**I.S.E.E. 29th Annual Conference on Explosives and Blasting Technique,**

**Nashville, Tennessee, U.S.A. February 2-5, 2003**

# Environmental Impact Statement for Mining with Explosives:

# A QUANTITATIVE METHOD

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## Abstract

This article describes the method used to quantify the Environmental Impact for the mining, by drilling and blasting, of a borrow pit for a gravity-dam.
The affected environment was broken down into a number of components, such as public health and safety, social relationship, air and water quality, flora and fauna. The effect of the various impacting factors from the mining activities, both directly and indirectly, was then calculated for each environmental component. To do this, each impacting factor was first given a magnitude, a number based solely on the range of scenarios possible for the impacting factor. A matrix of weighting factors was then derived to systematically quantify, and normalise, the effects of each impacting factor on each environmental component. The overall impact upon each individual environmental component was then calculated by summing the weighted magnitudes for all the impacting factors.

The method, which is outlined here in a schematic form, was originally developed for a mining operation in Sardinia, Italy. It has subsequently been successfully used for trough and other mining ventures and more general industrial activities, such as waste dumping, recycling and, energy production.

As with any evaluation, the method requires an element of subjective assessment but it does at least give transparency to the process used to assess environmental impact. The method can be used to ensure the consistency of approach required to allow realistic comparisons to be made between various design solutions, mitigation measures.
In a wider sphere, for instance a provincial mining district, it could be used to ensure a consistent means of comparison between the environmental impacts due to different mining sites.

## 1. Introduction

A borrow pit, with a related dump for waste materials, was started in order to produce the aggregates required for the concrete of a dam-body, bituminous conglomerates and the foundations for service streets.

The volume of rock to be quarried, and the waste area, were situated within the area to be flooded by the dam. Physiography was harsh, with steep slopes and narrow valley, all covered with wood and Mediterranean bush. The rock mass, consisting of granite, had generally good geo-mechanical characteristics. It was jointed, with "onion type" cooling joints and plane tectonic joints, and also had local bands of metamorphic alteration.

The open pit was dimensioned for the supply of 800,000 tons of rock in two years, about 300,000 $m^3$ (about 10.6 million $ft^3$) of in situ rock. Mining was planned in three benches with progression in parallel, blasting with vertical holes and haulage at the bench toe, with backhoe excavators and dumper trucks, see Figure (1).

Because both the pit and dump for waste materials would subsequently be inside the area flooded by the dam, there would be no post-mining environmental interference. Therefore, the Environmental Impact Statement had only to consider the mining activity itself and the study was conducted in the following manner:

1. Characterising the pre-existing environmental context in terms of geology, geotechnics, hydrology, weather, economy, etc.
2. Identifying the IMPACTING FACTORS, namely those factors, that during mining, could modify the pre-existing environmental conditions
3. Defining the possible ranges for the MAGNITUDE of the variation caused by each IMPACTING FACTOR
4. Singling out the ENVIRONMENTAL COMPONENTS whose pre-existing condition could be modified as a result of the mining
5. Correlating each IMPACTING FACTOR and each ENVIRONMENTAL COMPONENT
6. Estimating the specific MAGNITUDE for each IMPACT FACTOR, using the already defined ranges
7. Calculating the weighted sum of the environmental impact induced from the IMPACTING FACTORS on each ENVIRONMENTAL COMPONENT.

## 2. Pre-existing environmental context

The area for the open pit mining was located in the mountains, about 3 km away from the nearest town and 25 km away from the sea.

The geological and geotechnical surveys that had been undertaken for the design of the dam were used for the study. Weather and economic data were obtained from existing databases.

Seventy percent of the surrounding area was covered with wood and Mediterranean bushes. The remaining thirty percent was dedicated to meadow-pasture with a small area containing olive trees, vineyards, domestic vegetable gardens and to a much lesser extent, stock-raising. For the meteorological characterization, data was obtained from the Italian Institute of Statistics.

## 3. Impacting factors

The following ten IMPACTING FACTORS were taken into account:

**i. Alteration of the area's potential resources**

Both the pit and the waste dump were in the area that was covered by wood, no activity of any sort, took place in that area. Also, the area had been expropriated for the dam construction and would be within the flooded dam basin.

