MINERAL RESOURCE ASSESSMENT
An illustration as to how numbers behave

Introduction

This is a simple paper designed to illustrate how numbers behave in the context of mineral bearing areas of land.

Geologists, mineral surveyors, land surveyors, mining engineers, civil engineers and landscape architects are just some of the professionals who deal with point source data in relation to land that might be mined, quarried or otherwise engineered. Volumes and levels of various materials in, on, or under the land are key measurements.

The author believes that the principles illustrated in this paper apply to both manual calculation and sophisticated software analysis. The source data is often of the same nature and there needs to be a fundamental understanding into what is going on for a computer assessment.

Land areas and the distribution of information points

The focus of this paper is the typical distribution of information or data that might be derived from site investigation boreholes, trial pits, trenches, excavations or survey profiles. Three dimensional modelling packages are now used routinely to produce modelled surfaces or interfaces between, for instance, geological layers and it is easy to forget that these apparently continuous surfaces are usually derived from point source data. Ground surfaces in a world of drone surveys producing truly huge amounts of data are not far off continuous but buried or underground surfaces are still usually dependent on boreholes or similar discrete investigation locations.

Any mineral bearing landholding has internal and external boundaries of some sort be they physical, geological, or legal. Hedges, walls, rivers, land ownership, landscape features, soil classification, owners preference, quarry phase boundaries, all of these factors can create a limit of a resource area under consideration and while some features may be related to subsurface geology many are simply surface attributes. A practitioner dealing with mineral resources must make decisions on how to handle the boundary, or edge, effect both when they plan ground investigations and when they interpret the results.

Some of the statistical analysis techniques such as Kriging and hexagons of influence around boreholes, that are not covered in this paper, can or should deal with the edge effects but the reality is that many people work in construction materials with the basic numbers and will not be familiar with techniques mainly deployed in the metalliferous mining fields.

Even when dealing with basic numbers however we still will pay attention to raw statistics such as the minimum, maximum, mean, median and mode of a series of numbers. Minimum and maximum are self explanatory but not everybody is familiar with the other terms:

- Mean - usually what most people will call the average.
- Median - the middle value in a series such that there are an equal number of higher and lower values.
- Mode - this is the most frequently occurring number in the data series.

In this paper we are only dealing with the Mean, or Average, values.

Some numerical exercises

The schematics below all show the same distribution of numbers but treat them in different ways. These numbers could be sand and gravel thicknesses, ore percentages, a laboratory parameter from rock testing, a particle size distribution, a chemical value, or anything that requires a statistical understanding of the characteristic being measured. It is all point source information from a particular location.

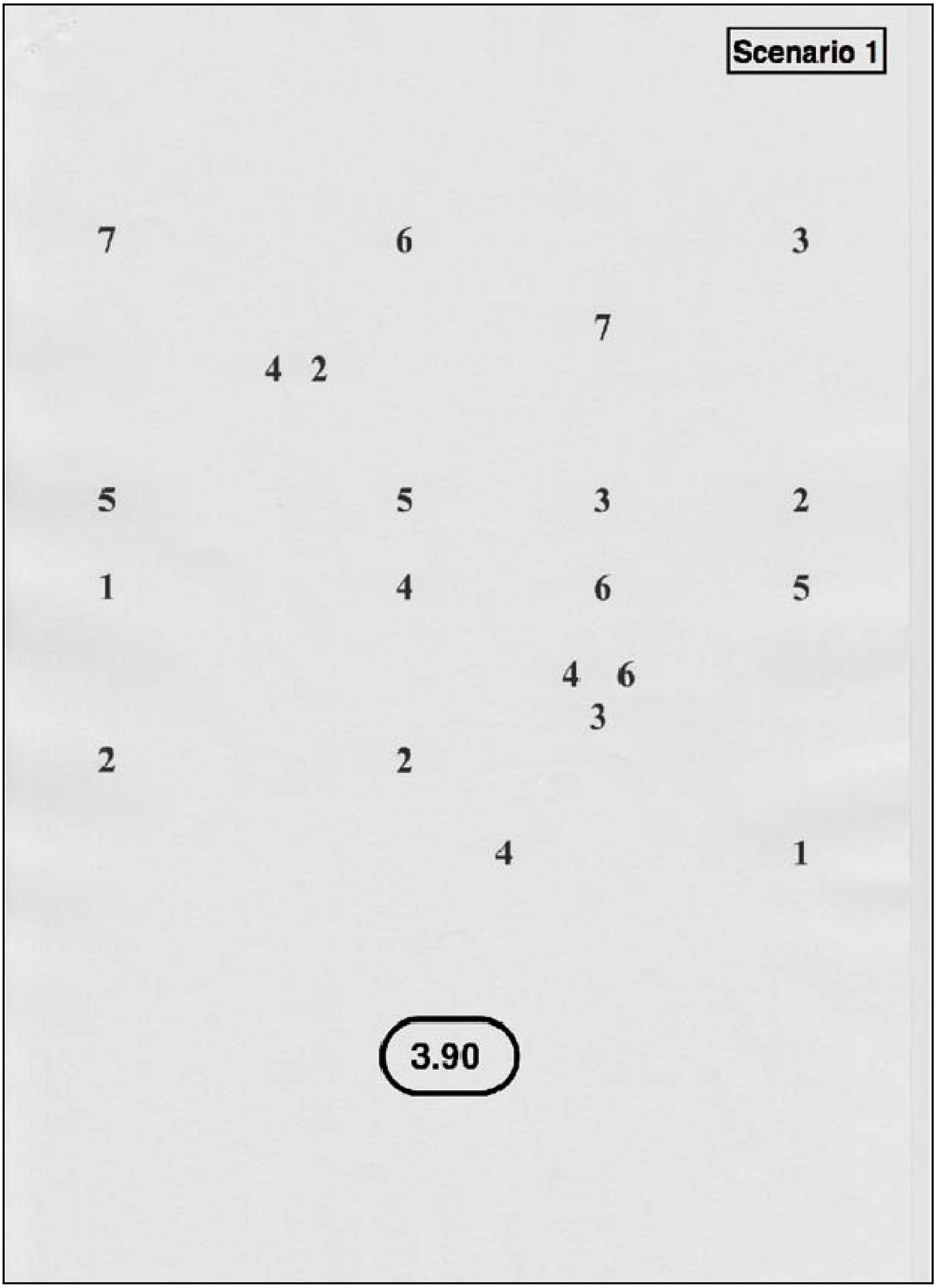
In the aggregate material assessment arena the classic would be calculating sand and gravel thicknesses. People often take the basic approach of using a simple average identified by boreholes on a particular area of land. There may be nothing wrong in this at all but this exercise deals with which information to use when there is a choice.

