THE COMBINED APPLICATION OF MODERN PORTFOLIO THEORY AND COST-UTILITY ANALYSIS TO INFORM DECISION PROCESSES IN A CHANGING CLIMATE

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ABSTRACT

This paper presents and evaluates the combined Application of Modern Portfolio Theory and Cost-Utility Analysis to inform decision processes in a Changing climate that represents a significant part of a more complete modeling process required to fully allocate and release Modern Portfolio Theory for application to Cost Utility Analysis. The complete process is also described at a more general level including discussion of additional requirements for application to reinsurance. While the specific modeling presented is based largely on concepts from modern portfolio theory.

These negative effects can be mitigated by land use changes and/or intervention measures such as the construction of artificial wetlands and water treatment plants. Usually budget constraints limit the number of measures that can be implemented by the catchment management authority. This creates a selection problem: to maximise the total water quality benefits subject to a budget constraint. Here we present a case study, Cost Utility Analysis and subsequent combinatorial optimisation is applied to determine an optimum portfolio of intervention sites. We furthermore apply modern portfolio theory and demonstrate how Modern Portfolio Theory and CUA can be jointly used to take into account aspects of climate change. We find that the methodologies represent auditable ways to determine a robust project portfolio and help to inform environmental investment decision processes.

Keywords: ***Multi-criteria analysis, Climate change, Modern portfolio theory, Optimisation, Risk, River catchment***

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1. INTRODUCTION

Suffer from high nutrient loads that can eventually lead to eutrophication, shifts in habitat characteristics and replacement of fish species (FAO 1996) or even fish killings, which in turn may cause economic losses and impair the recreational value of a region. Prevention or mitigation of these effects can be achieved by appropriate land-use management practices, soil conservation and/or the establishment of riparian and other buffer zone (Withers and Jarvis, 1998). Alternatively structural controls can be established which might involve construction and installation of bioengineering techniques, sedimentation basins and others (USEPA, 2008). A decision whether or not to put such an intervention measure in place will depend on its technical efficiency, the benefits it can achieve and its cost. If a variety of intervention measures are suggested within a catchment we usually need to account for a budget constraint which implies that not all suggested measures can be realized.

This creates a selection problem where a subset of potential interventions sites needs to be selected such that the aggregated benefits are maximized while accounting for a budget constraint. A discussion on the problem of selecting an optimal subset of decision options or projects subject to a constraint is not new and quite generic, especially in financial investment optimization. However the combined use of multi-criteria analysis and subsequent optimization in a natural resource management context is quite recent (Hajkowicz et al. 2005) .What is not dealt with is to link the results of a multi-criteria with a theory that addresses risk diversification in light of an uncertain future. In this paper we plausibly assume that the efficiency of water management investment decision options are related to the uncertainties included in climate change projections, which imposes a risk on water management investments.

As climate change models generally project increases in temperature and/or changes in precipitation severe impacts on overland flows and river flows can be expected. Changes in these flow regimes are of particular interest to water management decision makers (e.g. Swan River Trust, 2007). As climate change is not a phenomenon of the distant future but will affect the lifecycles of many water management assets that are designed and built today, water management investments that are made today should be evaluated in light of projected climate change.

Here we present a case where cost of waterway health intervention measures subject to a fixed budget constraint. However, in light of climate change, the benefits that are returned by the selected projects are uncertain and this imposes a risk on the investment. We account for these uncertainties by applying Modern-Portfolio Theory (MPT) which has risk and return at its centre (Figge, 2004). MPT has predominantly been applied for decades in the financial sector and economic research. It is less frequently applied in water management with the exception of a few recent efforts (e.g. Wolff 2008, Aerts et al. 2008). It should also be mentioned that there are a variety of other efforts – though not based on MPT - to tackle uncertainty in water management (e.g. Chung et al. 2009, Rosenberg and Lund 2009, Brekke et al. 2009). The authors are aware that the suggested workflow is based on simplifications and assumptions. However our primary objective is to develop a consistent methodology which helps inform investment decision processes in light of an uncertain future.

