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Valuing regional geoscientific data acquisition programmes: addressing issues of quantification, uncertainty and risk

Margaretha Scott, Roussos Dimitrakopoulos and Richard P.C. Brown

Abstract

Geological surveys worldwide are involved with research in support of sustainable mineral resource development. The socio-economic benefits to be derived from these activities, however, continue to raise organisational and government sector questions. Fundamental questions include whether or not the resources committed are appropriate and in economic balance with the total benefits to be derived. Another question concerns the degree to which such services should be funded by the community at large. These questions in turn raise important issues regarding the role and cost of geological surveys, the impact of their services, and how they should maximise community benefit from their activities and expertise. To assess the value of geoscientific information, standard valuation processes need to be modified. This paper reports on a methodology designed to quantify the 'worth' of programmes upgrading regional geoscientific infrastructure. An interdisciplinary approach is used to measure the impact of geoscientific information using quantitative resource assessment, computer-based mineral potential modelling, statistical analysis and risk quantification to model decision-processes and assess the impact of additional data. These modelling stages are used to address problems of complexity, uncertainty and credibility in the valuation of geoscientific data. A case study demonstrates the application of the methodology to generate a dollar value for current regional data upgrade programmes in the Geological Survey of Queensland. The results obtained are used for strategic planning of future data acquisition programmes aimed at supporting mineral resource management and stimulating effective exploration activity.

Keywords: Geoscientific data; Resource management; Exploration; Government; Strategic planning; Quantitative resource analysis; Quantitative risk assessment

1. Introduction

In the last 20 years, geological surveys worldwide have experienced significant operational as well as structural changes. These changes have been associated with government policy and have resulted from reviews and official inquiries. A range of issues have affected the operational environments of surveys, including issues related to access to land, sovereign risk, government mineral policies, government financial management (for example, benchmarking, performance-based resourcing), major advances in computer systems and software packages in the 1990s, and the change of political philosophy in many developing countries. The latter change is underpinning investor confidence in emerging markets, whilst the opposite trend is noticeable in developed countries, where more difficult access to land and tighter environmental legislation is tending to increase the risk to reward ratio perceived by exploration companies.

Most geological surveys have implemented major changes in response to their new environment. These changes have included moves to incorporate technological advances into their operations as rapidly as possible. New information in the form of systematic airborne magnetic and radiometric surveys is routinely acquired by many surveys to improve resolution of different rock types, identify errors in existing mapping, assist in the identification of concealed features and provide a new picture of prospectivity (Cook, 1995).

To design an approach to assess the value of information requires an adequate background on the objectives of the organisation providing the information and an understanding of who the main clients are and how those clients make

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decisions on the basis of the information provided. These issues are crucial in determining and quantifying the actual impact of upgraded geoscientific information. In Australia, mission statements of the state geological survey organisations indicate that their common fundamental role remains to record and interpret the regional geology. Mission statements and recent reviews also indicate that the geoscientific data collected, interpretations based on these data, need to be provided to government, industry, and the general public is the principal client is now the exploration industry. This strategy has been adopted on the basis of the rationale that:

(i) Sustainable state mining wealth can best be achieved by facilitating successful exploration; and
(ii) The public sector can influence exploration decisions through the provision of regional geoscientific data.

To this end, a major priority for state surveys in recent times has been to enter existing and newly acquired information into digital database systems.

State surveys have attempted to create a 'climate' where basic incentives exist to explore for minerals. By providing regional data, surveys have sought to reduce the time component of exploration whilst also ensuring access for small and medium sized companies, which would be unable to finance large regional data gathering projects. The importance of the activities of small and medium sized companies is increasingly being recognised, as such companies take on the role of project generation as larger companies downsize exploration activities. The provision of data sets has been combined with the strategy of promoting the data to enhance the perception of exploration potential within a state. This recognises the fact that perceived prospectivity is a fundamental criterion for a mining company when selecting areas for exploration. Also, risk associated with geological factors plays a significant role in determining competitive advantage in the mining sector. Although the invested capital at risk during exploration is not large, the aspects of geological risk remain crucial to the future financial position of an organisation because the mining sector is not as intensely competitive in marketing as in acquiring good quality, mineable ore reserves and mining leases. Clearly, geological risk is reduced by the availability of government geoscientific data, as all new information serves to increase the knowledge of the region's geology. The actual amount by which risk is reduced, however, remains to be established.

Whilst Australian state surveys do contribute to mineral policy, there has been a decline in their influence on policy formulation since the 1980s, with the shift of this responsibility to non-technical analysts within mines departments and central agencies. With this new orientation, the focus of surveys is to support government strategic planning by maintaining suitable databases, and developing expertise in the areas of mineral deposit formation and resource assessment so as to improve forecasting credibility. As mineral resource assessment allows data on physical geology to be given economic value; the information can be used readily in policy processes (Findlay, 1982).

Currently, Australian state surveys principally serve government as economic policy tools by providing programmes that upgrade geoscientific data to reduce discovery risk and thereby stimulate exploration activity. A secondary benefit is that these data can contribute to the strategic planning and management of state mineral resources. In both instances, the economic goal of government is to optimise the use of the state's mineral resources and maximise the generation of economic wealth through investment in mining and the creation of employment and income, including mining royalties.

This study presents a methodology for the valuation of government programmes that upgrade regional geoscientific data, for the purpose of improving resource management and exploration activity. This methodology moves away from the more general approach of monitoring operational behaviour of exploration companies (number of tenements taken, number of new players, number of discoveries made in an area where data have recently been released) to focus on the decision-making processes. The emphasis is placed on isolating and measuring the impact of datasets, varying in quality and type, on company perceptions of prospectivity and investment decision-making, and on government mineral policy resource management. The value of geoscientific data in terms of hazards, environmental or infrastructure planning is not considered here as those issues are covered in other recent research (Bernknopf *et al.*, 1993). A case study is presented which demonstrates the process with the quantitative valuation of data-upgrade programmes being undertaken by the Geological Survey of Queensland (GSQ). Two separate decision-making processes are considered: (1) decisions by the mining industry to explore in a certain area are stimulated by the provision of up-to-date information, which reduces discovery risk and increases perceived prospectivity; and (2) decisions by government regarding mineral policy.

2. Valuation framework

There are significant difficulties in quantifying the impact or worth of investment in the production of geoscientific data through standard economic analyses. Whilst the consequences of known errors in information can be calculated, the quantification of benefits from improved quality, quantity and different data types is extremely difficult. These difficulties stem from the fact that geoscientific information is usually not a final product, but an input into other planning processes. Thus, the relationship between the costs of data collection and analysis, and the final benefit to the client is complex. For example, an issue for Australian state geological surveys is that there is not a simple direct correlation between the provision of government regional geoscientific information and exploration investment. Numerous factors, apart from geoscientific information obtained from geological surveys, are involved in a mining company's decision to invest in exploration, including market trends, the presence of adequate infrastructure, perception of sovereign risk, and company perception of discovery risk or prospectivity. This type of evaluation problems are common to research organisations and have resulted in the use of arbitrary figures to represent the linkage between information and outcomes. Recently, however, the credibility of evaluations of geoscientific data has improved through advances in technology and in the application of quantitative modelling techniques. The recent study by Bernknopf *et al.* (1993) is an example of the use of geographic information system technology and statistical analysis to assess the impact of geological information on environmental management. Watson *et al.* (1984) incorporate computer-based prospectivity modelling, and Powers and Bergsman (1983) and Stanley (1994) use Monte Carlo simulation to deal with issues of uncertainty associated with using geoscientific data and assessing the cost effectiveness of exploration projects.