Within a large mineral area proven by exploration there is often some type of surface sub division applied - this could be planned working phases, a limit on a potential quarry from environmental or landscape constraints, economic soil stripping areas, land ownership parcels or field boundaries. Such boundaries may well have no relationship to the underlying geology. If it is necessary to determine mineral content in these individual areas it is crucial to properly consider how to deal with data at the edges of the areas.

It is commonly the case that people choose to use only the data points within the boundary of the area in question be it a phase, field or other area. The author's contention in essence is that this is not the best approach if there are also data points adjacent to the boundary of the area. The effect of using various data points is one of the key points in the exercise.

Scenario 1

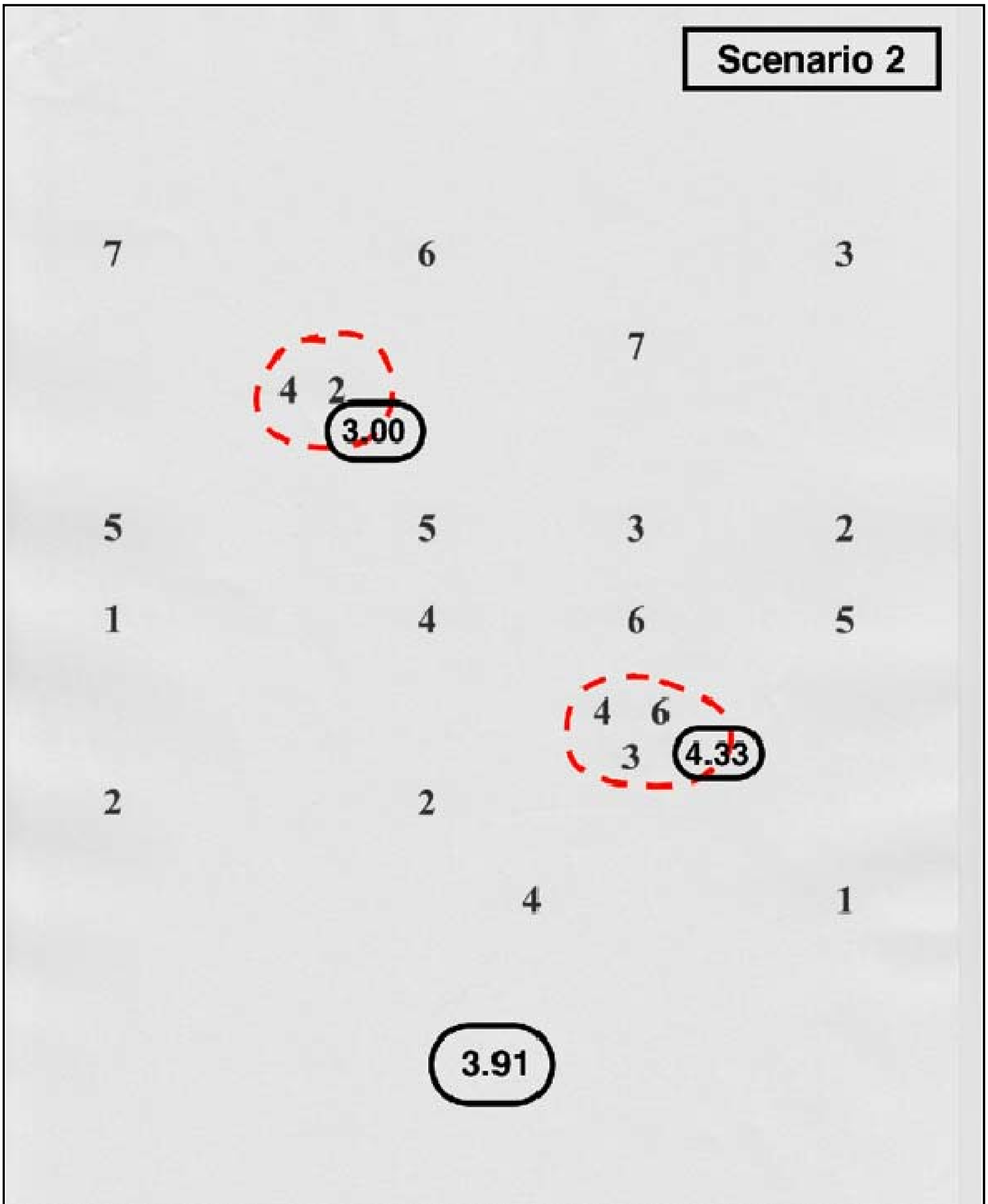
This Scenario, with no other boundaries, can be considered as a proxy for a large area of land with mineral proving boreholes or data points. The Mean of the 21 numbers is 3.90.