2. METHODS

- **Cost Utility Analysis**
- **Combinatorial Organization**
- **Modern Portfolio Theory**

2.1 Cost Utility Analysis

A comparison of available economic evaluation frameworks including recommendations on how to select an appropriate method is given in Hajkowicz (2005) who concluded that many natural resources management investment decisions may be solved with Cost Utility Analysis or Multi-Criteria Analysis. Hajkowicz (2005) also provides a review of the history of Cost Utility Analysis. Cost Utility Analysis as it is used here can be regarded as an extension of Multi-Criteria Analysis: the utility scores of the suggested intervention measures are computed with a Multi Criteria Analysis and these scores are put in relation to their costs giving the Benefit Cost Ratio. The Benefit Cost Ratio is a measure that reflects how much benefit is returned for every dollar spent, or in other words, how effectively expenditure is allocated? The costs assigned to the intervention sites evaluated in this paper are discounted lifecycle costs which reflect the value of an intervention site over the lifetime of the asset. To compute the utility scores a Multi Criteria Analysis method called Compromise Programming is used which is a well established method that is frequently used in water management and other NRM contexts (Hajkowicz and Collins 2007). As it is not a new method it is not discussed in any detail in this paper. 2386 the combined application of Cost-Utility Analysis and Modern Portfolio Theory, The imposed budget constraint was AU$$ 1.437 million.

2.2 Combinatorial optimization

Combinatorial optimisation aims to find the combination of intervention sites that return the maximum attainable aggregate utility score (benefit) for a given fixed budget. This problem is an inherently binary decision problem with two possible outcomes for each site: select or not select. The finding of the optimal combination subject to one or more constraints is well known in operations research as the Knapsack Problem (KP) (e.g. Martello et al., 2000, Gomes da Silva et al., 2006). To solve the given combinatorial problem an exact solution method (branch and bound) was used.

2.3 Modern Portfolio Theory

Harry Markowitz published his research titled “Portfolio Selection” in The Journal of Finance during 1952. He led with: “The process of selecting a portfolio may be divided into two stages. The first stage starts with observation and experience and ends with beliefs about the future performances of available securities. The second stage starts with the relevant beliefs about future performances and ends with the choice of the portfolio. This paper is concerned with the second stage.

Modern Portfolio Theory (MPT) was developed in the early 1950’s and is primarily based on the work of Markowitz (1952). MPT is routinely applied by financial asset managers who usually are not aiming at investing in a single asset but into a portfolio of assets. While investing into one asset may result in a higher return, it may be considerably riskier. The term risk is used here as it is used in corporate financial terms, namely as the standard deviation of the expected returns. However, assets should not arbitrarily be combined to form a portfolio as in the presence of highly positively correlated assets, asset returns may move up and down together which would be risky. If returns are not correlated, diversification can even eliminate risk (Markowitz, 1959). As mentioned above the expected returns of the individual portfolio assets, their standard deviations and the correlation between the returns of the assets involved are central to portfolio theory. The expected return of an asset R_i (with i = 1...n where n is the number of assets) is given by

$$E(R_i) = \sum_{k=1}^{m} p_k E(R_{ik}) \quad (1)$$

where $E(R_i)$ is the expected return of asset i across a set of given scenarios k (with $k = 1,..,m$), e.g. a set of climate scenarios, p_k is the probability that a scenario k occurs and m is the total number of possible scenarios. $E(R_{ik})$ is the expected return of asset i for a scenario k. The variance of an individual asset's return $\mathrm{Var}(R_i)$ is

$$Var(R_i) = \sum_{k=1}^{m} p_k (R_{ik} - E(R_i)) \quad (2)$$

its standard deviation is accordingly

$$\sigma_i = \sqrt{Var(R_i)} \quad (3)$$

The expected return $E(R_p)$ of a portfolio of n assets is

$$E(R_p) = \sum_{i=1}^{n} w_i E(R_i) \quad (4)$$

where w_i is the weighting or the share of asset i within the portfolio p. The portfolio variance or the risk of a portfolio σ_p^2 is given by

$$\sigma_p^2 = \sum_{i=1}^{n} w_i^2 \sigma_i^2 + \sum_{i=1}^{n}\sum_{j=1}^{n} w_i w_j \sigma_i \sigma_j \rho_{ij} \quad (5)$$

where ρ_{ij} is the correlation between two assets i and j. ρ_{ij} is determined by

$$\rho_{ij} = \frac{\sigma_{ij}}{\sigma_i \sigma_j} \quad (6)$$

with σ_{ij} being the covariance between two assets i and j which is computed via

$$\sigma_{ij} = \sum_{k=1}^{m} p_k (E(R_{ik}) - E(R_i))(E(R_{jk}) - E(R_j)) \quad (7)$$

