$ | $M_{4A}$ | $P_{4A}$ |
| **B** | 1 / $R_{4AB}$ | 1 | $R_{4BC}$ | $R_{4BD}$ | $M_{4B}$ | $P_{4B}$ |
| **C** | 1 / $R_{4AC}$ | 1 / $R_{4BC}$ | 1 | $R_{4CD}$ | $M_{4C}$ | $P_{4C}$ |
| **D** | 1 / $R_{4AD}$ | 1 / $R_{4BD}$ | 1 / $R_{4CD}$ | 1 | $M_{4D}$ | $P_{4D}$ |

The original AHP decision matrix is then produced by copying the respective priority vector columns from the above options priority matrices into a single matrix, with the criterion priorities from the criterion priority matrix in the top row, as shown below:

| ORIGINAL AHP DECISION MATRIX | | | | |
|---|---|---|---|---|
| **Options / Criteria** | **$C_1$** | **$C_2$** | **$C_3$** | **$C_4$** |
| **Criterion Priority** | $P_{C1}$ | $P_{C2}$ | $P_{C3}$ | $P_{C4}$ |
| **A** | $P_{1A}$ | $P_{2A}$ | $P_{3A}$ | $P_{4A}$ |
| **B** | $P_{1B}$ | $P_{2B}$ | $P_{3B}$ | $P_{4B}$ |
| **C** | $P_{1C}$ | $P_{2C}$ | $P_{3C}$ | $P_{4C}$ |
| **D** | $P_{1D}$ | $P_{2D}$ | $P_{3D}$ | $P_{4D}$ |

This matrix is then used to produce the ideal mode AHP decision matrix, by adjusting the relative options priority values through a second normalisation, by dividing the entries in each column by the largest entry in that particular column, using the formula below, where $IP_{xA}$ represents the ideal mode relative priority of option A for criterion x for n options:

$$IP_{xA} = P_{xA} / (\text{maximum of } P_{1A} ; P_{1B} ; P_{1C} ; P_{1D} ; \ldots\ldots\ldots.P_{1n})$$

For the given example, $IP_{1A}$ representing the ideal mode relative priority of option A for criterion 1, is calculated by:

$$IP_{1A} = P_{1A} / (\text{maximum of } P_{1A}\ ;\ P_{1B}\ ;\ P_{1C}\ ;\ P_{1D})$$

Similarly, these relative priority values are normalised for the other options and criterion, resulting in the ideal mode AHP decision matrix below, with the maximum IP value per criterion column having the value of 1:

| IDEAL MODE AHP DECISION MATRIX | | | | |
|---|---|---|---|---|
| **Options / Criteria** | **$C_1$** | **$C_2$** | **$C_3$** | **$C_4$** |
| **Criterion Priority** | $P_{C1}$ | $P_{C2}$ | $P_{C3}$ | $P_{C4}$ |
| **A** | $IP_{1A}$ | $IP_{2A}$ | $IP_{3A}$ | $IP_{4A}$ |
| **B** | $IP_{1B}$ | $IP_{2B}$ | $IP_{3B}$ | $IP_{4B}$ |
| **C** | $IP_{1C}$ | $IP_{2C}$ | $IP_{3C}$ | $IP_{4C}$ |
| **D** | $IP_{1D}$ | $IP_{2D}$ | $IP_{3D}$ | $IP_{4D}$ |

The final option priority of option A is then calculated by using the formula below, where n represents the number of criteria:

$$P_A = (IP_{1A} \times PC_1) + (IP_{2A} \times PC_2) + (IP_{3A} \times PC_3) + (IP_{4A} \times PC_4) + \ldots(IP_{nA} \times PC_n)$$

For the given example, the final option priority of option A is then calculated by:

$$P_A = (IP_{1A} \times PC_1) + (IP_{2A} \times PC_2) + (IP_{3A} \times PC_3) + (IP_{4A} \times PC_4)$$

Similarly, the final option relative priorities of other options are calculated and represented in the final ideal mode AHP decision matrix:

| FINAL IDEAL MODE AHP DECISION MATRIX | | | | | |
|---|---|---|---|---|---|
| **Options / Criteria** | **$C_1$** | **$C_2$** | **$C_3$** | **$C_4$** | **Final Option Relative Priority** |
| **Criterion Priority** | $P_{C1}$ | $P_{C2}$ | $P_{C3}$ | $P_{C4}$ | - |
| **A** | $IP_{1A}$ | $IP_{2A}$ | $IP_{3A}$ | $IP_{4A}$ | $P_A$ |
| **B** | $IP_{1B}$ | $IP_{2B}$ | $IP_{3B}$ | $IP_{4B}$ | $P_B$ |
| **C** | $IP_{1C}$ | $IP_{2C}$ | $IP_{3C}$ | $IP_{4C}$ | $P_C$ |
| **D** | $IP_{1D}$ | $IP_{2D}$ | $IP_{3D}$ | $IP_{4D}$ | $P_D$ |

As stated previously, these final option relative priorities are usually again normalised by dividing each through the total of all and is often also represented as a relative percentage value for ease of comparison. It should be noted that the numerical values of the results should not be interpreted directly, other than for the purposes of indicating relative importance.