Scenario 2

On this Scenario there are two clusters of very closely spaced data points. In the top left hand quadrant are 4 and 2 (Mean 3.00) and in the bottom right hand quadrant are 4, 6 and 3 (Mean 4.33). If these were boreholes very close together there is a case for calculating the local Mean and treating each cluster as a single data point. The Mean of now 18 data points is 3.91 - not a big difference from the figure for Scenario 1 but different nonetheless.

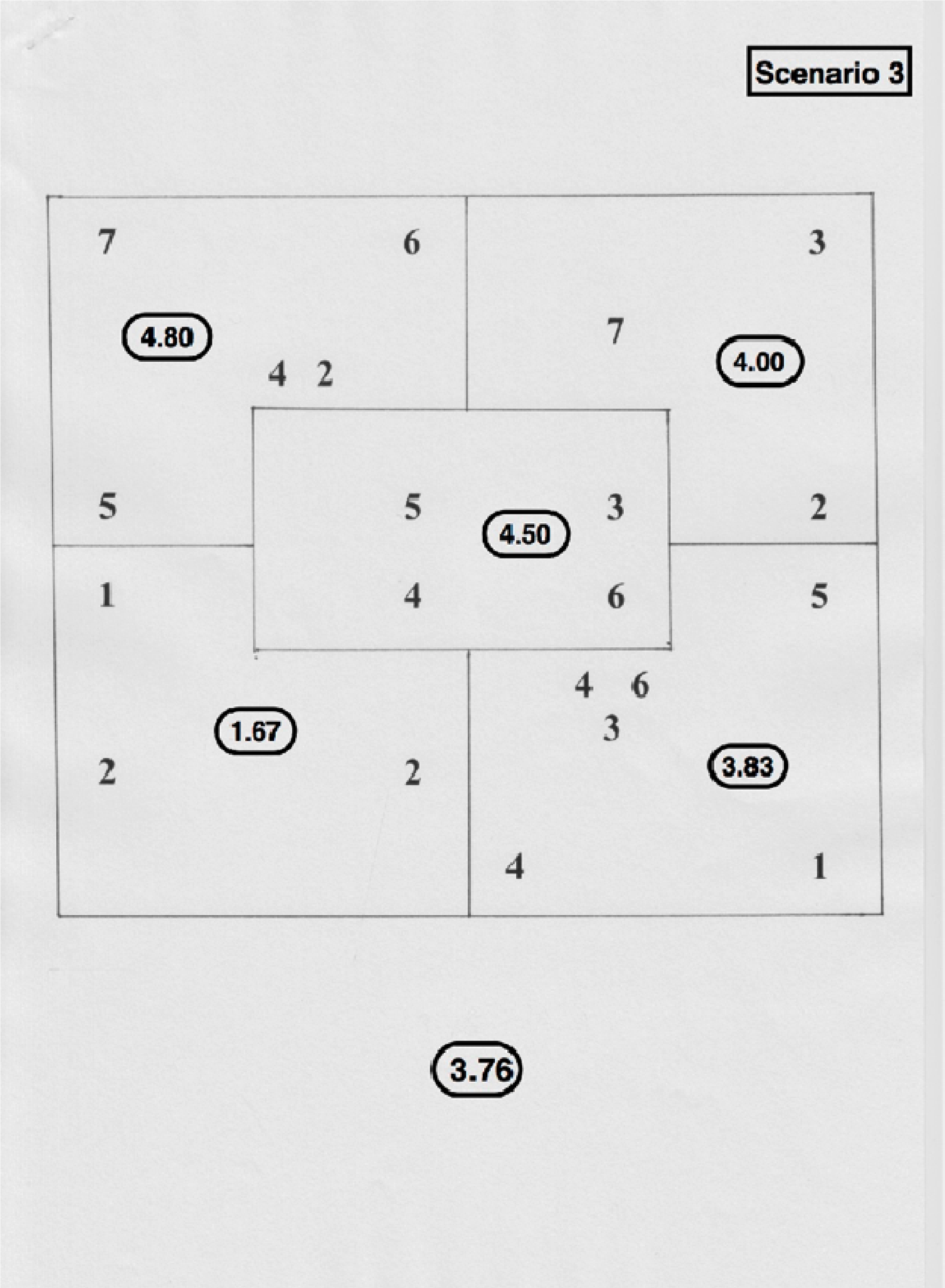
But how close is close? The geostatistical technique of plotting hexagons of influence around boreholes largely addresses this matter but this is time consuming to do manually and if the computer is doing it invisibly it is important to understand what is going on.



