NERA
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Environment Agency: Water Resources Management Planning - Real Options Analysis

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List of Abbreviations

AMP – Asset Management Plan

Defra – Department for Environment, Food and Rural Affairs

EA – The Environment Agency

Ofwat - The Water Services Regulation Authority

ROA – Real options analysis

RSA – Restoring Sustainable Abstraction

SDB – Supply Demand Balance

SDS – Strategic Decision Statements

SEA – Strategic Environment Assessment

UKWIR – UK Water Industry Research

WRMP – Water resource management plan

WRZ - Water Resource Zone

Executive Summary

An Introduction to Real Options

Real options analysis is an approach to decision making that formally recognizes uncertainty and examines how current decisions limit or expand our ability to learn and react in the future.

There are three necessary conditions for real options analysis to be of value:

1. First, there must be **uncertainty**. Without uncertainty, there is no need to consider the possibility of switching strategies in the future. The future is known and the best decision under certainty can be made now. It can be made deterministically.
2. Second, there must be **learning**; that is, the state of information regarding uncertainty must change over time. With uncertainty but without learning, the future may not be known but that state of knowledge (or lack thereof) remains constant. There is no reason to postpone any decision-making and the best decision under uncertainty can be made now. It can be made probabilistically.
3. Third, there must be **flexibility**; that is, there must be the possibility of acting on the basis of new information over time. With learning but without flexibility, there is no ability to take advantage of that learning and switch strategies. The decision can then be optimised deterministically or probabilistically depending on the case and criteria.

Where factors 1, 2, and 3 are present a real options approach may be able to find better solutions than a deterministic or probabilistic approach.

Real options analysis can be applied at different scales as indicated in the table below. Best practice is to first apply real options thinking using a less demanding approach such as scenario analysis or scenario analysis with quantification. If this analysis suggests there is probably significant real options value, then the organization can move on to apply a fuller and more demanding modelling approach.

Table 1
Alternative Real Option Approaches

Analysis Approach	Description
Scenario Analysis	Initial decisions and uncertainties are formally identified. Uncertainties may be ranked and combined into scenarios. There is a formal discussion of the future response to each initial decision – scenario combination. The analysis is usually limited to four to twelve combinations.
Scenario Analysis with Quantification	The analysis is similar in process and size to Scenario Analysis, but some measure of the comparative likelihood of the scenarios and some measure of the comparative benefits or costs of the decision – scenario combinations are made. The CATALYST process is a good example of this approach.[1]
Small Structured and Quantified	The analysis is limited to less than 100 outcomes and only two decision periods are recognized (initial decision, and response after one period of learning). Decisions and uncertainties are sufficiently well defined that a formal calculation of outcomes and expected value is made. It is recognized that the analysis is incomplete and that considerable judgment should be used in interpreting results. Specialized software for manipulating uncertainties is not needed.
Medium Structured and Quantified	An attempt is made to quantify all key uncertainties. Multiple decision periods may be examined. The analysis may have millions of outcomes calculated. Specialized software for the management of uncertainty data is utilized. Decision makers must rely on the structure of the model and the input data, because they will have limited ability to trace results in detail. Model outputs are assumed to accurately summarize a large number of relationships.
Large Scale Analysis	Large scale analysis is most often used to optimize resource portfolios. The modelling of individual portfolio items is similar to that for Medium analyses, but the portfolio analysis requires additional software capabilities. Often some customization of standard software is necessary.

Applications and Potential Benefits of Real Options for WRMP

Real options thinking may be applied in optimising at least three types of decisions in water planning in England and Wales.