**ii. Exposition, visibility of the pit**

The pit and waste dump would be visible from the nearby town and from local roads up to 5 km away. However, all the roads in the area were little more than tracks, with no asphalt covering, and consequently, traffic volume was low, less than 50 vehicle passages per day.

**iii. Interference with the above-ground water system**

The mining would take place at a short distance from a river. The surrounding terrain was impermeable and trough valleys conveyed water directly to the river. The location of the pit and its supporting infrastructure, such as ramps, paths and yards, were all designed to minimize any interference with the above-ground water courses. The presence of the pit was minimal, compared to the existing river basin, and would not cause any significant perturbations in the above-ground water system.

**iv. Interference with the underground water system**

The permeability of the surrounding rock mass was so low that no underground water system existed.

**v. Increase in vehicular traffic**

Access to the pit area, for personnel, supply of materials, spare parts and explosives, would take place via the existing public roads. Transportation of the blasted and crushed rock would take place within the dam construction area, without any need to access public roads.

**vi. Atmospheric release of gas and dust**

Emissions into the atmosphere, together with acoustic emissions and ground vibration, can be one of the most significant IMPACTING FACTORS for open pit mining with explosives. Drilling and blasting both produce a fine dust that contains silica. Due to a strong, year long round wind, the dust could be distributed over a wide area and at some considerable distance from the pit. A similar fine dust is also produced from haulage using "push and accumulation" into a dejection cone, a system which is frequently used in Italian quarries.

Haulage was planned to take place at the toe of the bench, with no push and accumulation in a cone. Drilling would be performed dry but the machines would be equipped with filters and paths and yards would be kept wet, to dampen down the dust. All these precautions, taken to provide an effective means of reducing the risk of silicosis, also significantly reduce any spread of the dust outside of the working area.

Gases such as $CO$, $CO_2$ and $NO_x$ would be produced by vehicles, compressors and detonation of the explosives.

**vii. Fly-rock**

A controlled blast was planned for optimization of explosives consumption and rock fragmentation. Drilling and blasting operations would be conducted by experienced personnel. These measures would ensure that fly-rock would be confined within a safety zone inside the pit yard. Besides, there were no public streets or any sort of facility close to the benches.

**viii. Noise**

Trucks, excavators and crushing plants produce low amplitude, low frequency, persistent acoustical impact. The blasting, once every couple of days, produces a high amplitude and frequency pulse acoustical impact.

The effects of acoustical impact on fauna are not well known. Past experience suggests that, following the initial desertion from the affected area, a tolerance is acquired and the abandoned territories are gradually re-inhabited. The time needed for this re-occupation ranges from weeks to months. The impacted area was expected to be extended by about 2 km (1.2 miles).

Conversely, the effects of acoustical impact on humans are well known. However, experience has shown that not exceeding "nuisance" threshold values is not a guarantee of freedom from complaints and law suits.

**ix. Ground vibration**

Rock blasting produces seismic waves with related ground vibration that can be felt at large distances away from the source of the blasting. This is usually the biggest cause of hostility from the surrounding neighbours, resulting in complaints and law suits. In the past, complaints have also been received as a result of induced vibration at levels well below the "no-damage" reference values given in standards such as DIN 4150-3 and UNI 9916.

Ground vibration due to the blast, often equated to the effect of a catastrophic event such as an earthquake, is the most frequent cause of litigation in Italy. Also, people living nearby sometimes confuse the air overpressure, which may be amplified by the rattling caused by loose glass panels in the window frames, as ground vibration and the basis of a complaint for "structural damage".

Dust and noise can often be reasonable causes for complaint but even if they are at levels higher than those given by law, they are not usually cited in law suits. In the last 3 years, there has been an increasing trend towards litigation based not on property damage but on "biological damage" to the inhabitants, due to the fears caused by ground vibration. This approach has been somewhat encouraged by Court sentences.

For the pit in question, the blast would be planed with a large ignition sequence, to maximize fragmentation. This would also drastically reduce the ground vibration impact.

**x. Employment of local work force**

Sardinia is a region with high unemployment and the new mining activity itself would bring new job opportunities to the nearby town and also increased trade for the service industries, hotels and restaurants.

## 4. Magnitude of the impacting factors

The possible scenarios for each IMPACTING FACTOR were then considered and a numerical value, or MAGNITUDE, was given to each scenario.