Scenario 3

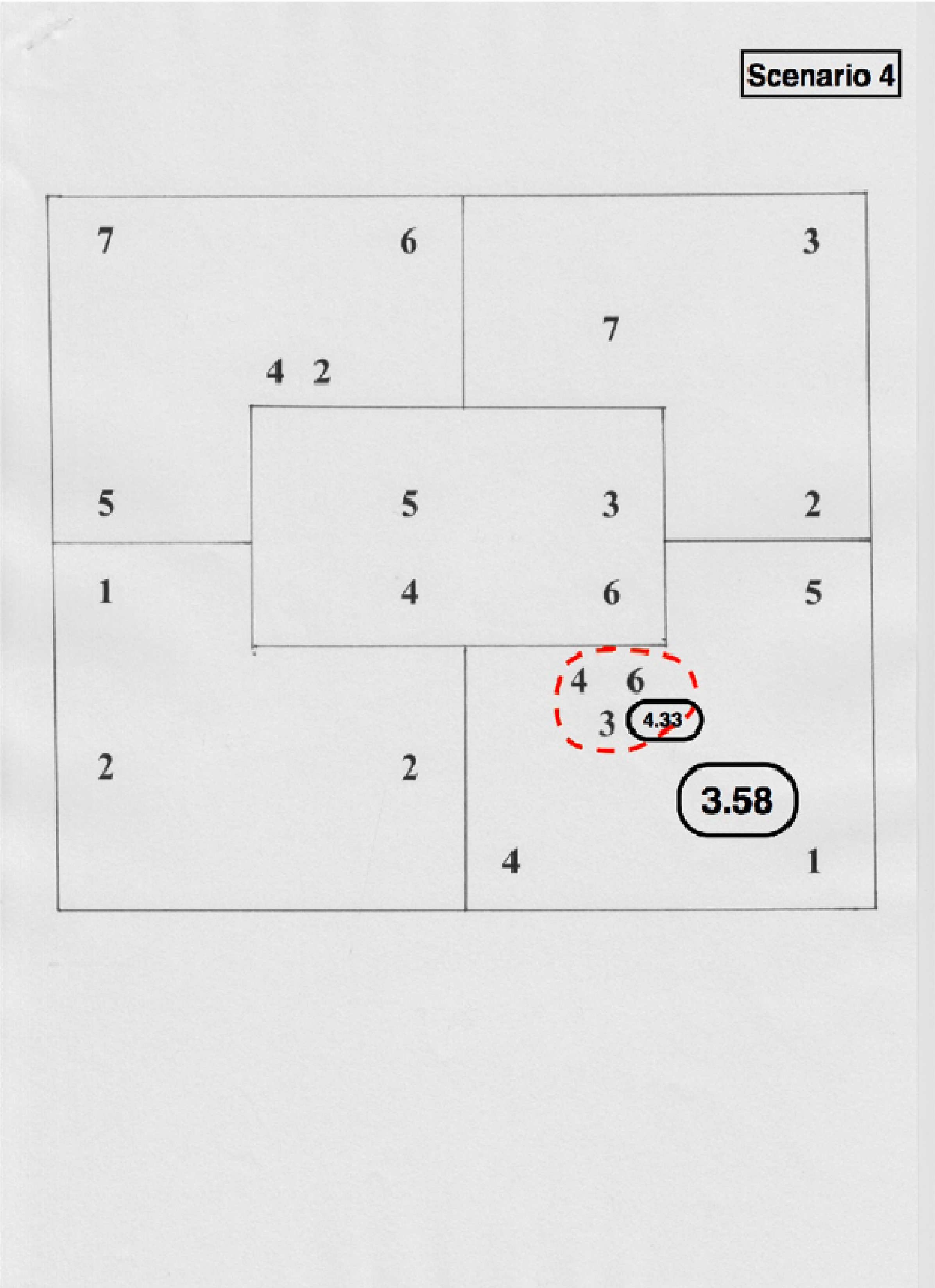
On Scenario 3 our notional area of land is split into 5 areas or phases. The individual Mean is shown for each phase when calculated using only the data points within the phase boundary. The mean of the 5 Means is 3.76 or some 4% less than the 3.91 above.

This is the base case phase scenario for the exercise. But which is correct?