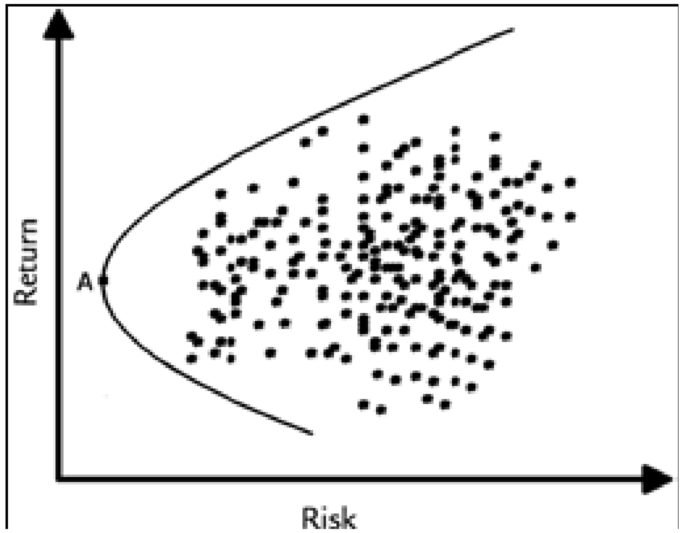

Figure. 1 Region of feasible portfolios

An asset can be understood as any entity money can be invested in. While financial asset managers can invest money e.g. in share companies NRM assets can be manifold and need to be defined in the problem context. If, e.g., the investment decision problem is to find an optimal portfolio of different tree species to optimize forestry returns every tree species considered could be defined an asset. If a set of *n* assets is defined, a set of feasible portfolios differing in the share of individual assets is established and the portfolio risk and return are computed. Three assets X, Y and Z having a share $wX = 0.5$, wY 0.2 = and $wZ = 0.3$ form one possible portfolio with a specific portfolio risk and portfolio return. Changing the shares of the individual assets leads to a different portfolio with a different risk and return. In Figure 1 every point represents one possible portfolio. Given a specific risk level a portfolio manager can easily determine the return that is associated to a specific portfolio of assets. The line in Figure 1 represents the most advantageous risk return combinations (Figge 2004) where point A represents the portfolio with the lowest risk. However some portfolio managers may be aiming to achieve a higher return and may therefore be willing to accept a higher level of risk. In this case they have to move their portfolio along the upper portion of the line until the desired return or level of risk they are willing to accept is reached.

3. CASE STUDY

All data used in this study, including criteria scores, criteria weights as well as cost data were provided by Swan River Trust officers and consultants. The computations were performed with the multi-criteria analysis tool which a user-friendly software package is providing multi-criteria analysis functionality as well as combinatorial optimisation algorithms.

3.1. Computation of benefits and subsequent optimization

To evaluate the different decision options with multi criteria analysis, a set of performance indicators must be defined. Figure 2 shows the criteria categories and criteria being used to define the utility of an option. The criteria weights, which measure their relative importance, were set in consultation with stakeholders. The evaluation matrix being used in this case study cannot be shown due to its large size. The assigned criteria scores were qualitative and ranged from 1 to 10 where the higher the score the better the performance. These qualitative scores were provided by an environmental and engineering consultant, who comprehensively assessed the catchment on behalf of the Swan River Trust (GHD 2007a, 2007b). The cost data being assigned to the intervention sites were similarly provided by this consultant. The costs are discounted costs over a period of 25 years which is the assumed lifecycle of the intervention sites. The locations to be evaluated were categorized according to their stream order: main stem, major and minor tributary sites. Figure 1 Region of feasible portfolios (after Figge 2004). Combined application of Cost-Utility Analysis and Modern Portfolio Theory