For simplicity, the value chosen for each scenario was between 1 and 10, the number chosen being indicative of the severity of the environmental impact, with 10 being the most severe.

The various scenarios and their related MAGNITUDE are shown for each IMPACTING FACTOR in Table (1).

## 5. Environmental components involved

The environment surrounding the pit was broken down into the following eleven components:

a. Human health and safety
b. Social relationship and quality of life
c. Water quality
d. Air quality
e. Use of territory, as naturalistic resources, socio-cultural and economical
f. Flora and fauna
g. Aboveground
h. Underground
i. Landscape
j. Noise
k. Economy

## 6. Weighted influence of each impacting factor on environmental component

An IMPACTING FACTOR will modify the pre-existing state of equilibrium of an ENVIRONMENTAL COMPONENT in a way that can vary from having no effect at all through to a severe impact. Four levels of perturbation, namely nil, minimum, medium and maximum, were chosen to describe the effect that an IMPACTING FACTOR has on an ENVIRONMENTAL COMPONENT.

The maximum perturbation level was numerically defined as double the medium perturbation level and similarly, the medium perturbation level was defined as double the value of the minimum level. The sum of all the perturbation levels for each ENVIRONMENTAL COMPONENT was normalized by imposing the sum equal to 10.

Table (2) shows the perturbation level of the IMPACTING FACTORS for each ENVIRONMENTAL COMPONENT and the related numeric weighting factors calculated as described above.

## 7. Calculation of the impact on each environmental component

Firstly, using the MAGNITUDE ranges defined in Table (1), each IMPACTING FACTOR for the proposed mining activity was assessed and its MAGNITUDE chosen, as shown in Table (3).

A matrix of the IMPACTING FACTORS against the ENVIRONMENTAL COMPONENTS was then drawn up, with the chosen MAGNITUDE weighted using the numeric values given in Table (2).

Table (4) shows the resultant matrix.

Then the overall effect on each ENVIRONMENTAL COMPONENT was calculated by summing the weighted magnitudes of all the IMPACTING FACTORS.

It was then possible to summarise the Environmental Impact Statement for the proposed mining activity as a simple graphical representation as shown in Figure (2).

## 8. Conclusions

As can be seen from Figure (2), the most significant impacts were on three ENVIRONMENTAL COMPONENTS, namely “Use of Territory”, “Noise” and “Landscape”. However, a major impact would have an Overall Impact value of 100 on any of the ENVIRONMENTAL COMPONENTS and therefore, the actual impacts on these three ENVIRONMENTAL COMPONENTS are low.

The Overall Impacts on the other ENVIRONMENTAL COMPONENTS, “Public Safety”, “Social Relationships”, “Water Quality”, “Air Quality”, “Flora and Fauna”, “Above Ground” and “Underground” were considered to be insignificant.

This quantitative analysis provided a neat method for demonstrating that that the proposed mining activity would not cause any relevant alteration to the surrounding environment. Something that was to be expected since the activity would only last two years and take place in a confined area, which would subsequently be covered by the lake produced by the dam.

**Acknowledgments**

Many thanks to David Jordan for his suggestions and critical review of this article.

**Table (1): Ranges of MAGNITUDE for IMPACTING FACTORS**

| IMPACTING FACTORS | SCENARIO | MAGNITUDE |
|---|---|---|
| I. ALTERATION OF AREA'S POTENTIAL RESOURCES | Parks, protected areas<br>Urban area<br>Agricultural area, wood<br>Industrial area | 8 - 10<br>6 - 8<br>3 - 6<br>1 - 3 |
| II. EXPOSITION, VISIBILITY OF THE PIT | Can be seen from inhabited areas<br>Can be seen from main roads<br>Not visible | 6 - 10<br>2 - 6<br>1 - 2 |
| III. INTERFERENCE WITH ABOVE-GROUND WATER | Interference with lakes and rivers<br>Interferences with non relevant water system<br>No interference | 6 - 10<br>3 - 6<br>1 - 3 |
| IV. INTERFERENCE WITH UNDERGROUND WATER | Water table superficial and permeable grounds<br>Water table deep and permeable grounds<br>Water table deep and un-permeable grounds | 5 - 10<br>2 - 5<br>1 - 2 |
| V. INCREASE IN VEHICLULAR TRAFFIC | Increase of 200%<br>Increase of 100%<br>No interference | 6 - 10<br>3 - 6<br>1 - 3 |
| VI. ATMOSPHERIC RELEASE OF GAS and DUST | Free emissions in the atmosphere<br>Emission around the given reference values<br>Emission well below the given reference values | 7 - 10<br>2 - 7<br>1 - 2 |
| VII. FLY-ROCK | No blast design and no clearance procedures<br>Blast design and no clearance procedures<br>Blast design and clearance procedures | 9 - 10<br>4 - 9<br>1 - 4 |
| VIII. NOISE | Peak air overpressure at 1 km distance: <141 db<br>< 131 db<br>< 121db | 8 - 10<br>4 - 8<br>1 - 4 |
| IX. GROUND VIBRATION | Cosmetic damage, above threshold<br>Tolerability threshold<br>Values under tolerability threshold | 7 - 10<br>3 - 7<br>1 - 3 |
| X. EMPLOYMENT OF LOCAL WORK FORCE | Job opportunities: High<br>medium<br>low | 7 - 10<br>3 - 6<br>1 - 2 |