Scenario 4

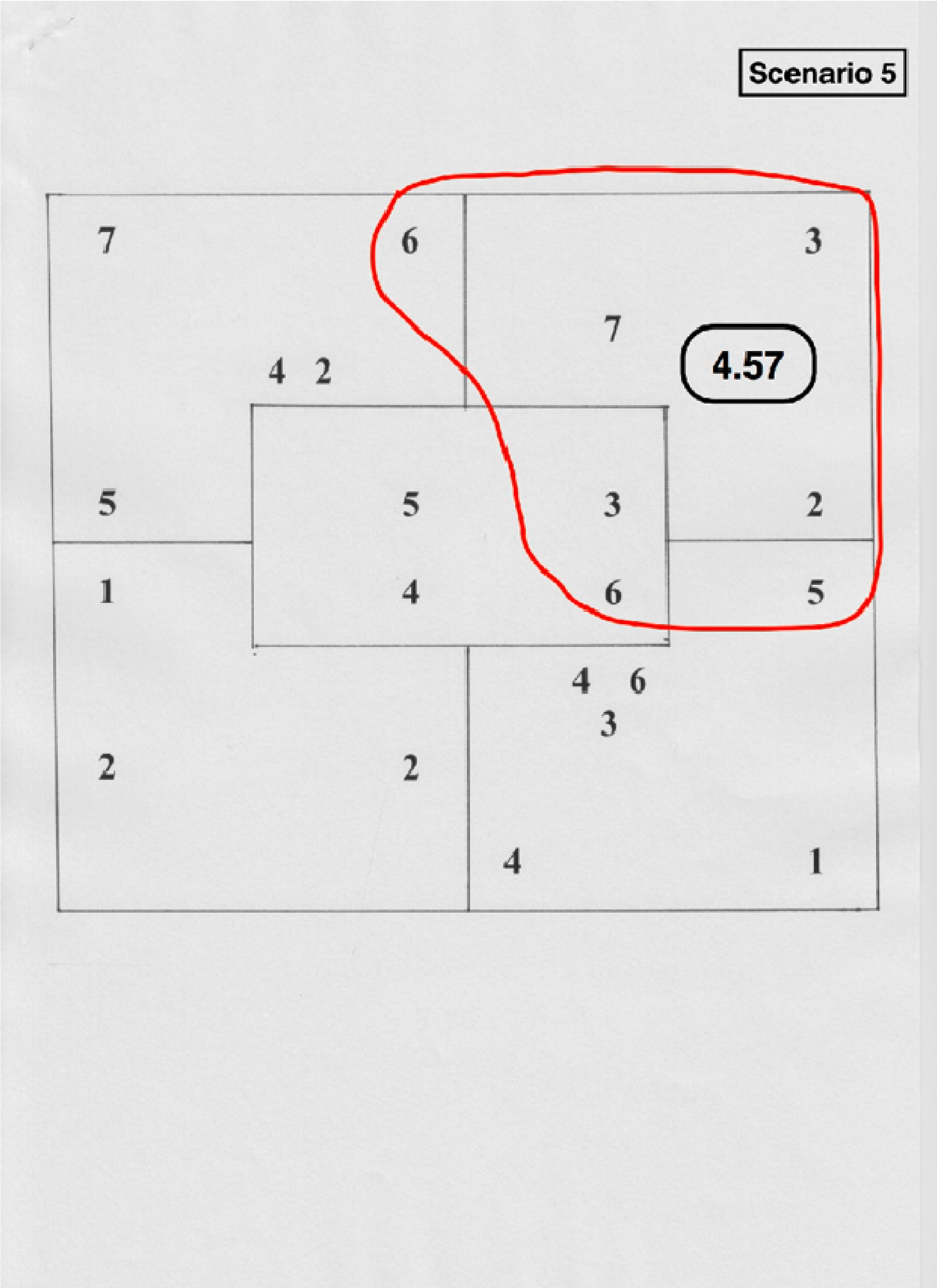
Scenario 4 considers the bottom right quadrant but uses the cluster Mean for the three closely spaced points. The phase mean then becomes 3.58 compared to 3.83 on



Scenario 3, a 6.5% difference.

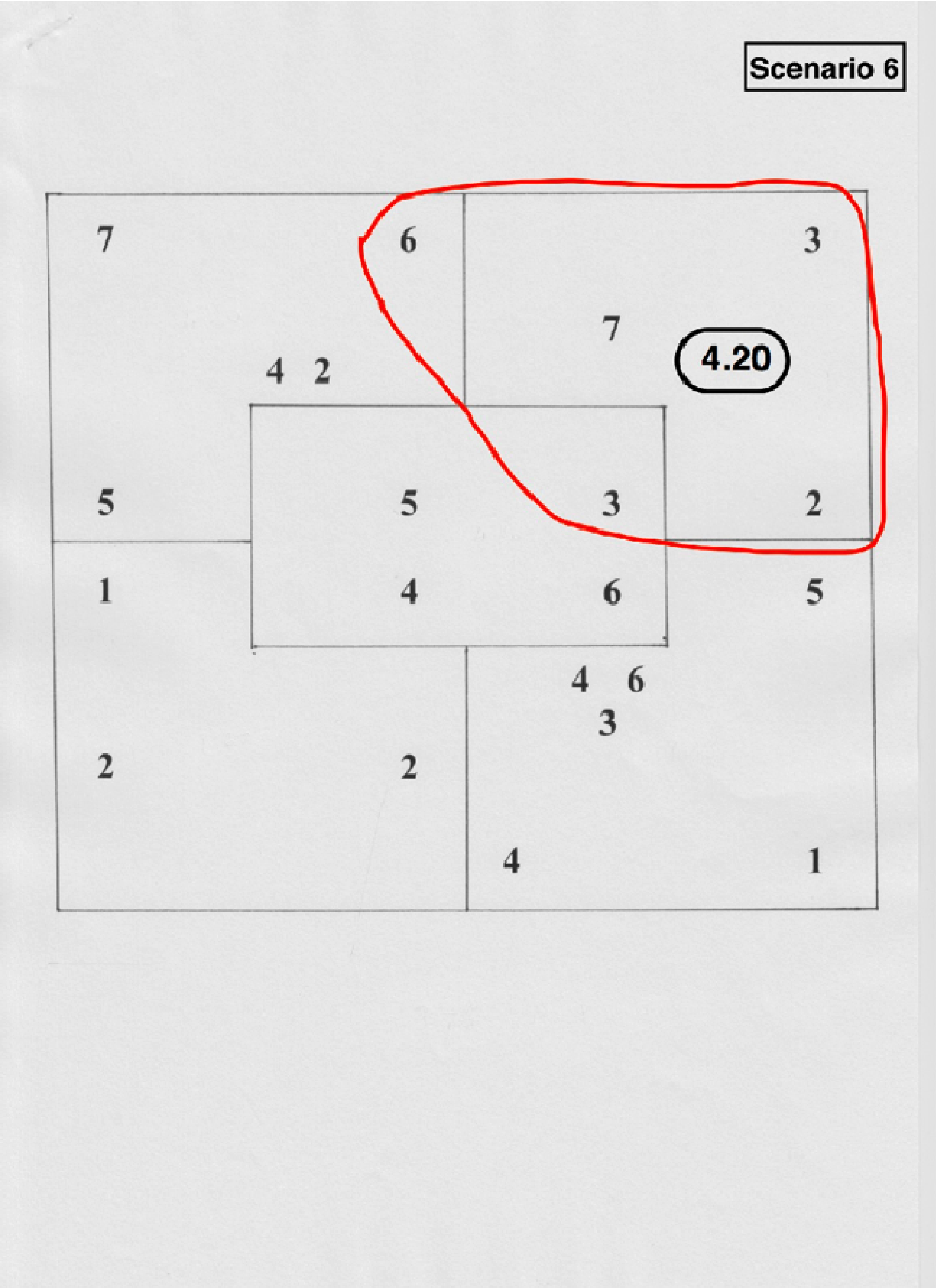
Scenario 5

Here the red line includes data points that lie just outside the artificial phase boundary and the mean becomes 4.57 compared with 4.00 on Scenario 3 base case, an almost 14% difference.