The methodology presented here expands on the models used in valuing information developed for census data (Spencer, 1980) and hydrological data (Wain *et al.*, 1992). In both these examples, the data themselves are not actually valued, but estimates are made of the costs arising from errors in the data. This basic concept is developed using prospectivity modelling, quantitative resource assessment, and measurements of perceived risk (Scott, 2000; Scott and Dimitrakopoulos, 2001). The method required the construction of models that compare different sets of information (varying in quantity and/or quality) to calculate expected changes in results. The contribution of the 'improved' data is interpreted as reduced error in the decision variables, and thus a reduction of economic loss. Economic loss is expressed as a 'loss function', which is defined here as the net benefit foregone (i.e. the opportunity cost) by not upgrading the existing geoscientific information. The underlying concept is that improved information reduces economic loss, with the question to be answered being how significant this reduction is.

The methodology is designed to value information in terms of decisions regarding initial exploration investment by the mining industry and resource management by the state (Figure 1). The valuation process may be considered in two stages, each requiring several modelling phases. Stage 1 quantifies the impact of data on decision-making processes. This stage incorporates the modelling of perceived exploration risk, quantitative resource assessment, and computer-based prospectivity modelling. Stage 2 calculates a monetary value for the data upgrade programmes and involves cost-benefit and risk analysis. The following sections outline the techniques used in the various modelling phases. Aspects of quantitative resource assessment and risk analysis are discussed in more detail as the links between geoscientific knowledge and the generation of a credible monetary valuation.

2.1. Measuring the impact of regional geoscientific data

Two techniques, revealed and expressed preference (Gough, 1990), are used to measure the impact of geoscientific data on exploration companies' decisions to acquire ground. Revealed preference uses statistics of behaviour to infer the proportion of exploration investment attributable to government geoscientific data. Expressed preference involves acquiring data directly from exploration companies using attitude surveys (Alreck and Settle, 1995) regarding the impact of different data types on their perceptions of prospectivity and discovery risk, and the statistical analysis of this intelligence. The revealed preference method considers both risks and benefits in deducing a decision rule and has the benefit of dealing with actual outcomes and decision-making processes.

Quantitative resource assessment was used to measure the impact of government data on mineral policy decision-making processes. Quantitative resource assessments are estimates of the quality and quantity of the undiscovered mineral wealth located in particular areas (Drew and Menzie, 1993). This type of assessment provides geological information in a form sufficiently detailed for economic calculations and comparative studies by linking geology and economics. A number of approaches can be used to assess potential mineral resources (e.g. Pan and Harris, 2000). The three-part USGS resource assessment process is used in this work because it has a major advantage over other quantitative methodologies in its flexibility with regard to the variety of information and modelling techniques that can be applied. Also important is that this process incorporates information on geological uncertainty, which is extremely useful for decision-making processes and as input to the valuation. The three-part approach, comprehensively described by Singer (1993a), can be summarised as follows. Part 1 is the delineation of permissive tracts which identifies areas where the geology permits the existence of deposits of one or more specific types, as inferred by analogy with deposits in similar geological settings elsewhere. Part 2 uses grade and tonnage models to estimate the amount of metal within a permissive tract. Grade and tonnage models, which are defined by deposit type, are in the form of frequency distributions of tonnages and average grades of well-explored deposits of each type (Singer, 1993b). Part 3 involves estimating the number of undiscovered deposits. There are no fixed methods for making estimates of the number of undiscovered deposits. Methods that can be used include: frequency of deposits in well explored areas (Allais, 1957; Bliss *et al.*, 1987; Bliss, 1992); extrapolations of local deposit density (Root *et al.*, 1992); counting and assigning probabilities to anomalies and occurrences (Cox, 1993); process constraints and relative frequencies of related deposit

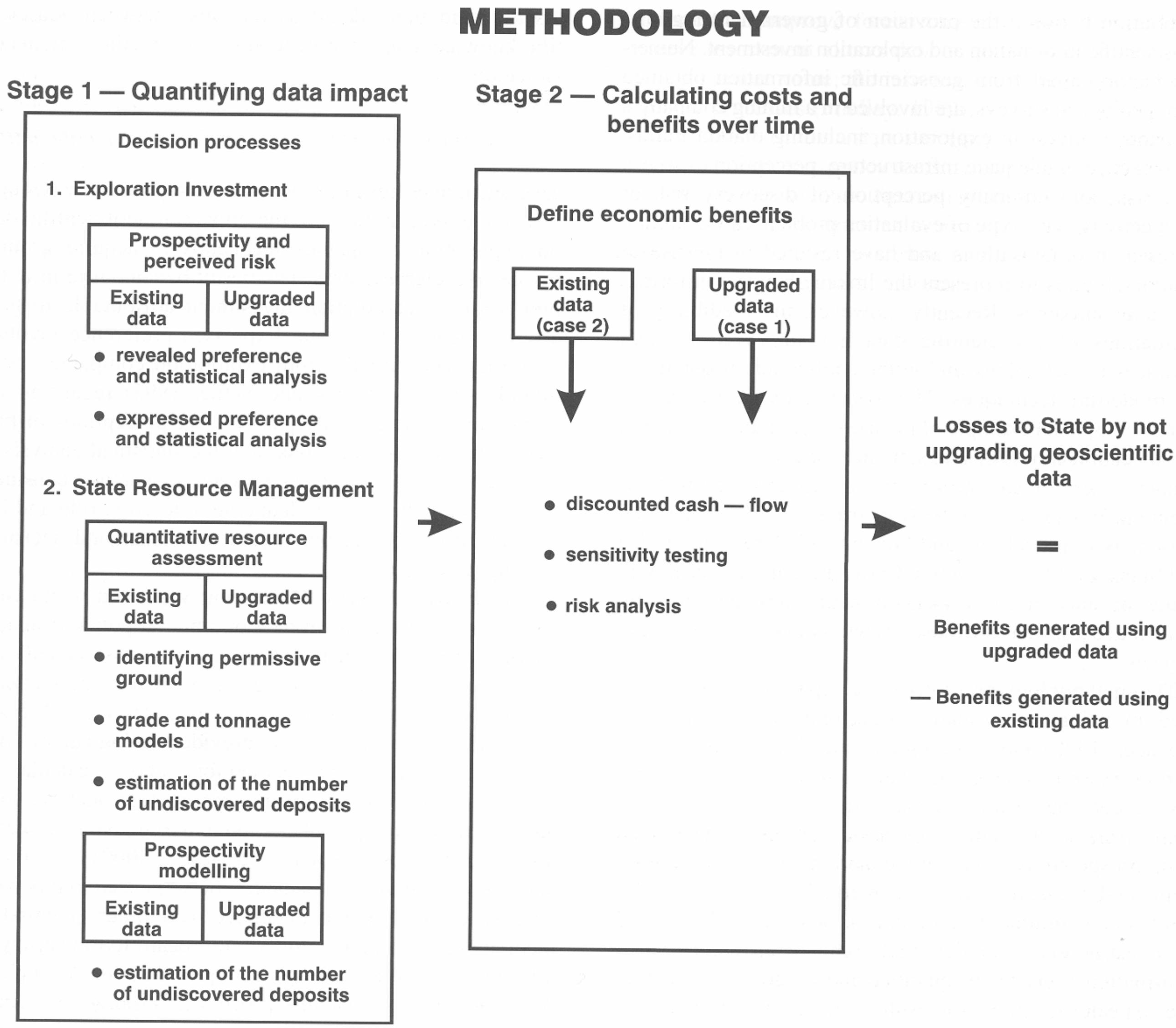


Figure 1. The information valuation methodology used in this study

types (Drew and Menzie, 1993). Estimates of the number of undiscovered deposits explicitly represent the probability that some fixed but unknown number of undiscovered deposits exists in the permissive tract. As such, these estimates reflect both the uncertainty of what may exist and a measure of the favourability for the existence of the deposit type. It is important to recognise that a necessary assumption made in applying this method is that any undiscovered deposit will be of a type already known.