**Table (2): Correlation matrix with values of the weighted influence of each IMPACTING FACTOR on each ENVIRONMENTAL COMPONENT**

| IMPACTING FACTORS | ENVIRONMENTAL COMPONENTS | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Human health and safety | Social relationship | Water quality | Air quality | Use of territory | Flora and fauna | Above ground | Underground | Landscape | Noise | Economy |
| I. ALTERATION OF AREA'S POTENTIAL RESOURCES | Med 0.80 | Min 0.77 | Nil 0 | Nil 0 | Max 5.71 | Min 0.63 | Nil 0 | Nil 0 | Max 2.86 | Nil 0 | Nil 0 |
| II. EXPOSITION, VISIBILITY OF THE PIT | Nil 0 | Min 0.77 | Nil 0 | Nil 0 | Med 2.86 | Nil 0 | Nil 0 | Nil 0 | Max 2.86 | Min 2.00 | Nil 0 |
| III. INTERFERENCE WITH ABOVE-GROUND WATER | Max 1.60 | Nil 0 | Max 4.44 | Nil 0 | Nil 0 | Max 2.50 | Med 6.67 | Nil 0 | Max 2.86 | Nil 0 | Nil 0 |
| IV. INTERFERENCE WITH UNDERGROUND WATER | Min 0.40 | Nil 0 | Max 4.44 | Nil 0 | Nil 0 | Nil 0 | Nil 0 | Med 6.67 | Nil 0 | Nil 0 | Nil 0 |
| V. INCREASE IN VEHICLULAR TRAFFIC | Max 1.60 | Max 3.08 | Nil 0 | Nil 0 | Min 1.43 | Max 2.50 | Nil 0 | Nil 0 | Min 0.71 | Nil 0 | Nil 0 |
| VI. ATMOSPHERIC RELEASE OF GAS and DUST | Max 1.60 | Min 0.77 | Min 1.11 | Max 10.00 | Nil 0 | Max 2.50 | Min 3.33 | Nil 0 | Min 0.71 | Nil 0 | Nil 0 |
| VII. FLY-ROCK | Max 1.60 | Nil 0 | Nil 0 | Nil 0 | Nil 0 | Med 1.25 | Nil 0 | Nil 0 | Nil 0 | Nil 0 | Nil 0 |
| VIII. NOISE | Med 0.80 | Max 3.08 | Nil 0 | Nil 0 | Nil 0 | Min 0.63 | Nil 0 | Nil 0 | Nil 0 | Max 8.00 | Nil 0 |
| IX. GROUND VIBRATION | Max 1.60 | Med 1.54 | Nil 0 | Nil 0 | Nil 0 | Nil 0 | Nil 0 | Min 3.33 | Nil 0 | Nil 0 | Nil 0 |
| X. EMPLOYMENT OF LOCAL WORK FORCE | Nil 0 | Nil 0 | Nil 0 | Nil 0 | Nil 0 | Nil 0 | Nil 0 | Nil 0 | Nil 0 | Nil 0 | Max 10.00 |
| **Total =** | **10** | **10** | **10** | **10** | **10** | **10** | **10** | **10** | **10** | **10** | **10** |