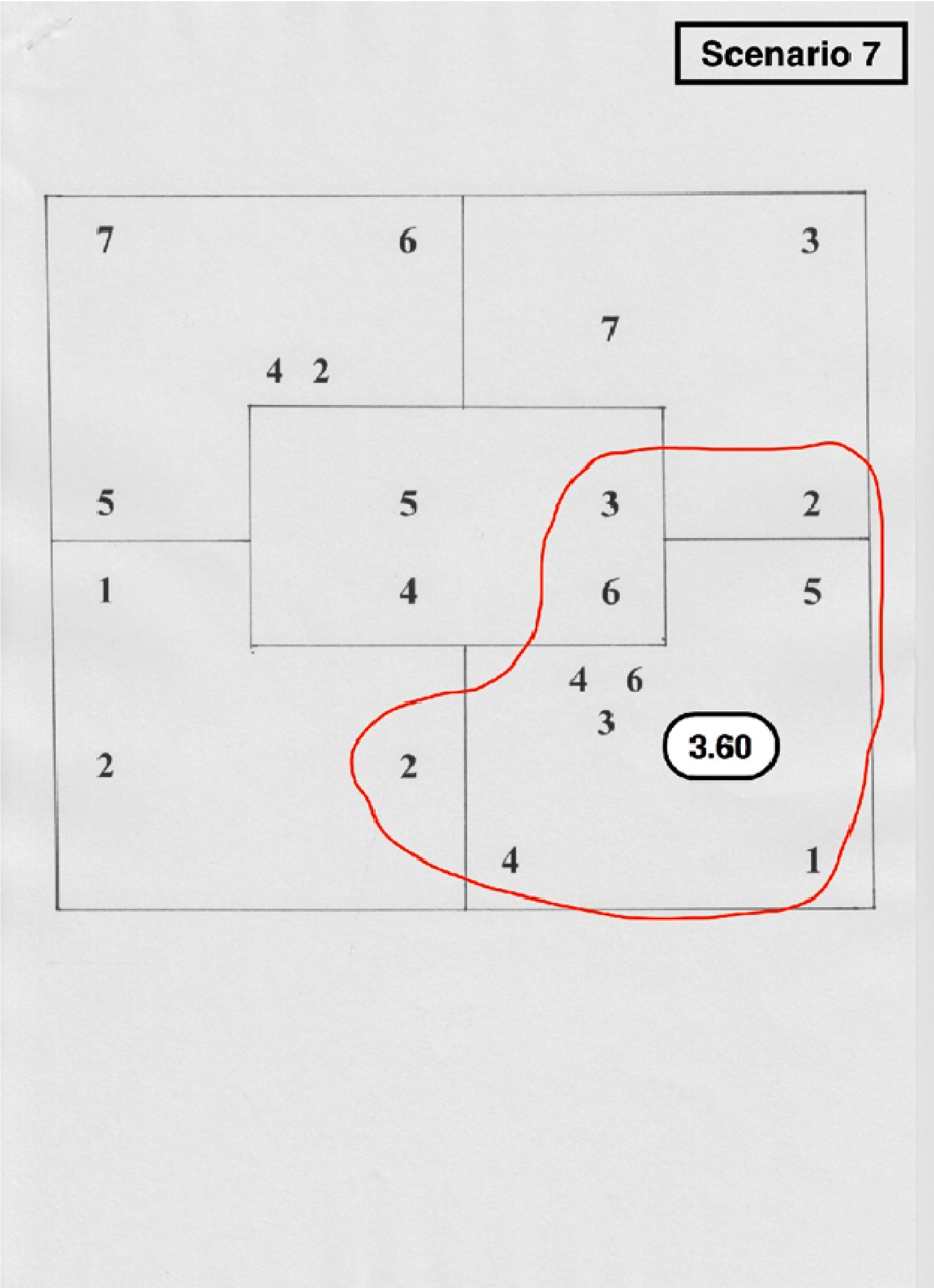
Scenario 6

This is a similar scenario but uses only two of the data points outside the boundary and gives a Mean of 4.20.