An advantage of this model is that the results are not dependent on perfect consistency, as this rarely exists in practice. Saaty (1980) concluded that a consistency ratio (CR) of less than 0.10 (or 10%) is considered adequate. To determine the consistency of ranking in any priority matrix (options priority matrix or criterion priority matrix), the consistency index (CI) value is calculated first using the formula below, where $E_{max}$ denotes the approximation of the maximum eigenvalue and n denotes the number of options or criterion, depending on whether the CI is calculated for an options priority matrix or the criterion priority matrix:

$$CI = (E_{max} – n) / (n-1)$$

In this formula, the approximation of the eigenvalue is calculated by adding each column in the priority matrix and multiplying the resultant vector by the priority vector, as shown below, where $R_xA$ represents the numerical total of the ratings in column A for criterion x, and then multiplying this resultant vector with the priority vector:

$$R_xA = R_{xAA} + R_{xBA} + R_{xCA} + R_{xDA}$$

A row could be added to the options matrix to indicate these totals (vector), as per the options matrix for criterion x below:

| OPTIONS MATRIX FOR CRITERION x | | | | | | |
|---|---|---|---|---|---|---|
| **Pairwise Comparison of Options Against Criterion $C_X$** | **A** | **B** | **C** | **D** | **Geometric Mean of Rating Against Criterion $C_x$** | **Option Priority Vector for Criterion $C_x$** |
| **A** | $R_{xAA}$ | $R_{xAB}$ | $R_{xAC}$ | $R_{xAD}$ | $M_{xA}$ | $P_{xA}$ |
| **B** | $R_{xBA}$ | $R_{xBB}$ | $R_{xBC}$ | $R_{xBD}$ | $M_{xB}$ | $P_{xB}$ |
| **C** | $R_{xCA}$ | $R_{xCB}$ | $R_{xCC}$ | $R_{xCD}$ | $M_{xC}$ | $P_{xC}$ |
| **D** | $R_{xDA}$ | $R_{xDB}$ | $R_{xDC}$ | $R_{xDD}$ | $M_{xD}$ | $P_{xD}$ |
| | $R_{xA}$ | $R_{xB}$ | $R_{xC}$ | $R_{xD}$ | | |

The calculation of the $E_{max}$ is then done by multiplication of the resultant vector of totals with the priority vector, using:

$$E_{max} = (R_xA \times P_xA) + (R_xB \times P_xB) + (R_xC \times P_xC) + (R_xD \times P_xD)$$

The consistency ratio (CR), that is used as the main indicator of ranking consistency, is then calculated by dividing the CI value by the random consistency index (RCI) value, given in the table below for different values of n (Saaty (1980)):

| RANDOM CONSISTENCY INDEX TABLE | |
|---|---|
| **n** | **RCI** |
| 1 | 0 |
| 2 | 0 |
| 3 | 0.58 |
| 4 | 0.90 |
| 5 | 1.12 |
| 6 | 1.24 |
| 7 | 1.32 |
| 8 | 1.41 |
| 9 | 1.45 |

The consistency ratio (CR) is given by:

$$CR = CI / RCI$$

Resultant CR values higher than 0.10 (or 10%) warrants a re-evaluation of the pairwise comparisons.

**Numerical Example**

In order to further illustrate the methodology and calculations, a numerical example is provided below. For this example, similar to the generic description above, four options and four criteria for decision making will be used. A typical environmental engineering application such as the selection of a suitable site for the establishment of a solid waste disposal facility from four available sites using multiple criteria (that will in this case be limited to four, although more are usually required) could serve as a suitable example.

Let us name the site options Site A, Site B, Site C and Site D respectively and limit the main criteria to Distance from source, Site geology, Environmental impact and Space availability. Arbitrary rating and calculation results are provided in the matrices below.

| EXAMPLE CRITERION PRIORITY MATRIX | | | | | | |
|---|---|---|---|---|---|---|
| **Pairwise Comparison of Criterion** | **Distance** | **Geology** | **Environment** | **Space** | **Geometric Mean of Criteria Rating** | **Criterion Priority Vector** |
| **Distance** | 1 | 2 | 3 | 2 | 1.86 | 0.42 |
| **Geology** | 1/2 | 1 | 2 | 1/2 | 0.84 | 0.19 |
| **Environment** | 1/3 | 1/2 | 1 | 1/2 | 0.54 | 0.12 |
| **Space** | 1/2 | 2 | 2 | 1 | 1.19 | 0.27 |

| EXAMPLE OPTIONS PRIORITY MATRIX FOR DISTANCE | | | | | | |
|---|---|---|---|---|---|---|
| **Pairwise Comparison of Options Against Distance** | **Site A** | **Site B** | **Site C** | **Site D** | **Geometric Mean of Rating Against Distance** | **Option Priority Vector for Distance** |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Site A** | 1 | 3 | 5 | 1/3 | 1.50 | 0.30 |
| **Site B** | 1/3 | 1 | 5 | 1/3 | 0.86 | 0.17 |
| **Site C** | 1/5 | 1/5 | 1 | 1/3 | 0.34 | 0.07 |
| **Site D** | 3 | 3 | 3 | 1 | 2.28 | 0.46 |