- Formation of water company long term supply demand plans, as documented in the Water Resource Management Plan (WRMP) and the Supply Demand Balance (SDB) submissions. The WRMP planning period is 25 years and a new WRMP must be submitted every five years. The simplest way to bring real options thinking into these plans would be to use the current WRMP toolset, which contains almost all the necessary data, but to formally look at how the current single 25 year plan would best be varied after five years to adapt to each of two to four different futures. Real options approaches could also be applied in a fuller manner with multiple stages, and over a much longer horizon to analyze learning about climate change. This may require simplifying the many feasible alternative investment paths into a handful of distinct strategies but allowing for much more detail on the range of uncertainties that could be faced.
- Examination of the merits of undertaking an individual scheme, within the prevailing WRMP context. Major resource investments, such as reservoirs, large new abstraction

[1] EPRI, CATALYST-A Group Process for Strategic Decision Making: Facilitator's Guidebook, Prepared by Applied Decision Analysis and the Brattle Group, EPRI TR-100583, Research Project 2631, Final Report, Palo Alto, CA: Electric Power Research Institute, 1992

schemes, and desalination plants, and other major commitments such as universal metering or large mains replacement programmes, almost always require analysis beyond that needed for the WRMP. Typically, these schemes are examined with more detail regarding costs and benefits and with greater attention paid to sensitivity analysis, possible dependencies, and ways of mitigating scheme or programme risk. The financial size, detail, and importance of these analyses suggest that they may be strengthened by real options analysis, and that they would make good initial demonstration cases for more complex real options analyses.

- Decisions on water operations, such as optimizing control curves for use of stored water, or for instigation of a hosepipe ban. These decisions often involve well defined short run uncertainties and fundamental tradeoffs between lowering current costs and maintaining future flexibility of supply. While on an individual basis these decisions involve lesser costs than long-run plans or major investments, their repetitive nature and the relative clarity of the uncertainties they face may make it worthwhile to apply formal real options methods to optimising them.

These problems have the three necessities to gain value from real options analysis:

- All of these problems face major uncertainties with respect to some or all of future water availability, water demand, water supply feasibility and capex, water supply opex and capital maintenance, and regulatory and social factors.
- With respect to each of these uncertainties, learning is achieved simply by the passage of time, or can be accelerated by specific actions.
- In each of these problems, alternatives differ with respect to the flexibility they allow for future actions. For example large reservoirs commit large sums of money irrevocably at specific points in time. Programs of many small additions to abstraction, efficiency improvements, and leakage reduction can be implemented with more flexibility regarding the expenditures in each time period.

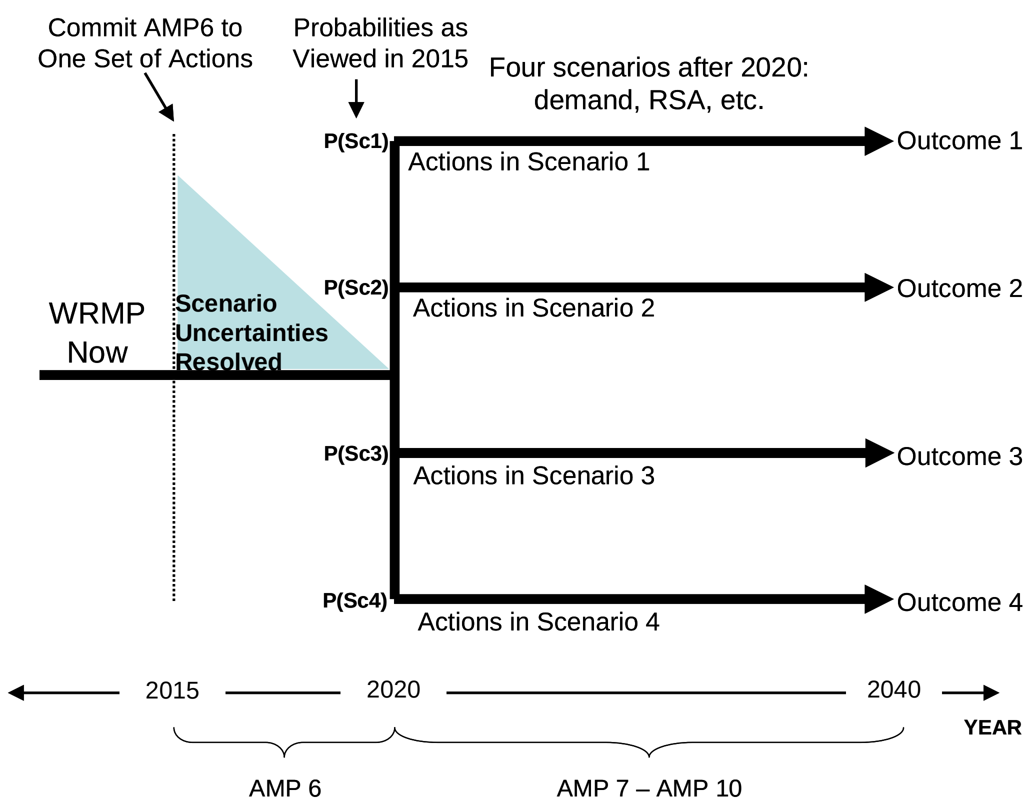
The potential benefits of moving to real options approaches are difficult to scale because they are situation dependent, but in aggregate the benefits could be substantial. For example, if moving to a real options approach enabled the water companies of England and Wales to delay their commitments in such a way that it put all their WRMP capex programs back by one year, this would save some £4,200 million out of the total projected £65,600 million of England and Wales WRMP capex in NPC terms. If instead a shift to a real options approach allowed water companies to reduce all their WRMP capex spending by 2% over the life of the WRMP, this would reduce the NPC by a figure in the region of £1,300 million.[2]