Scenario 7

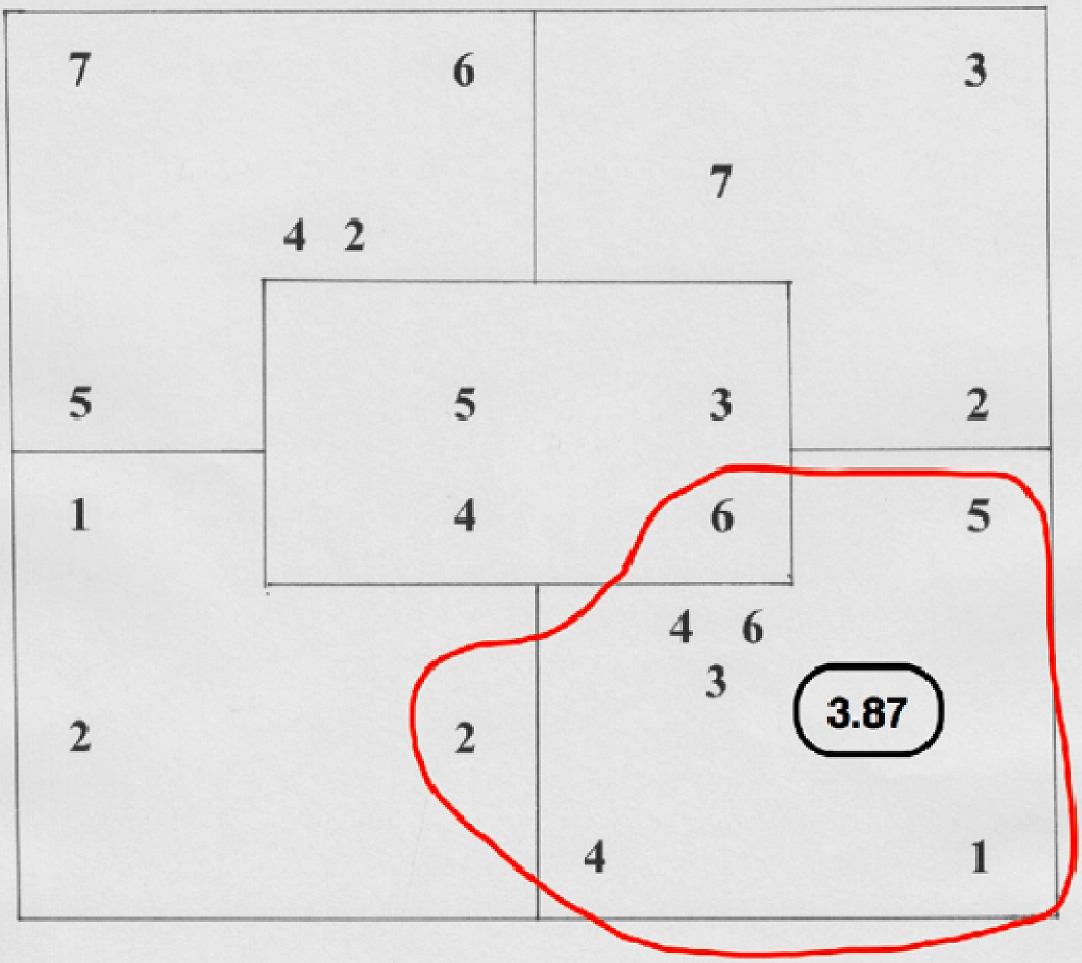
We turn here again to the bottom right hand quadrant and treat it in three different manners. Similar to Scenario 5 the data points just outside of the phase boundary are taken and the Mean is 3.60 compared with 3.58 or 3.83 as on Scenario 4.



Scenario 8

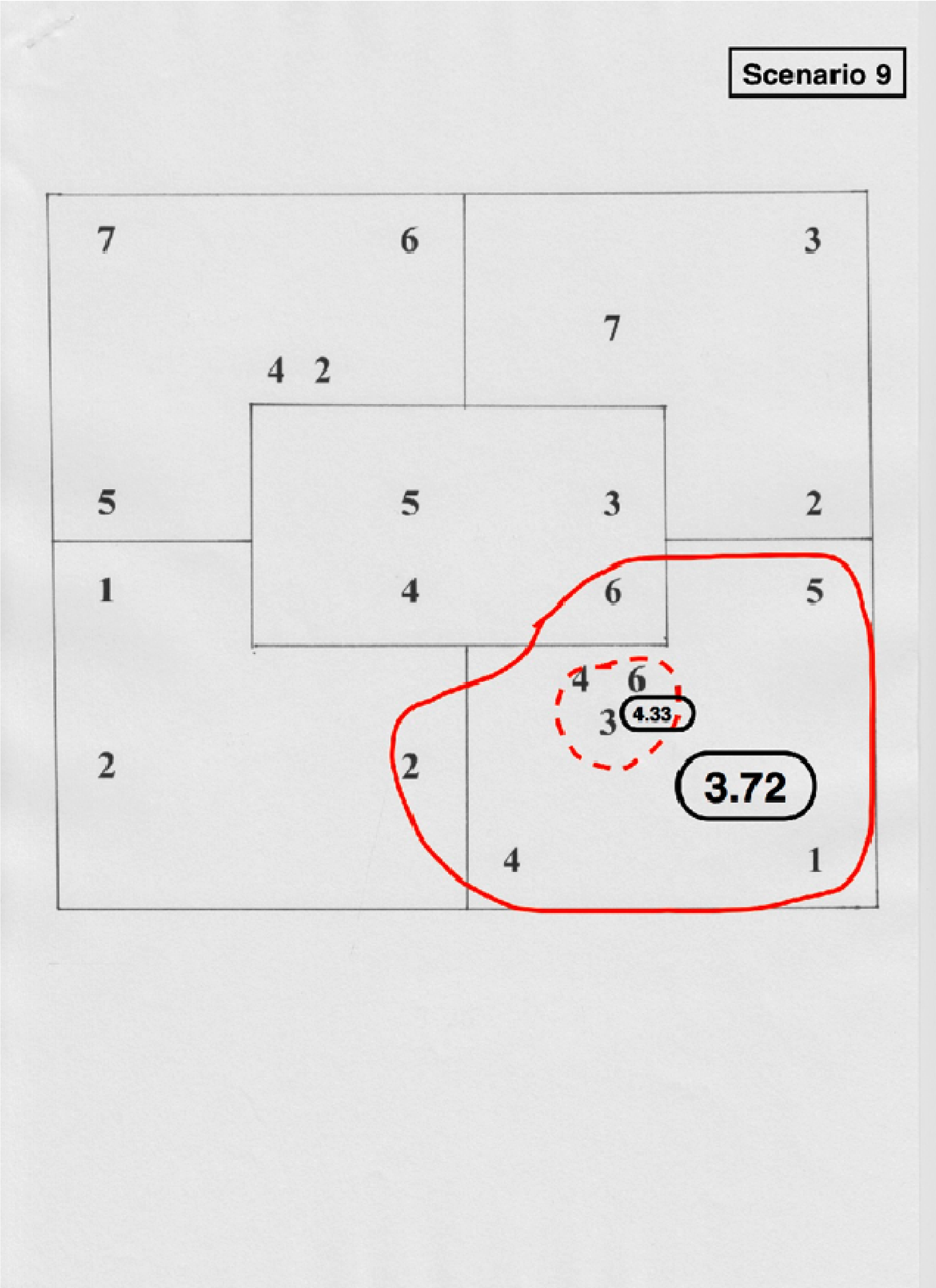
Taking here only two out of four data points just outside the boundary gives a Mean of 3.87. So the maximum difference between Scenario 4 and this scenario (3.58 v 3.87) is now 7.5%.