2.2. Integrating qualitative modelling and considering risk

Cost-benefit analysis (CBA) is used to integrate outputs from earlier modelling stages and to provide an evaluation in monetary terms. An abundant literature exists dealing with the principles of CBA with recent reviews of the current state provided by Perkins (1994) and Squire (1989). In simple terms, CBA measures and compares costs and benefits of programmes or projects in monetary terms. A CBA can be conducted from the perspective of the various stakeholder groups, ranging from the individual investors to society as a whole. Costs can include explicit costs such as wages and operational costs. Revenue earned and costs avoided are treated as project benefits. Secondary benefits or flow-on are usually not included, because if funds were not invested in a particular project, those funds would probably be used in some other activity with associated multiplier effects of a similar order. Identified costs and benefits are compared over time through discounting, which effectively reduces costs or benefits to an equivalent present value. Discounting forms the basis of what is known as discounted cash-flow (DCF) analysis where a project or investment is defined in terms of the cash-flow generated. A number of decision rules can be obtained from discounted cash-flow analysis (Perkins, 1994); net present value (NPV) and internal rate of return (IRR) are used in the case study presented here.

The calculations performed in deriving the net benefit streams for CBA occur under varying levels of uncertainty. Typical of research programmes spanning a number of years into the future is that the costs and benefits, particularly the latter, are estimated subject to a high degree of uncertainty. In this study, uncertainty and risk are major issues with respect to economic forecasting, the incomplete nature of geoscientific information and the fact that decision-making processes are involved. Because a range of factors can affect cash-flow variables, the figures used are often "best"-estimate point values from what may be wide probability distributions of random cost and benefit variables. Sensitivity analysis and risk analysis are used here to take account of this.

Sensitivity analysis involves the identification of the parameters affecting cash-flows and then reworking the discounted cash-flow analysis using several different combinations of values for these parameters. The range of values for the CBA outcome provides an indication of the degree to which the profitability of the investment will vary if parameter values diverge from the best-guess estimates. This technique also identifies the variables that are likely to be most significant for the project's success, but it does not provide information about the probability of a particular outcome being achieved under different assumptions.

Risk analysis estimates the variability of the CBA outcome by fitting probability distributions, rather than single point estimates, to the cash-flow variables that are considered to be significant. Probability distributions are estimated for variables expected to have the greatest uncertainty and impact on the overall project performance. The distribution estimates are based on historical data or subjective judgement using, for instance, a triangular distribution based on the 'best' estimate, most optimistic and most pessimistic values. This method was adopted in this study, using values based on the results of modelling discussed in section 2.1. Monte Carlo simulation is used to generate and select random observations from each of the estimated distributions. With thousands of iterations a probability distribution of the possible values of the CBA outcome is generated. Relative to sensitivity analysis, this mechanism more closely resembles real conditions where variables are likely to vary randomly, simultaneously and continuously over the life of a project. Risk and sensitivity analyses are applied as complementary techniques in this valuation methodology, providing additional information regarding the robustness of the valuation estimations for the final decision process.

3. Case study: The Geological Survey of Queensland

A study was undertaken that compared two operational options or 'cases' for the GSQ. Case 1 — where the current data upgrade programme by the GSQ continues to receive funding to the year 2005; and Case 2 — where only early, existing information is available. The economic value of upgrading geoscientific data is considered to be the net benefit foregone, or more explicitly the difference between the benefits generated using upgraded data (Case 1 — the 'with' case) and the benefits generated using only existing data (Case 2 — the 'without' case). The cash-flows for both cases are compared and presented in the form of NPV, IRR, benefit-cost ratio, and annual equivalent net benefit using base-case assumptions or 'best' estimates of key variables. Performance criteria are calculated using the discount rate of 6% which is regarded as being a reflection of the type of return that may be sought as a result of public investment (Queensland Treasury, 1997). The implicit price deflators used were sourced from the Queensland State Accounts, Queensland Treasury. The appraisals follow the general principles of an economic CBA, and were conducted from the point of view of society as a whole — in this instance the point of reference was the state of Queensland. The study did not consider to what degree the operations of state geological surveys benefit private exploration companies. Thus, gains made by exploration companies were not included in the final valuation of state geological surveys. The economic value of government regional geoscientific data is estimated in terms of the economic penalties incurred as a result of incorrect government decision-making for mineral policy in land-use, and strategic development. Exploration expenditure (associated with company perceptions of prospectivity) is an intermediate objective in the provision of geoscientific data by government. Whilst benefit is seen through investment by exploration companies in regional areas, the ultimate objective sought by government is successful exploration and deposit discovery. Benefits may occur locally from increased exploration activity, but activity alone is insufficient to ensure successful discovery. It is necessary that perceptions of prospectivity are not misleading, as incorrect perceptions result in losses either through insufficient exploration investment or ineffective exploration. Cost-benefit ratios are used to establish the effectiveness of government regional geoscientific programmes in influencing exploration investment.

In comparing GSQ operational options, two scenarios were considered. Scenario 1 conservatively assumes that an increase in royalty revenue is the only economic benefit to be gained by the general community from the activities of the state geological surveys. Scenario 2 assumes that a percentage of increased company profit is reinvested as exploration expenditures in the state, which along with royalty revenue, constitutes the benefits to the community. Scenario 2 is in fact a more realistic representation of the benefit of government geoscientific data to the state as it takes into consideration the nature of the exploration industry. The exploration and mining industries are characteristically mobile, with both infrastructure and expertise located wherever prospective ground or economic resources are identified. The retention by a state of company profit in the form of exploration money is a competitive process and in the absence of government geoscientific data, a percentage of the exploration investment would be lost. A percentage of exploration expenditure is used in the second scenario to proxy for company profit that is reinvested in the state. The percentage of exploration expenditure used to estimate total economic benefit is that which is attributed to the effect of government geoscientific data.

3.1. Measuring the impact of two generations of data

3.1.1. Exploration decision-making

The revealed preference procedure involved sampling, database design, and statistical analysis. In the GSQ case study this technique was applied to confidential records of mineral exploration permit applications. A database was constructed using a sample of the population of applications. The design requiring the selection of variables so as to permit the testing of postulated relationships including those between: age, type, and detail of government geoscientific data; size of exploration company; and exploration dollars spent. Statistical analysis used standard multiple regression modelling with the objective of measuring the effect of information variables on total exploration expenditure of the companies sampled. The postulated regression models were based on two assumptions:

- The amount of exploration expenditure by companies associated with initial ground selection decisions is related to geoscientific information sources including government data; and
- The impact of government data varies depending on the size of the company and the type and detail of data available.