Figure 1 summarizes a “real options” view of the situation a water company is facing in the context of the current regulatory regime. In the figure, the utility is compiling the WRMP for AMP6 starting 2015. It will have to commit to one set of actions during AMP6 but it is uncertain as to which demand it will have to meet over the medium-term. There are four possible demand scenarios, each of which requires different actions to deliver the optimal outcome. The scenario uncertainties will (by assumption in this view) be resolved at the end

[2] NERA analysis of WRMP expenditure projections

of AMP6, after which the company can revise its WRMP given what has been learnt about the scenario for the remaining planning period. This simple real options structure could be implemented by most water companies using current planning tools. This structure avoids the unrealistic extremes of assuming the future is known perfectly (a single **deterministic** future and plan) and assuming that there is no adaptation to future change (a fixed plan, evaluated by probabilistic **simulation** under different futures, but not allowing for adaptation). The simple real options view presented in Figure 1 provides a truer picture of the future to stakeholders and a more accurate valuation of AMP6 actions than the deterministic or simulation approach.

Figure 1
Decision Process



Possible Barriers

The costs of the analysis, public and regulator unfamiliarity, and lack of staff skills and experience are all significant potential barriers to the adoption of probabilistic methods and, specifically, real options analysis.

Costs can be significantly reduced and the benefit/cost ratio kept high if real options analysis is applied in phases. A qualitative review, informed by real options principles, can be used to determine where quantitative real options analysis is likely to have high value. Zones currently not facing a supply demand gap, or apparently not having any flexibility, uncertainty or learning possibilities, should generally not be targets for real options analysis.

Real options analysis will in some cases show that preparation expenditures or risky innovative schemes are worthwhile even where the associated projects have a significant possibility of never being completed. A traditional perspective may view such decisions as being wasteful or as poor management, or may fail to identify that there is time to try a new method. A recognition of the value of such actions as "insurance" or "trials" needs to be developed to stop that sort of thinking being a barrier to better planning.

The ideas in circulation for revisions to the WRMP and SDB guidance (broadly considered), and to the HMT Greenbook[3], as well as the comments in the Thames Water WRMP Planning Inquiry, and the direction of several current or impending studies[4], all suggest that in England and Wales a need for better-structured ways of dealing with uncertainty is increasingly being recognized in water supply demand planning, and at several levels. Real options analysis should be developed in conjunction with probabilistic methods, not ahead of them.

There is a particular issue to address about how best to allow for risk aversion in water planning. Approaching planning with hard supply demand constraints or Minimax type decision rules may mean that the step to real options is less able to provide further insight – the constraint dominates the solution selection. However, measurement of willingness-to-pay and simulation of under-service events is becoming more common. A trend towards placing a value on the supply-demand balance will have significant positive impacts on the quality of the economic evaluation inherent in water planning, and make real options approaches more able to provide insights. So will increased use of scenarios in forming general company plans including Strategic Decision Statements (SDS), and by policy-makers and regulations. And so will a need to consider longer horizons to adequately reflect the uncertainties about climate change, and the way those uncertainties may resolve over many decades.