**Table (3): MAGNITUDE of IMPACTING FACTORS for the borrow pit**

| | | MAGNITUDE |
|---|---|---|
| I. ALTERATION OF AREA'S POTENTIAL RESOURCES | The mining of the pit would have permanently modified the potential resources of the area. Although this aspect would not be relevant after the mining phase after the flooding of the lake, it had to be taken into account during mining activity. | 6 |
| II. EXPOSITION, VISIBILITY OF THE PIT | The pit would have modified a landscape characterized by woods and meadows. Harsh physiography will help to adsorb visual impact. | 4 |
| III. INTERFERENCE WITH ABOVE-GROUND WATER | The pit was placed to avoid interference with the river and to minimize alteration of the hydraulic basin. | 3 |
| IV. INTERFERENCE WITH UNDERGROUND WATER | Because of the very low permeability of the rock mass and consequent lack of a underground water system, no real interference was foreseen. | 1 |
| V. INCREASE IN VEHICLULAR TRAFFIC | Transportation would take place in internal paths. No relevant traffic increase would be apparent on public roads. | 1 |
| VI. ATMOSPHERIC RELEASE OF GAS and DUST | Dust and gas emissions would be kept below given threshold values: filters for drilling equipment, paths and yards kept wet. Negligible gas pollution from machinery and blast. | 2 |
| VII. FLY-ROCK | The blast would be planed to keep rock throw distance within the quarry area. Haulage at the bench toe, without push and stocking in a dejection cone, reduces the quantity of fines and minimize the quantity of dust. | 1 |
| VIII. NOISE | The blast will keep air overpressure much below the tolerability levels. Physiography will keep machinery noise to tolerable levels for nearby housing. | 4 |
| IX. GROUND VIBRATION | To maximize fragmentation, the total explosive charge would be detonated in a high number delay sequence, thus reducing induced vibrations. Also the low productivity required, 150,000 $m^3/y$, would mean low levels of vibration. | 2 |
| X. EMPLOYMENT OF LOCAL WORK FORCE | For the mining of the pit, it would be necessary to hire non qualified local workforce and some truck drivers. Also related economical activities, gas stations, small hardware stores, hotel, restaurants, etc. would benefit. | 3 |

**Table (4): Matrix of weighted MAGNITUDES for each IMPACTING FACTOR on each ENVIRONMENTAL COMPONENT**

| IMPACTING FACTORS | ENVIRONMENTAL COMPONENTS | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Human health and safety | Social relationship | Water quality | Air quality | Use of territory | Flora and fauna | Above ground | Underground | Landscape | Noise | Economy |
| I. ALTERATION OF AREA'S POTENTIAL RESOURCES | 4.8 | 4.6 | 0.0 | 0.0 | 34.3 | 3.8 | 0.0 | 0.0 | 17.2 | 0.0 | 0.0 |
| II. EXPOSITION, VISIBILITY OF THE PIT | 0.0 | 3.1 | 0.0 | 0.0 | 11.4 | 0.0 | 0.0 | 0.0 | 11.4 | 8.0 | 0.0 |
| III. INTERFERENCE WITH ABOVE-GROUND WATER | 4.8 | 0.0 | 13.3 | 0.0 | 0.0 | 7.5 | 20.0 | 0.0 | 8.6 | 0.0 | 0.0 |
| IV. INTERFERENCE WITH UNDERGROUND WATER | 0.4 | 0.0 | 4.4 | 0.0 | 0.0 | 0.0 | 0.0 | 6.7 | 0.0 | 0.0 | 0.0 |
| V. INCREASE IN VEHICLULAR TRAFFIC | 1.6 | 3.1 | 0.0 | 0.0 | 1.4 | 2.5 | 0.0 | 0.0 | 0.7 | 0.0 | 0.0 |
| VI. ATMOSPHERIC RELEASE OF GAS and DUST | 3.2 | 1.5 | 2.2 | 20.0 | 0.0 | 5.0 | 6.7 | 0.0 | 1.4 | 0.0 | 0.0 |
| VII. FLY-ROCK | 1.6 | 0.0 | 0.0 | 0.0 | 0.0 | 1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| VIII. NOISE | 3.2 | 12.3 | 0.0 | 0.0 | 0.0 | 2.5 | 0.0 | 0.0 | 0.0 | 32.0 | 0.0 |
| IX. GROUND VIBRATION | 3.2 | 3.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 6.7 | 0.0 | 0.0 | 0.0 |
| X. EMPLOYMENT OF LOCAL WORK FORCE | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 30.0 |
| **Overall Impact =** | **22.8** | **27.7** | **20.0** | **20.0** | **47.1** | **22.6** | **26.7** | **13.3** | **39.3** | **40.0** | **30.0** |