A key finding of the analysis was that recently upgraded data sets had a higher investment response by exploration companies. Upgraded government data sets, including geophysical data, accounted for about 7% of variance in proposed exploration expenditure, whilst existing (old) data sets contributed approximately 4%. The results were minimum values with the estimates of 5% (existing data sets) and 10% (upgraded data sets) considered more realistic recognising the limitations of the technique applied. It is important to note that these figures are not arbitrary and that they isolate the effect of government data.

The expressed preference procedure involved surveys of personnel in exploration companies who make decisions regarding initial ground selection. Statistical analysis used standard techniques, including one-way analysis of variance ANOVA (used to test whether total mean values recorded are representative of company groups), two-way mixed-factor ANOVA (used to analyse mean response to questions common to two surveys made), and repeated measures of ANOVA (used to test responses by the same individual under different conditions, in this study as a function of company size and survey). Results from questions that compared existing and upgraded data sets showed that respondents clearly favoured the upgraded data sets. Of particular interest are the results from respondents asked to estimate the number of targets worth further investigation using both data sets. The mean response for upgraded data sets was 2.8 times greater than for existing data sets. Small and medium size companies considered that there were 2.8–3 times as many potential targets generated using the upgraded data sets, and large companies considered there were 1.2 times as many. Thus the perception of prospectivity at least doubled with the provision of upgraded data sets.

3.1.2. Government decision-making

Quantitative resource assessment and prospectivity modelling were used to measure the impact of upgraded data on government decision-making processes. In the case study of the GSQ, it would have been preferable to apply these techniques to all metallogenic provinces in Queensland for all potential deposit types, but restrictions of time and limited resources made this impractical. Instead the methodology was demonstrated with a study of porphyry-type deposits in the Yarrol Province in central Queensland (Figure 2). To address the issues of scale and geological variability that arise from generalising from a focused study, the total benefit estimates for resource management are included as variables in the risk analysis.

In the resource assessment, grade and tonnage models and estimates of the number of undiscovered deposits are identified as key elements in quantifying resources and as such are fundamental to the valuation framework. It is relevant to the valuation of the GSQ case is that there are no comprehensive published grade and tonnage models dealing with Australian deposits. To test the appropriateness of global models, comparisons were made with grades and tonnages of porphyry deposits in eastern Australia. In considering local data, several issues need to be recognised including the limited number of known deposits, the incomplete nature of resource records, and the use of immature grade and tonnage estimates from incompletely understood deposits. These are, however, issues that are common to many grade and tonnage studies and necessitate the revision of models over time. Figures 3 and 4 show the grade and tonnage frequency distribution curves for the USGS general Cu porphyry and Cu-Au porphyry models. Grades and tonnages for 10, 50 and 90% intervals are indicated, as are the corresponding values for the 'local' eastern Australian representatives. For Australian deposits, these diagrams highlight lower grade and tonnage values for median and tail-end members (median values at about 40 Mt and 0.3% Cu). Estimations of the number of undiscovered deposits made in the case study use the generalised 'Cu-Au-Mo' porphyry grade and tonnage models to better reflect the character of the local porphyry population.

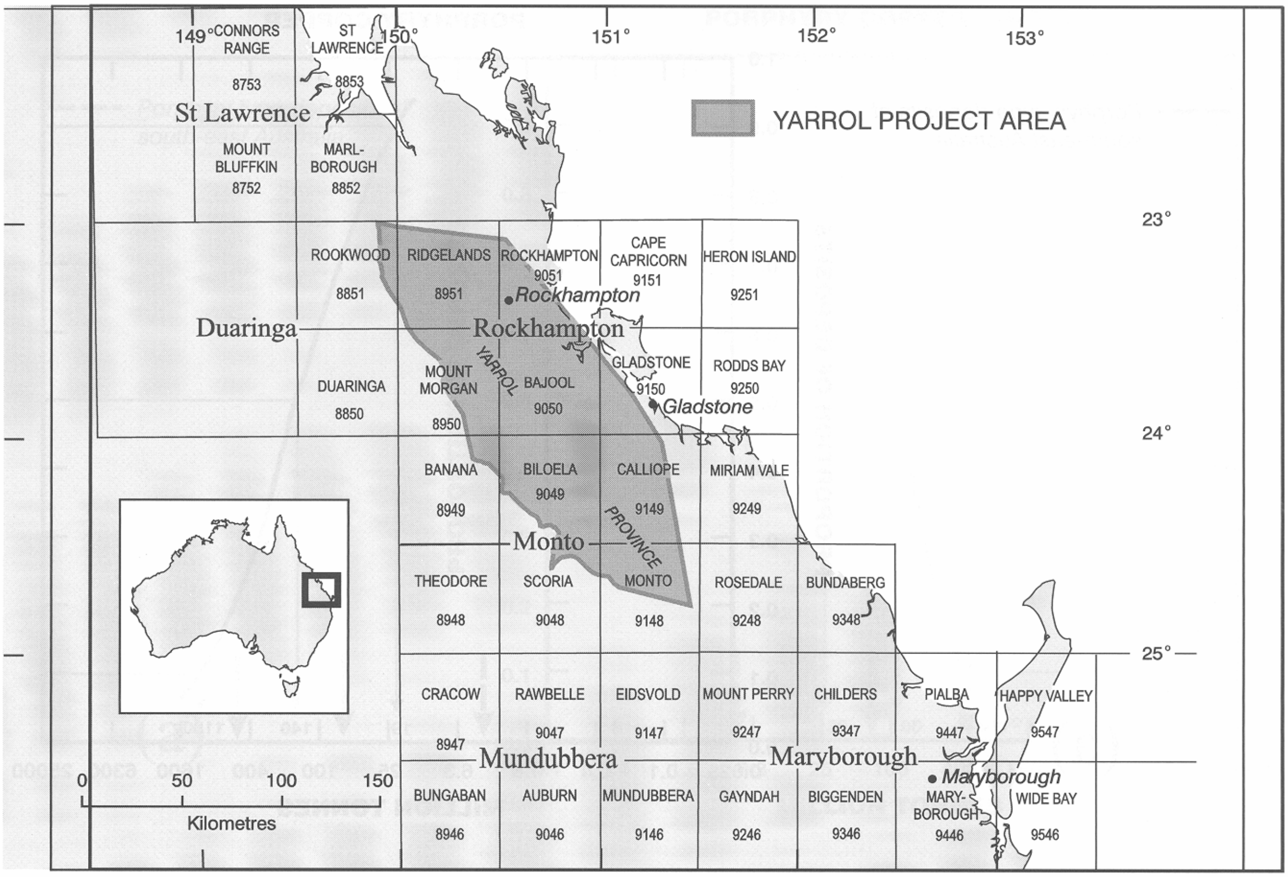
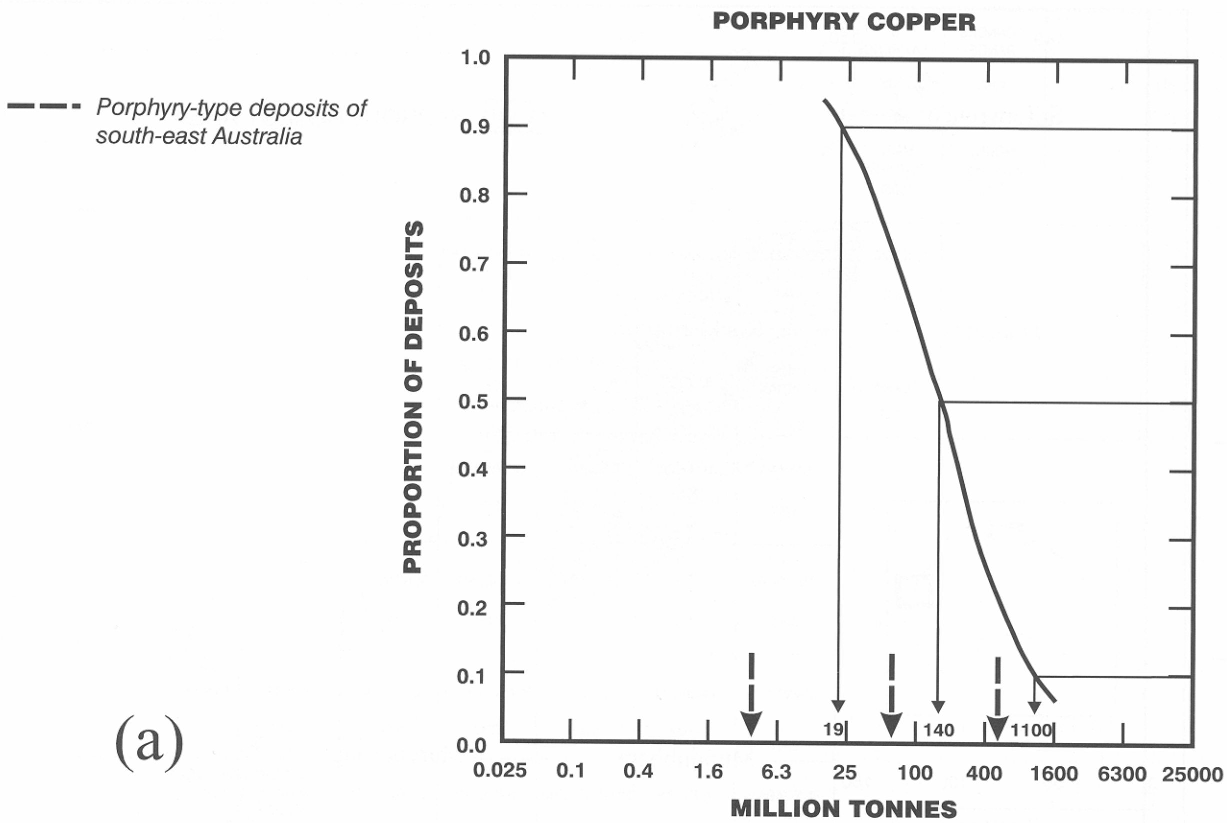