Gaining acceptance by the wide variety of stakeholders in the water planning process is certainly a challenge. Some appear to be willing to deal with the added complexity of probabilistic analysis. The further step of introducing real options thinking to stakeholders should be a gradual and ongoing process. It should initially be used only where it has the highest and clearest benefits. After demonstrating its value, the approach can then be gradually introduced wherever it has positive benefit. Uptake by water companies will be helped by demonstrations that the analysis is beneficial to them within the prevailing incentive arrangements. A shift towards real options thinking seems well aligned with the current interest in addressing the capex/opex incentive balance and in moving from an outputs focus to an outcomes focus.

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3 See Chapter 2 of HM Treasury Supplementary Green Book guidance on the environment, *Accounting for the effect of climate change*, July 2009, pp.5-13. available at http://archive.defra.gov.uk/environment/climate/documents/adaptation-guidance.pdf

4 See, for example: UKWIR, *WR27 Water Resources Planning Tools Project: Interim Technical Report No. 3*, December 2011; *UKWIR Resilience – Making a Business Case for PR14* – work in progress; Darch, G., Arkell, B. and Tradewell, J. 2011. *Water resource planning under climate uncertainty in London*. Atkins Report (Reference 5103993/73/DG/035) for the Adaptation Sub-Committee and Thames Water. Atkins, Epsom.

Comparison of Real Options to Current Approaches and Recommendations

Table 2
Current Approach Versus Real Options, Issue by Issue

Issue	Current	Real Options
Issues related to decision quality		
Does the method lead to appropriate answers?	Basic method is satisfactory for low uncertainty and low flexibility. Advanced method is satisfactory for some uncertainties only.	Superior in situations with high uncertainty, flexibility, and learning. Recognises the value of flexible solutions.
Uncertainty and learning	Largely ignores learning. Will provide inaccurate NPV estimates where probabilities of events are significantly skewed.	Explicitly recognizes flexibility and learning. Takes into account shapes and interactions.
Detail	Addresses a high level of detail in alternatives. Mathematical programming approaches in particular are capable of looking at millions of combinations.	Addresses a high level of detail in future events, often requires simplification of the range of alternatives.
Issues related to cost of analysis		
Cost of analysis vs. its benefits	Usually less costly. May miss better solutions.	Generally more costly, though an approximate ROA may be cheaper (and better) than very "exact" LP/IP SDB.
Data	Requires a known data set.	Requires additional estimates of probabilities and of costs under alternative scenarios.
Training	Most organizations have skills in place. May need outside support for mathematical programming or other sophisticated analyses.	Requires acquisition of significant new skills or use of outside consultants. The most basic skills can be obtained in combination of 2-3 days training and 1-2 joint projects.
Issues related to communication and acceptance		
Comprehension	Stakeholders familiar with present methods of analysis and presentation. Authorities not always convinced.	Stakeholders may find probabilistic concepts and flexible strategies difficult to understand. Level of comfort rises with experience of both presenters and reviewers.
Completeness	Plans are incomplete and may provide unwarranted assumption of future certainty.	Plans clearly indicate potential future actions and drivers of change.
Clarity	Assumptions regarding risks are not quantified and can be misinterpreted.	Assumptions regarding risks are explicit, lessening chance for miscommunication.

In summary, there are many water supply demand decisions in England and Wales which exhibit the flexibility, uncertainty and learning characteristics necessary to make real options thinking valuable above and beyond deterministic and probabilistic single-plan approaches. The financial benefits, which correspond to lower customer bills, could be substantial in particular cases and in total.

Much of the information and modelling capability needed to apply real options thinking is already held by water companies, and in some cases water company analyses are bordering on a real options approach. A number of parties are looking for a more robust and coherent approach to incorporating uncertainties into supply demand planning – which is what real options modelling provides. Ways to limit the costs of the extra steps necessary and to build experience focusing on the most promising applications are available and should be adopted. Our case examples for stylized situations in England and Wales demonstrate that even very simple applications of the real options approach can generate a richer understanding of the problem and solutions, and find a better overall result.