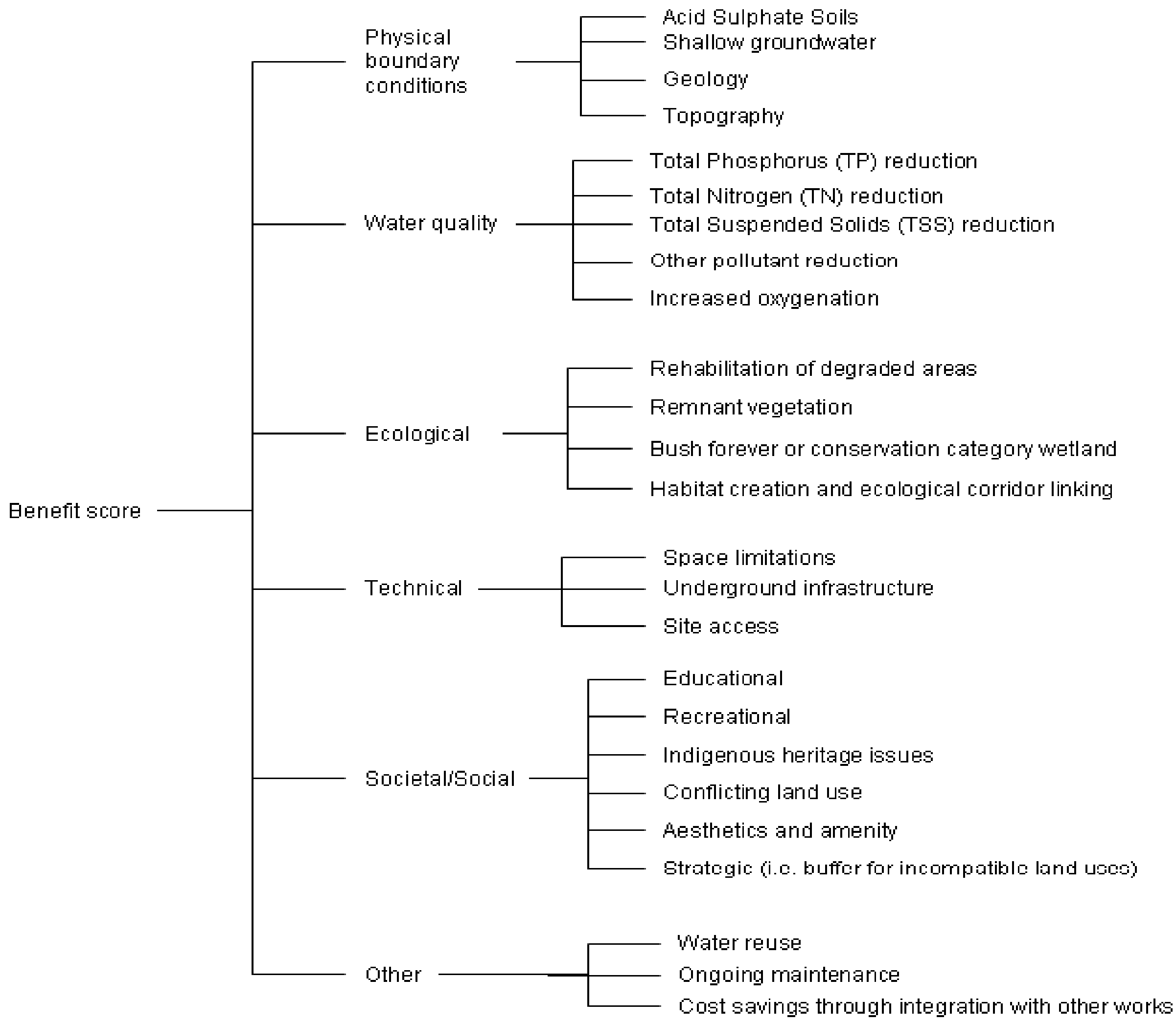

Figure 2: Criteria hierarchy**.**

4. CONSIDERATIONS OF CLIMATE CHANGE

The results presented in Table 1 are not accounting for changes in the regional climate implying changes of temperature and precipitation. For the south western regions of Australia the projected rainfall change for the year 2030 relative to 1990 is between -5 and -7 % (CSIRO 2007a, CSIRO 2007b). The probability for this projection is greater than 70%. These figures are based on a climate scenario A1B which is based on a world population that peaks in the middle of the century and declines thereafter assuming a balance between fossil intensive and non-fossil energy sources (IPCC 2007). Given these projected dryer conditions, it is likely that smaller tributaries in catchments may run dry for greater periods of time or at least seasonally. Neglecting climate change for medium to long-term investments may result in building intervention measures at locations which could potentially run dry. These sites cannot perform their original purpose, i.e. to remove nutrients from the water, which would make these investments ineffective. However this does not automatically call for the exclusive funding of sites at the major stem which may have a higher likelihood of not running dry. The proposed intervention sites at the major stem are very costly and – as the cost-utility analysis showed – not as cost efficient as the minor or major tributary sites.

4.1 Results of the analysis based on modern portfolio theory

The results of the portfolio analysis are shown in Figure. Each of the 2000 points in this chart represents a portfolio consisting of different proportions of the three assets: major stem, major and minor tributaries. The proportions were randomly determined and the risk return computations where performed for each of the 2000 individual portfolio compositions using the equations given in section 2.3. Figure 3 shows that the lowest risk (and the lowest return) is returned at point A. This point represents a portfolio that exclusively consists of the asset major stem. Points B and C stand for a portfolios consisting 100% of minor