Figure 2. The study area: Yarrol region, Queensland, Australia

The estimates of the number of undiscovered deposits for the Yarrol study were based on three models, results of which were verified using subjective estimates by the government geoscientist most familiar with the area (C. Murray, pers comm.). The first model was based on intense exploration and detailed geological knowledge that exist over a designated control area within the Yarrol study region. The assumption was made that permissive ground in the well-explored control area was typical in the number of deposits that could be expected within the permissive ground throughout the Yarrol Province. In the second model, estimates were based on the regional government information available over the entire study region and the results of computer-based prospectivity modelling. The concept was that the more likely the combination of geological processes required for the formation of a deposit type, the more likely that the deposit type would occur. This approach was considered to be more robust than the first model, in that it used information from the entire region rather than extrapolating from a small control area. At the same time, however, it was recognised that some deposits may be present that were not identified because of the modelling technique and/or the information that was used. 'Weights of evidence' (WofE), a data-driven prospectivity modelling technique, was used in this study because of its simplicity. This technique uses statistical calculations to estimate the relative importance of evidence and to assign 'weights'. These calculations are based on the measured associations between locations of known deposits and map patterns or features. A technical discussion on WofE and other modern prospectivity mapping techniques is provided in Bonham-Carter (1994), Scott and Dimitrakopoulos (2001), and Luo and Dimitrakopoulos (2002). The final product of WofE is a favourability map identifying target regions. As target areas do not necessarily indicate the presence of an economic deposit, Model 2 also involved the development of rules by which the number of undiscovered deposits was estimated based on the number of targets identified. This follows the well-established idea of counting and assigning probabilities to anomalies (Reed *et al.*, 1989; Cox, 1993). Target cut-off values were derived from the control area and equated to known deposits, porphyry systems, and geological features closely associated with porphyry systems. Based on these results, three rules were derived:

- For targets in the top 10 percentile were assigned a 1:1 ratio to deposits;
- For targets ranking in the top 20 percentile used the ratio of targets to known deposits in the control area; and
- For targets ranking above the 50 percentile, the generalisation was used that only one in ten systems is likely to be mineralised.