We consider that the water regulators and companies should begin deliberately to build experience of real options approaches, in a stepwise fashion, by:

Immediate actions

- making it clear that a convincing real options analysis will be well received by the regulators, particularly on large, complex, and contentious decisions;
- encouraging real options analysis of decisions about strengthening links between water companies; and
- undertaking joint training exercises and demonstration cases.

Intermediate actions

- considering how the WRMP guidance, and the SDB scrutiny and incentives which will determine the effects on customers and investors, need to be revised to foster real options thinking where appropriate;
- making preliminary checks, zone by zone at the appropriate point in the next WRMP round, for the presence of the flexibility, uncertainty and learning possibilities that make a real options approach worthwhile. If some companies can use real options thinking to produce optimal strategies in the next round that should be welcomed;
- for subsequent WRMP rounds, revising the WRMP and SDB guidance to suggest application of real options analysis in specified categories of zone-situations; and
- jointly developing common scenario frameworks and common probabilities to use for longer term WRMP work such as climate change uncertainty.

Supporting actions

- developing real options and probabilistic analysis in parallel. Quantitative probabilistic analysis and quantitative real options analysis go hand-in-hand;
- considering long-horizon real options work for long-lived investment, e.g. introducing climate change learning in scenarios for climate drift over several decades after year 25;
- expanding medium-term uncertainty analysis beyond supply and demand forecasting into regulatory, technological, commodity price, and customer response factors. The appropriateness of addressing these other uncertainties should be affirmed; and

- recognizing that placing an economic value on water, in the environment, and on customer water shortage, will lead to formulations which make real options easier to apply, and will also result in more potential for value creation via real options analysis.

1. What is Real Options Analysis?

1.1. Definition of Real Options

1.1.1. Simple Illustration

Real options analysis is an approach to decision making that formally recognizes uncertainty and examines how current decisions limit or expand our ability to learn and react in the future. The real options approach to decision making can be most clearly understood in contrast to alternative approaches. We consider three approaches to analysis:

- Deterministic
- Simple probabilistic, and
- Real options

We illustrate each with a simple figure.

Figure 1.1
Deterministic Analysis

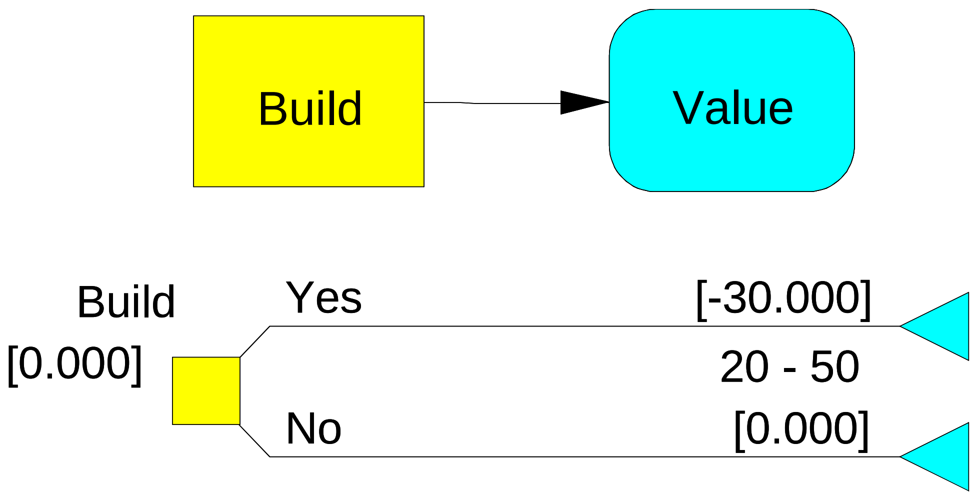

Figure 1.1 illustrates our decision problem in two ways. The top half is an "influence diagram." The influence diagram illustrates the key elements of a decision problem. Here there are two key elements. The yellow box represents a decision, and the blue rounded rectangle represents the value obtained. The arrow indicates that the decision influences or determines the value.