**Figure (1): The area for the open pit mining**

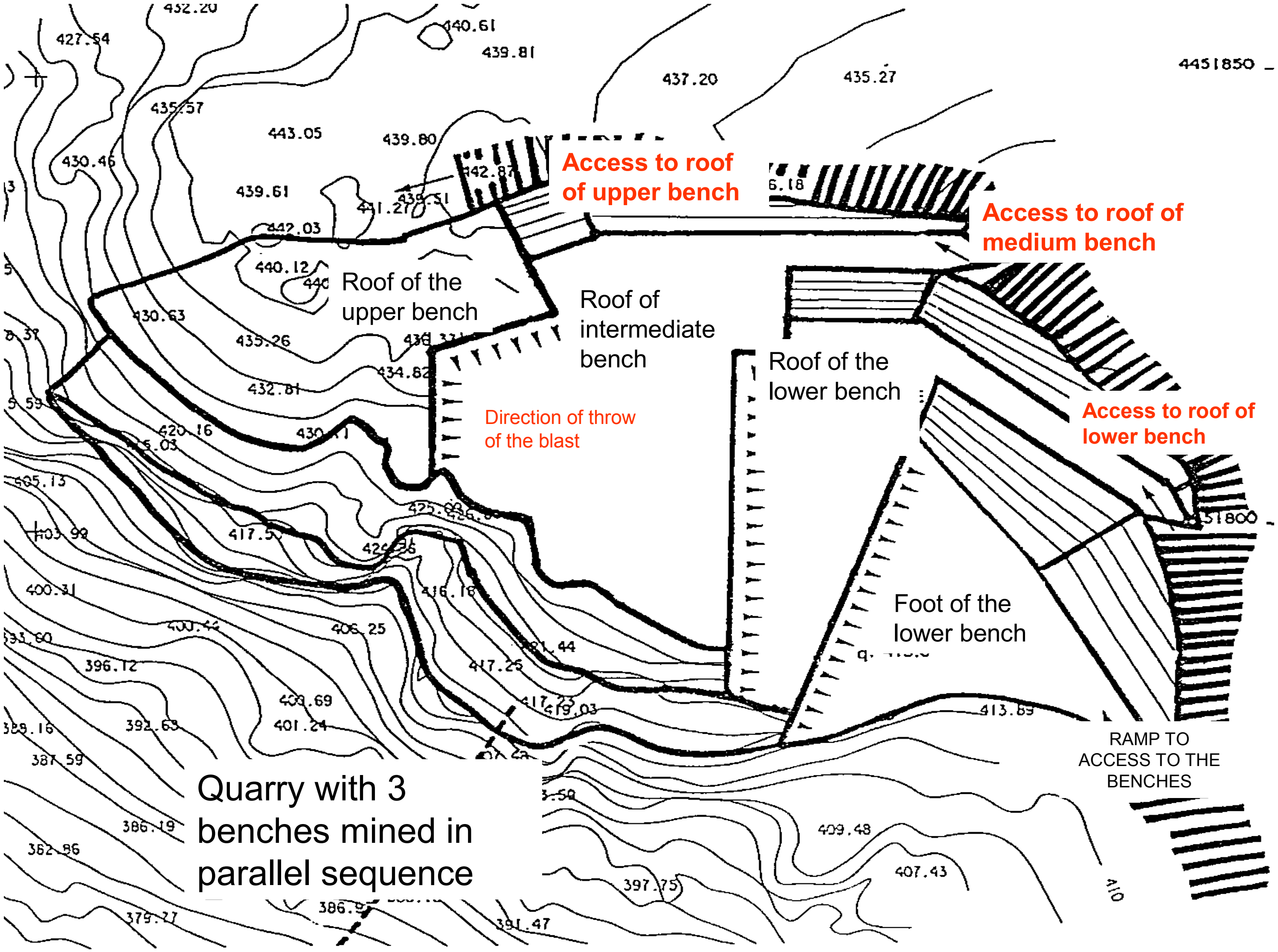

**Figure (2): Quantitative Environmental Impact Statement**