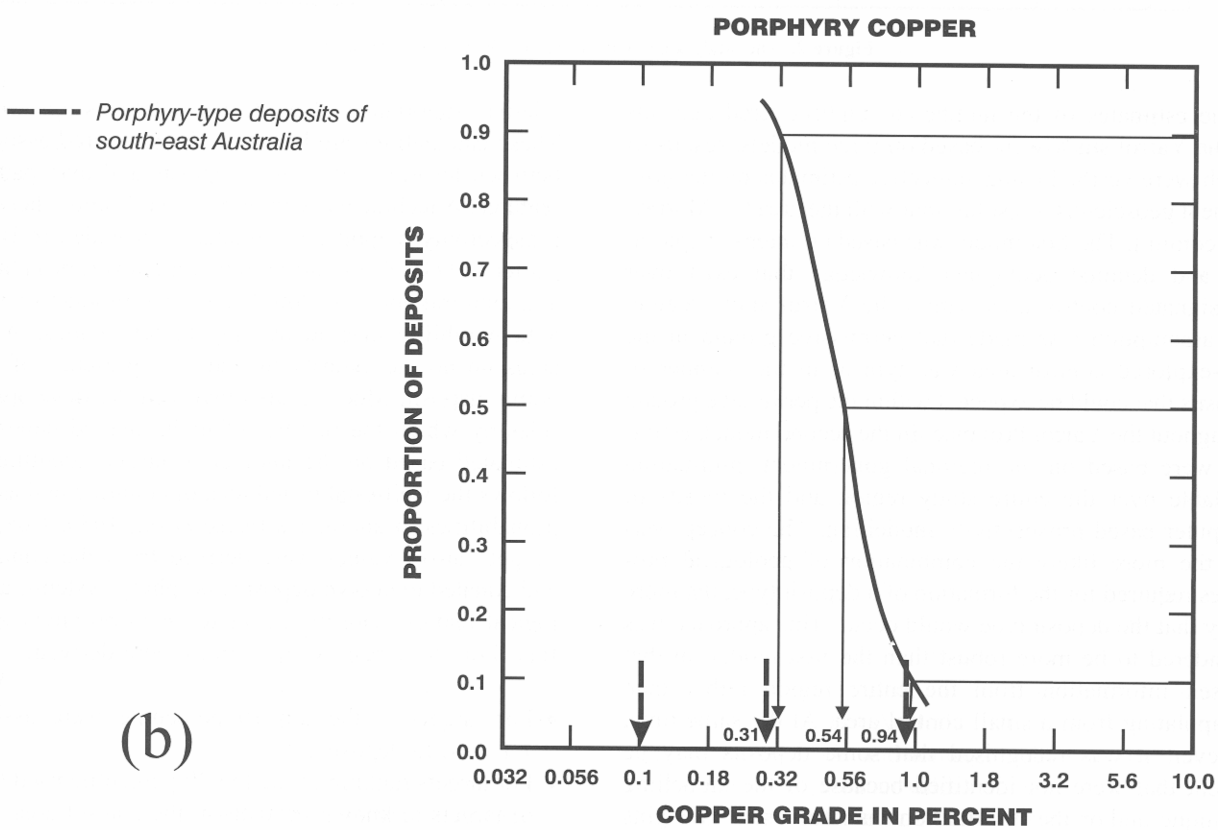
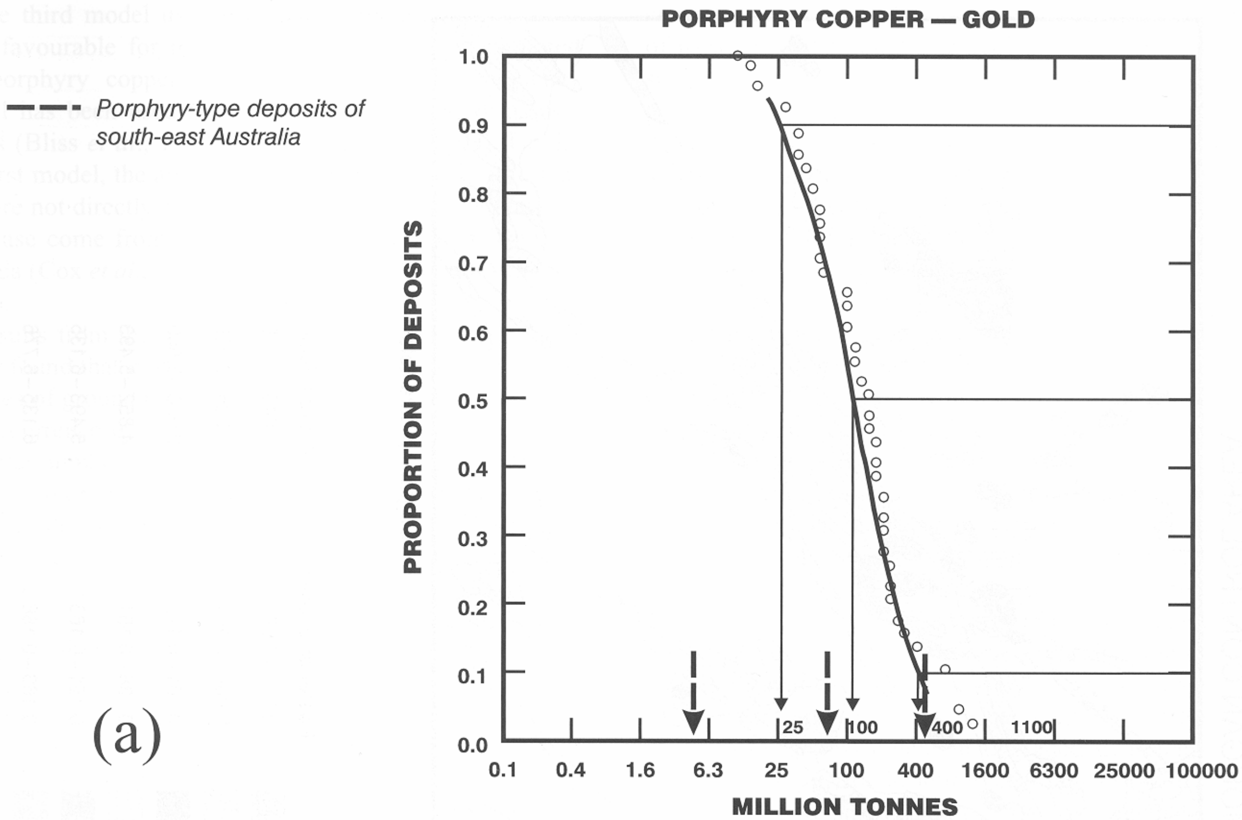


Figure 3. (a) Tonnages and (b) copper grades of porphyry copper deposits (modified after Singer *et al.*, 1986)



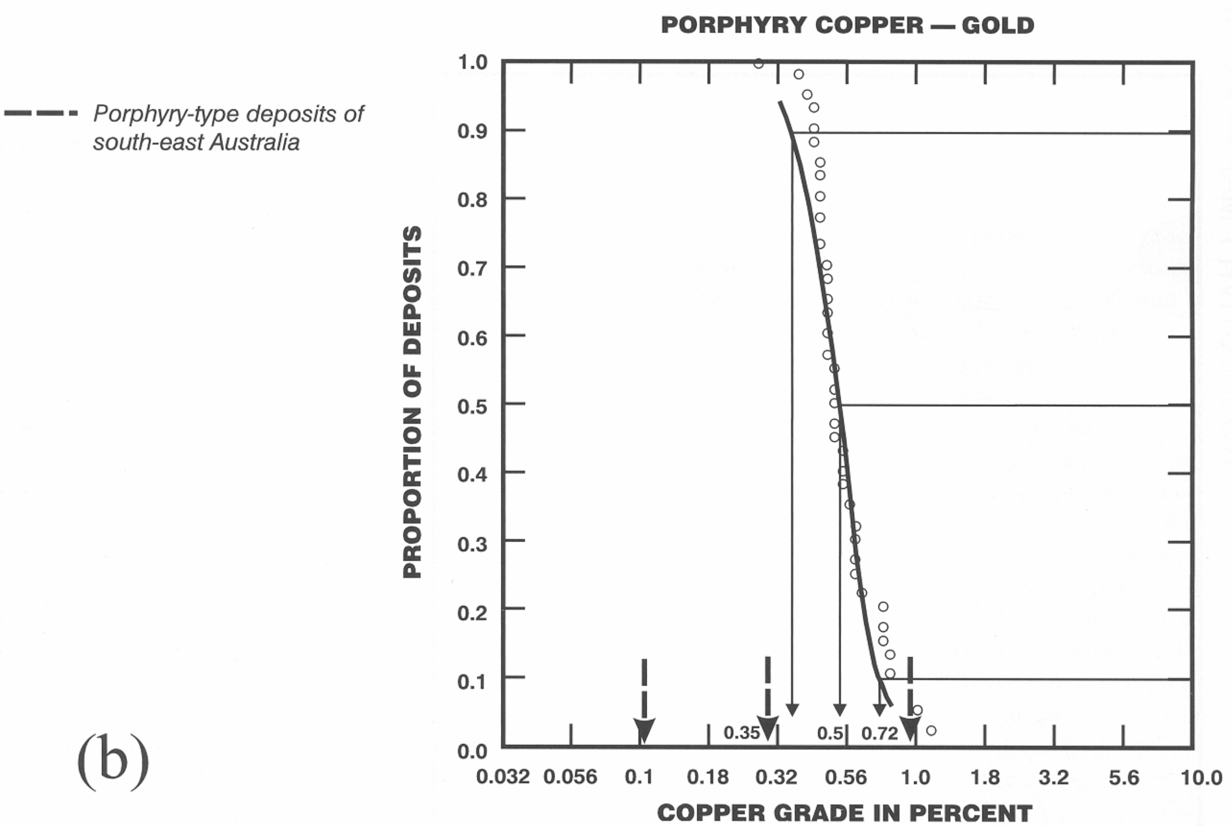


Figure 4. (a) Tonnages and (b) grades for copper-gold deposits (modified after Singer *et al.*, 1986)