The bottom half of Figure 1.1 is a "decision tree." The decision tree uses similar icons but provides more detail on the problem structure. Again, the yellow rectangle represents the decision. This decision has two alternatives, for example: 1) Yes, Build a new reservoir or 2) No, do not Build a new reservoir. The blue triangles show that each decision leads to a single outcome. In this simple example for Build – Yes, the most likely outcome is that the reservoir costs 50 to build and has benefits of 20, a loss of 30. The Build – No alternative has no cost and no benefits. We choose Build – No and a value of 0. Note that these calculations are shown in square brackets in the figure. We make one set of assumptions about the future and calculate a single value for each of our decision alternatives.

Figure 1.2
Probabilistic Analysis

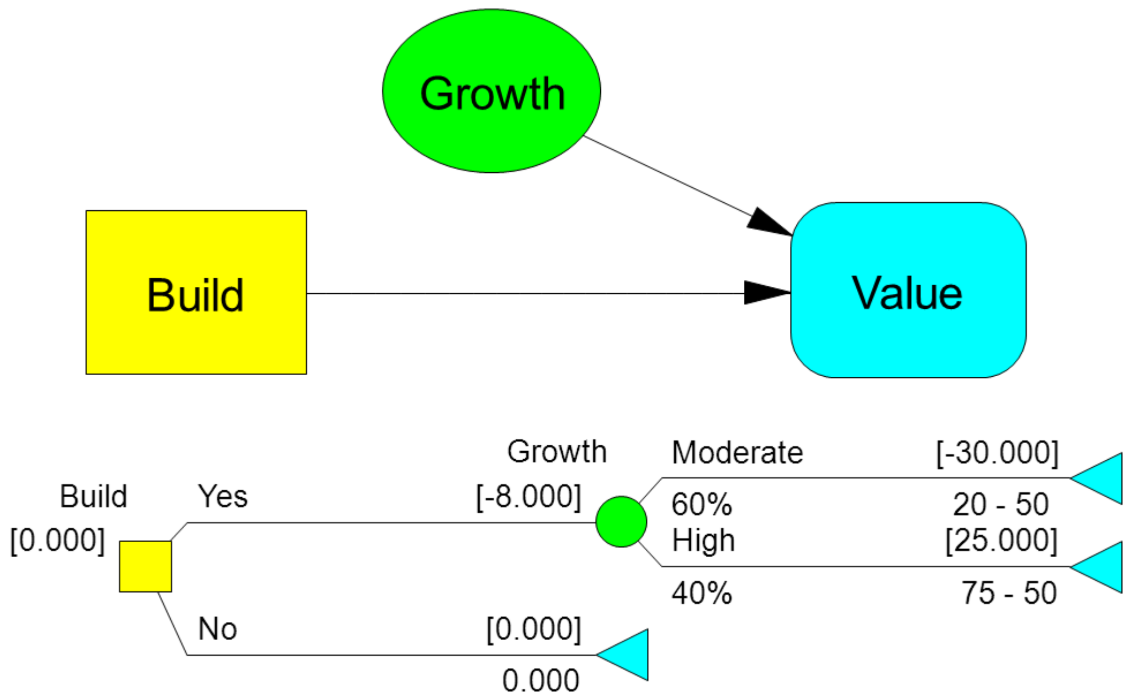

Figure 1.2 introduces a third key element, a chance or uncertainty. This is represented by the green oval. Again, we have an influence diagram at the top of the figure and a decision tree at the bottom. Now we recognize that we can't be certain of the future. The chance represents multiple possible states of the future – in the figure's decision tree, moderate demand growth or high demand growth. Each decision alternative may now produce a range of values influenced by the uncertainty. In this example, the alternatives are evaluated by expected value or the outcomes weighted by their probabilities[5]. If the demand is moderate (60% probability), the value is 20 in benefits minus 50 in cost or -30. If the demand is high (40% probability), the value is 75 in benefits minus 50 in cost or 25. The expected value of the Build – Yes alternative is 0.60 * -30 + 0.40 * 25 or -8.0. Again values are shown at each point in the decision tree in square brackets. While the decision is closer, Build – No, at 0, is still preferred.