tributary (B) and major tributary (C), respectively. Since we aim to attain as much return for a given level of risk, we have to move at the edge of the point cloud between points A and C indicating that the portfolio of assets should exclusively consist of the assets major stem and major tributary, but should not include the asset minor tributary. This is in contrast to the findings shown in Table 1 where a portfolio exclusively consisting of major and minor tributary sites - which is the edge of the point cloud between points B and C - was suggested

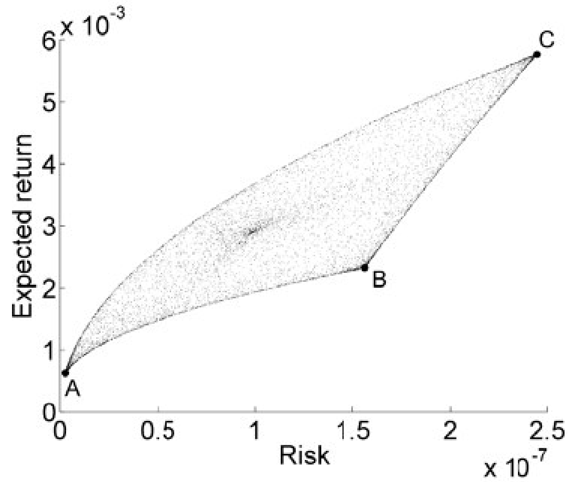

Figure 3: Possible portfolios of the assets main stem (A), Minor tributary (B) and major tributary (C).

5. DISCUSSION AND CONCLUSIONS

The findings based on modern portfolio theory are counterintuitive to the result of the previous Cost Utility Analysis which indicated that no major stem sites should be funded. The results of the Cost Utility Analysis have a strong focus on cost efficiency and the selection of sites heavily depends on the benefit cost ratio. This implies that even exceptionally beneficial options are unlikely to be part of the selected portfolio if their costs are high. The presented results of the Cost Utility Analysis do not imply any future uncertainties. Performing simulations with the Cost Utility Analysis along criteria performance scores gives insight into probabilities of benefits achieved but there is no link to a risk component which is accounted for if modern portfolio theory is applied. We suggest that if asset returns Figure 3: Possible portfolios of the assets main stem, Joint application of Cost-Utility Analysis and Modern Portfolio Theory are quantified with a triple bottom line score as provided by multi-criteria analysis, Cost Utility Analysis and subsequent combinatorial optimization should not be conducted in isolation but should be jointly used with Modern Portfolio. Theory if future uncertainties are to be taken into account. We believe that the application of portfolio theory has considerable potential to be used more frequently in natural resources management.

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