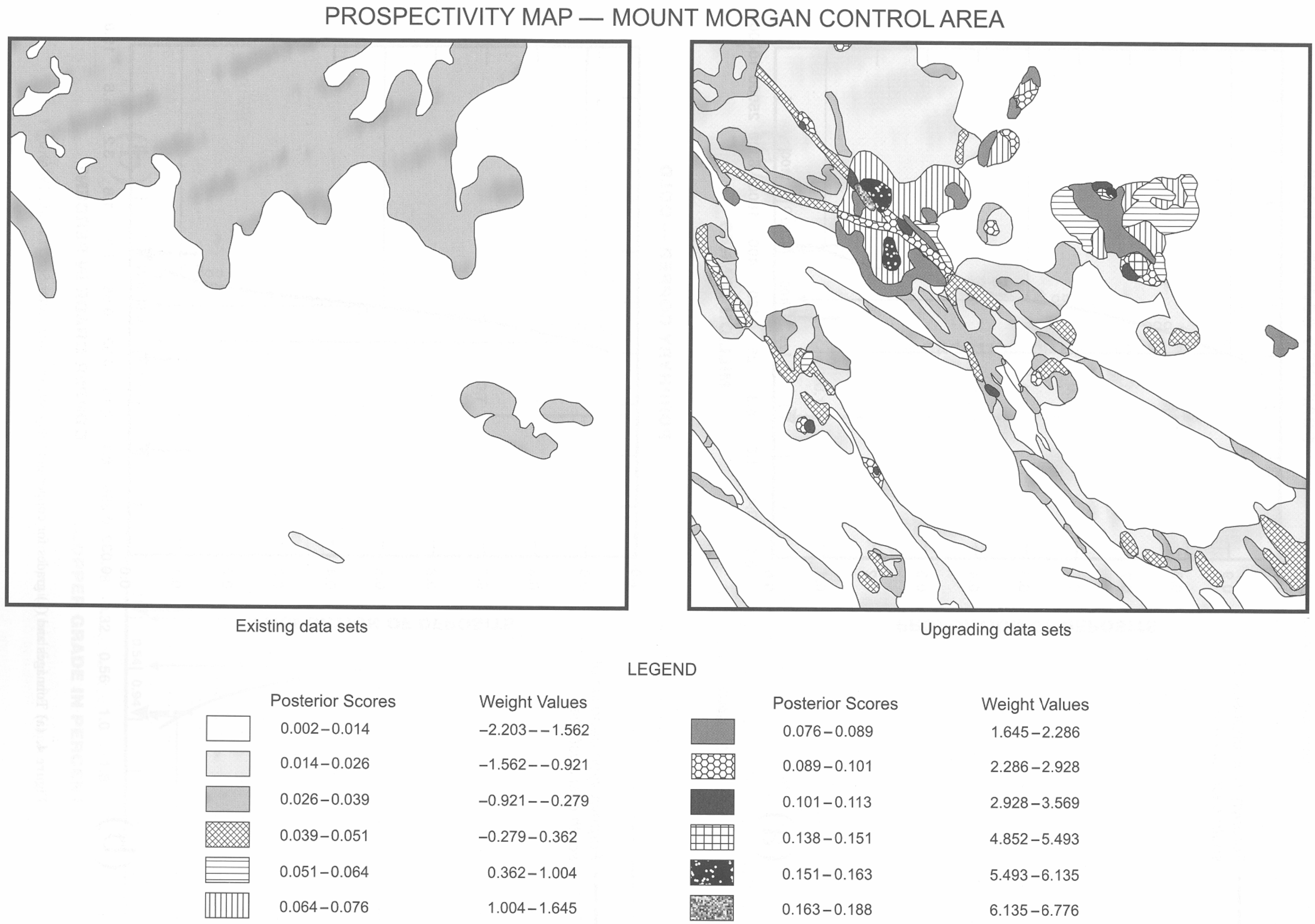


Figure 5. Output maps from prospectivity modelling and comparison of existing (left) and upgraded (right) data. Note the marked improvement using upgraded data in prospectivity modelling

The third model used base-rate estimations from areas both favourable for the occurrence of and well explored for porphyry copper deposits. This type of frequency model has been used in a number of quantitative assessments (Bliss *et al.*, 1987; Bliss, 1992; Cox, 1993). Unlike the first model, the areas used to generate density information are not directly associated with the study region and in this case come from studies made in the United States in Nevada (Cox *et al.*, 1996) and Arizona (Titley and Anthony, 1989).

Results from the quantitative resource assessment modelling found that going from existing to upgraded data sets, the area of ground that would be considered permissible for the occurrence of porphyry type deposits almost doubled, with the number of exploration targets increasing dramatically — more than fivefold (Figure 5). The implication of these results is that large tracts of potentially mineralised land would not be identified using the existing data and that there is a significant reduction in discovery risk associated with the upgraded data set. This conclusion is supported by the fact that known mines with surface exposure were not identified using the existing data. These results highlight the absence in the existing data sets of critical information necessary to identify prospective ground. Based on grade and tonnage information and the results of modelling for permissive and prospective ground, estimates of the number of undiscovered deposits showed a more than threefold increase going from existing to upgraded data. In this study, a value for upgraded data was estimated based on the approximately threefold increase in the number of undiscovered deposits and potential resources, and is therefore about three times that of existing data.

3.2. Integrating qualitative modelling and incorporating risk

A dollar value for current upgrade programmes undertaken by the GSQ was derived from a CBA using the results of the modelling discussed above. The impact of government data in terms of increasing total exploration expenditure is estimated at 10% where upgraded information is available, and 5% where only first-pass information is available. Estimates for exploration expenditure were based on figures from the Australian Bureau of Statistics. Because of the range of factors that influence exploration expenditure and the uncertainty attached to their behaviour, exploration revenue was included as a variable at the risk analysis stage.

The contribution of upgraded geoscientific data to strategic mineral resource planning processes (represented financially by the maintenance of royalty revenue into the future) is estimated at three times that of existing data. Government geoscientific data are considered as determining the future royalty revenue because of the fundamental requirement to ensure that land containing these resources is not withheld from mining. Making the conservative assumption that the state's objective is to maintain the current level of mining royalties into the future, estimates of royalties lost through the depletion of current resource stocks over time can be used to estimate 'future new' revenue requirements.

The cash-flow analysis was dependent on a number of assumptions including those made due to the nature of information (shelf-life – Mackenzie, 1997; and negative information – Amos *et al.*, 1988), the character of exploration and mining, which introduces the effect of lag time (Table 1).

The project involved investment over a period of ten years. The exploration benefits of this investment accrued for a period of 15 years, with the effect from the first year. Royalty benefits extended over a period of 20 years. By comparing the CBA outcomes for Cases 1 and 2, using best estimates, scenario 1 revealed an overall gain to the community from the current geoscientific upgrade programme of $117 million or an annual equivalent net benefit of $13 million, assuming a discount rate of 6% per annum. Scenario 2 had a NPV of $166 million or an annual equivalent net benefit of $17 million at a 6% discount rate. The IRR is estimated at 23% and 78% under the assumptions of scenario 1 and scenario 2 respectively. The effectiveness of government investment in upgraded geoscientific data was supported by the benefit to cost ratios of 4.7 (Scenario 1) and 6.2 (Scenario 2). It is worth noting that the cost effectiveness of existing data was greater than upgraded data, reflecting the greater expense in acquiring new data types.

Uncertainty is an important factor in modelling stages of this study. There is uncertainty due to a lack of information (geology under cover) and uncertainty associated with variability in natural and economic systems. There is uncertainty in future political decision-making (native title, tax regime changes, or infrastructure development programmes), and changes in mineral policies in other countries. There is also the impact of technological advances and changing geological concepts. These issues are considered as part of sensitivity testing and risk analysis and are discussed in detail by Scott (2000).