Scenario 8



Scenario 9

Using here the same boundary as for Scenario 8 but using the cluster mean as before gives a Mean of 3.72, a difference of nearly 4% just on the treatment of one small area of data.



Observations

By making decisions on which data points to include, each phase in the scenarios above can legitimately be attributed 3 or 4 values for the Mean. It is difficult to be definitive as to which approach will be the most accurate and a geologist is entitled to use some intuition and professional judgement. The author suggests that as a general rule it is prudent to deal with edge effects by utilising data points outside a boundary, where such data exists.

There are several reasons for this. One is simply that more data points makes the whole numerical model less susceptible to influence by a single local number; but more crucially an approach that only uses data from within a surface boundary is in effect (in cross section) asking the geology to make a step change in characteristic (such as thickness) at the boundary line. This is simply unrealistic unless a surface boundary is in fact controlled by subsurface geology.

One approach to dealing with the professional judgement requirement is to model the situation in a number of ways to test how sensitive the scenarios are to different data selections. This itself must be done with knowledge and intuition.

A not uncommon approach amongst some practitioners is to carry out mineral assessments on a phase by phase basis and then add the numbers together to arrive at a total resource or reserve. The author believes that this is not the correct approach. Instead it is preferable to derive a resource volume for a whole site, then divide into phases and reconcile the phase numbers to the whole, rather than the reverse. By taking the whole site one is always utilising the maximum number of data points, and since the ratio of the boundary length to surface area is minimised any edge effects are also minimised. Variations in, say, sand and gravel thicknesses or quality are in effect smoothed by using the bigger area with more data.

A site total can be derived and compared with the total of phase by phase calculations - there will usually be a difference as illustrated by Scenario 3 above. The numerical difference (positive or negative) can be divided up and attributed to each phase pro rata the phase contribution to the whole.

A complication occurs where two or more populations of numbers might exist within one landholding, in which case a whole site approach as outlined above may not be appropriate. The thickness of a sand and gravel layer or the characteristics of a rock body may be controlled by geological features such as faults, upwarps in bedrock, edges of glacial terraces, erosion features and many other circumstances. In such cases there will be internal edge effects and, depending on the nature of the feature, these may need to be treated as 'hard' or precise edges. In such cases the data points just outside of the hard edge are not appropriate to use.

It is helpful if the data in such sites fall into 2 or more clear populations, for instance if the maximum in one population is always less than the minimum of another population then the mineral prospect can be divided with confidence. This circumstance can be seen on Scenario 3 in the bottom left quadrant. Here the population of ones and twos is always less than the threes, fours and fives outside of the artificial phase boundary and a real curved geological boundary could legitimately be drawn across the top and right hand edge of the phase.

Good ground investigations are iterative and where such internal boundary features are identified it is good practice to define them more precisely by additional borehole drilling either during an ongoing investigation or in a follow up exercise. Then the resource area can be confidently divided up and all of the processes set out in this paper can be applied.

Final note

The author believes that resources professionals should be very careful in the use of statistics generally and especially with the level of uncertainty such as quoting a number plus or minus X percent. Very often this is seen as equivocation where the alternative is to present a single number as one's best professional judgement.

However, it is prudent and professional to assess the level of uncertainty in our work, not least so that some percentage of sensitivity can be given to financial colleagues when economic appraisals are carried out. It is perfectly reasonable for a Net Present Value analysis to be conducted using the geologist's best professional judgement figures, and then look at the effect of adjusting the mineral reserve by X%.

A very good and practicable statistical process is set out as an Appendix in the sand and gravel resource reports of the former Industrial Mineral Assessment Unit (IMAU) of the British Geological Survey, available on download from their website.

Note

In this paper there are phrases that have common alternatives in the quarrying industry.

Mineral bearing areas can be prospect sites; exploration targets; resource areas; preferred areas; sites; hereditaments; landholdings; reserve blocks.

Mined or quarried can be worked; extracted.

Phases can be steps; stages; increments; blocks.

Sensitivity can be variance; error; limits; uncertainty.

Ground investigations can be drilling; probing; boring; site investigation.

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