**EXAMPLE OPTIONS PRIORITY MATRIX FOR GEOLOGY**

| Pairwise Comparison of Options Against Geology | Site A | Site B | Site C | Site D | Geometric Mean of Rating Against Geology | Option Priority Vector for Geology |
|---|---|---|---|---|---|---|
| **Site A** | 1 | 3 | 1/2 | 1/2 | 0.93 | 0.21 |
| **Site B** | 1/3 | 1 | 1/3 | 1/2 | 0.49 | 0.11 |
| **Site C** | 2 | 3 | 1 | 1 | 1.57 | 0.36 |
| **Site D** | 2 | 2 | 1 | 1 | 1.41 | 0.32 |

**EXAMPLE OPTIONS PRIORITY MATRIX FOR ENVIRONMENT**

| Pairwise Comparison of Options Against Environment | Site A | Site B | Site C | Site D | Geometric Mean of Rating Against Environment | Option Priority Vector for Environment |
|---|---|---|---|---|---|---|
| **Site A** | 1 | 7 | 1/2 | 2 | 1.63 | 0.30 |
| **Site B** | 1/7 | 1 | 1/9 | 1/5 | 0.24 | 0.04 |
| **Site C** | 2 | 9 | 1 | 2 | 2.45 | 0.46 |
| **Site D** | 1/2 | 5 | 1/2 | 1 | 1.06 | 0.20 |

**EXAMPLE OPTIONS PRIORITY MATRIX FOR SPACE**

| Pairwise Comparison of Options Against Space | Site A | Site B | Site C | Site D | Geometric Mean of Rating Against Space | Option Priority Vector for Space |
|---|---|---|---|---|---|---|
| **Site A** | 1 | 1/2 | 3 | 7 | 1.80 | 0.32 |
| **Site B** | 2 | 1 | 3 | 9 | 2.71 | 0.49 |
| **Site C** | 1/3 | 1/3 | 1 | 4 | 0.82 | 0.15 |
| **Site D** | 1/7 | 1/9 | 1/4 | 1 | 0.25 | 0.04 |

**EXAMPLE ORIGINAL AHP DECISION MATRIX**

| Options / Criteria | Distance | Geology | Environment | Space |
|---|---|---|---|---|
| **Criterion Priority** | 0.42 | 0.19 | 0.12 | 0.27 |
| **Site A** | 0.30 | 0.21 | 0.30 | 0.32 |
| **Site B** | 0.17 | 0.11 | 0.04 | 0.49 |
| **Site C** | 0.07 | 0.36 | 0.46 | 0.15 |
| **Site D** | 0.46 | 0.32 | 0.20 | 0.04 |

**EXAMPLE FINAL IDEAL MODE AHP DECISION MATRIX**

| Options / Criteria | Distance | Geology | Environment | Space | Final Option Relative Priority |
|---|---|---|---|---|---|
| **Criterion Priority** | 0.42 | 0.19 | 0.12 | 0.27 | - |
| **Site A** | 0.66 | 0.59 | 0.66 | 0.66 | 0.65 |
| **Site B** | 0.38 | 0.31 | 0.10 | 1.00 | 0.50 |

| | | | | | |
|---|---|---|---|---|---|
| **Site C** | 0.15 | 1.00 | 1.00 | 0.30 | 0.45 |
| **Site D** | 1.00 | 0.90 | 0.43 | 0.09 | 0.67 |

The best option in the given example, based on the ratings as above, is Site D followed by Site A, Site B and Site C. It should be noted that final option relative priority results as close together as these should normally be reconsidered by either re-evaluating the ranking or adding additional criteria that could further differentiate between options to result in a wider distribution. The relative preference is however indicated by the results, based on the arbitrary ratings.

## 3. Conclusion

The AHP Pairwise Comparison Model provides an effective solution when faced with MCDM. It has the advantages that it is easy to use, has a robust mathematical foundation, is transparent (as the results are directly linked to the relative ratings) and allows for the rankings to be done by a team of specialists as is typically required in MCDM scenarios, involving a different specialist or team of specialists per criterion. In addition, it allows for a sensitivity analysis in terms of the relative priorities, by adjusting ranking values, especially if a spreadsheet or commercially available AHP software package is used for the calculations.

## 4. References

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