In the case study, both cost and revenue items attributed to government data are adjusted in sensitivity testing to test how critical they are in determining project success. Royalties were allowed to vary from 10–50% of their 'with' investment level — 10% being the optimistic scenario and 50% the pessimistic scenario. Exploration revenue was allowed to vary between 90 and 100% of what their level would have been in the absence of the investment. For investment cost the 'additional' and operations' components were assumed to range between 20% above and 20% below the best estimate. Sensitivity testing showed that even using extreme minimum values, upgrade programmes generated gains of about $70 million in terms of the investments NPV at a discount rate of 6% per annum.

In the risk analysis uncertain variables are allowed to vary randomly in a triangular distribution around a "best"

Table 1. Assumptions and cash-flow analysis

Incremental cash-flow

Year	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Costs	4.51	3.93	3.85	4.01	4.08	4.08	4.08	4.08	4.08	4.08	0	0	0
Exploration Expenditure	0	5.95	4.76	4.56	5.32	5.32	5.32	5.32	5.32	5.32	5.32	5.32	5.32
Royalties	0	0	0	0	0	2.06	4.14	6.21	8.27	10.35	12.42	14.48	16.55
NCF	−4.51	2.02	0.92	0.55	1.24	3.31	5.38	7.45	9.52	11.59	17.74	19.80	21.87
NCF (Royal)	−4.51	−3.93	−3.85	−4.01	−4.08	−2.02	0.06	2.13	4.19	6.27	12.42	14.48	16.55

	13	14	15	16	17	18	19	20	21	22	23
Costs	0	0	0	0	0	0	0	0	0	0	0
Exploration Expenditure	5.32	5.32	0	0	0	0	0	0	0	0	0
Royalties	18.62	20.69	22.76	24.83	26.89	27.59	29.65	31.72	33.789	35.18	36.56
NCF	23.94	26.01	22.76	24.83	26.89	27.59	29.65	31.72	33.789	35.18	36.56
NCF (Royal)	18.62	20.69	22.76	24.83	26.89	27.59	29.65	31.72	33.789	35.18	36.56

Discount rate	4.00%	6.00%	8.00%
Present value costs	34.43	31.86	29.61
Present value exploration expenditure	55.62	48.92	43.37
Present value royalties	200.64	148.46	111.39
NPV scenario 1	166.21	116.60	81.78
NPV scenario 2	221.83	165.52	125.15
PV(B)/PV(C) scenario 1	5.83	4.66	3.76
PV(B)/PV(C) scenario 2	7.44	6.20	5.23
Annual equivalent cost	−2.20	−2.49	−2.77
Annual equivalent exploration revenue	3.56	3.83	4.06
Annual equivalent royalties revenue	12.84	11.61	10.43
Net annual equivalent benefit (scenario 1)	14.20	12.95	11.72
Net annual equivalent benefit (scenario 2)	17.76	16.77	15.79
IRR scenario 1 = 23%			
IRR scenario 2 = 78%			

Source: Geological Survey of Queensland.

estimate. The minimum and maximum values shown in Table 2 were assigned to the uncertain variables.

Table 3 presents the minimum, mean and maximum values for each of the CBA decision rules, and shows their values at the 95% confidence level. Risk analysis from an extremely conservative position, using figures generated with confidence levels of 95%, had scenario 1 with a NPV of $104 million and scenario 2 with $144 million at a discount rate of 6%.

The question of whether the emphasis of geological surveys on stimulating exploration is in balance with the contribution that geoscientific data and expertise can make to the state can be considered by comparing the separate contributions made by exploration investment and effective resource management. The net benefit from the upgrade programmes in terms of additional exploration investment was estimated at $55 million, and in terms of royalty revenue at $148 million. These amount to a net annual revenue equivalent to $4.3 million for exploration and $12 million for royalties at a 6% discount rate. The effect of revenue loss, through the depletion of major base metal mining operations in the next 20 years, greatly increased the value of the upgrade programme in terms of the state's needs and resource management.

Table 2. Random variables used in risk analysis

Costs	Minimum	Estimate	Maximum
Operational, additional	–20%	$	+20%
Benefit	Minimum	Estimate	Maximum
Resource royalties	10%	30%	50%
Exploration investment	90%	95%	100%

4. Concluding comments

It has been argued extensively within Australia and in other countries, particularly the United States and Canada, that geological maps provide benefit to society. Discussions on privatisation, commercialisation, and the need to justify programmes to obtain funding continue to place pressure on government geological surveys. The justification process has occurred through organisational reviews and budgetary mechanisms, which in general have failed to address the need to quantify the impact of geoscientific data. The valuation of the GSQ is presented here as an example of the application of a methodology designed to

Table 3. Summary statistics of the risk analysis

	SCENARIO 1 ($1997–98M)				SCENARIO 1 ($1997–98M)			
	Minimum	Mean	Maximum	95% Confidence	Minimum	Mean	Maximum	95% Confidence
IRR	21%	23%	26%	22%	40%	76%	242%	46%
NPV	93.8	116.6	142	104.2	123	165.5	210.6	144.1
Net annual equivalent benefit	9.8	11.6	13.5	10.7	11.3	15.4	20.3	13.3
	Minimum		Mean			Maximum		
Annual equivalent exploration expenditure	1.6		3.8			6.8		
Annual equivalent royalty revenue	9.7		11.6			13.5		

quantitatively value programmes upgrading geoscientific data and support the objective assessment of the socio-economic benefits to be derived from investment in such programmes. The case study, whilst demonstrating the methodology, also provides information currently sought by Australian state geological surveys (Australian and New Zealand Chief Government Geologists' Conference Report, 1999).

Similarities between the GSQ and other surveys, where the primary objective of acquiring regional geoscientific data is to stimulate exploration activity, mean that the results generated have broader implications. The case study shows that companies are definitely affected by the release of new geoscientific data: results indicate the potential for perceptions of prospectivity to double and there is a 10% contribution in decisions to invest exploration monies. Clearly, new geoscientific data are an influential tool, but there are other critical factors involved in a decision to invest exploration monies. Such factors include commodity prices and the issue of native title, which is currently being viewed as of primary concern and an overriding factor in Queensland. Recognising the impact of native title, a more significant finding of the study is the financial benefit to be gained by the state from the operation of the GSQ in sustainable resource management and the overall contribution that geoscientific data and expertise can make to state needs. Results show that upgrade programmes contribute $148 million in royalty revenues as compared to $55 million that is directly attributable to exploration investment.

The present methodology integrates a number of quantitative modelling techniques relevant to two distinct, economically important decision processes that government surveys intend to influence: exploration investment and the management of mineral resources. The approach used, focusing on decision processes and economic impact to value geoscientific data, in principle could also be applied to the assessment of private-sector data acquisition programmes. With the general move towards quantitative analysis and computer simulation of geological systems, there will be an increasing demand for more detailed information to be used to reveal subtle patterns to aid in targeting concealed deposits. New and costly data acquisition projects warrant valuation studies to support their introduction and to ensure that strategies exist to maximise benefits from investment dollars (the effect of diminishing returns needs to be assessed). Ironically, continuing developments in technology and technical applications that require more detailed and usually more costly data input, are not only providing the impetus to assess the costs and benefits of specific types of data, but are also providing the means by which credible quantitative assessments can be made.

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