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5 Often, the expected value calculation will be modified to account for risk aversion. For simplicity, these calculations are not adjusted.

Figure 1.3
Real Options Analysis

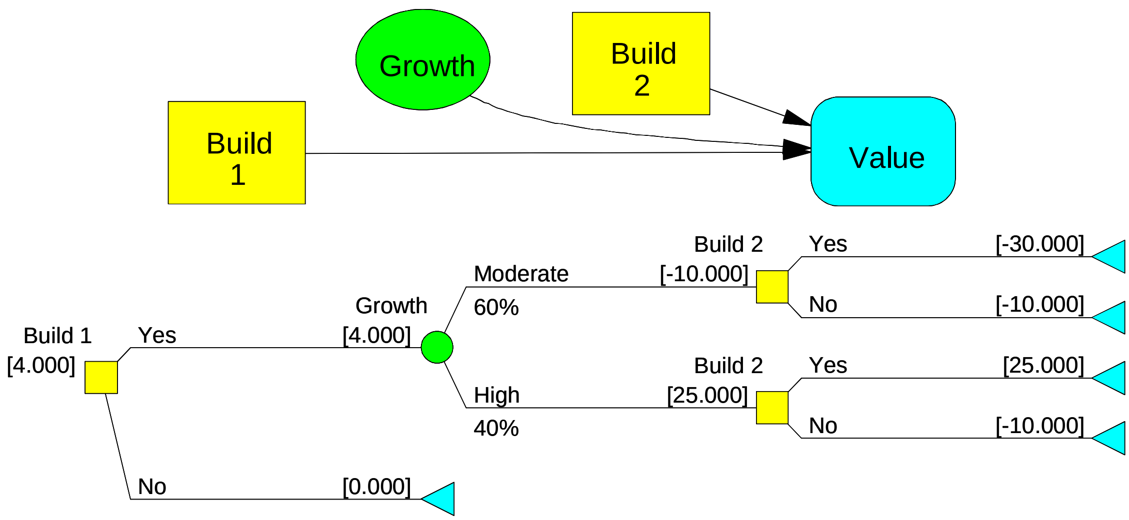

Figure 1.3 introduces a second decision that occurs after the chance. The placement of the decision after the chance is critical. It indicates that we learn something about the chance and can react to this new knowledge. In this model, we assume that we can reserve the right to build the reservoir by buying the land for 10. This is the Build 1 decision. If Build 1 –Yes is chosen, we will spend 10 in all cases. Then we learn about demand growth. For illustration, we make the very strong assumption that we will know the demand growth perfectly before we need to complete construction of the reservoir. If we choose Build 2 – Yes, reservoir completion, we will spend another 40. If we complete the reservoir, values are as in Figure 1.2. If we do not complete the reservoir, we assume 0 benefits. Considering benefits and costs along the Build 1 – Yes path, we have the outcomes shown in Table 1.1.

Table 1.1
Value Calculations for Build 1 - Yes

Growth	Build 2 Decision	Calculation (Benefit - Build 1 Cost - Build 2 Cost)	Final Value
Moderate	Yes	20 - 10 - 40	-30
Moderate	No	0 - 10 – 0	-10
High	Yes	75 - 10 – 40	25
High	No	0 - 10 – 0	-10

If growth is moderate, we do not complete the reservoir. We lose 10 from our land purchase. If growth is high, we complete the reservoir and receive 25 in net benefits.

The expected value calculation is now: 0.60 * -10 + 0.40 * 25 or 4. Build 1 – Yes (4) is now preferred to Build 1 – No (0). We buy the land for the reservoir. 60% of the time the land is not used and we lose 10. However, 40% of the time, we complete the reservoir and obtain significant benefits. If units are £ Millions, real options has saved £4 Million. In our experience, 90% of real options studies for single projects by an experienced consultant fall in the £10,000 to £300,000 cost range. In this simple example, real options analysis provides a ratio of benefits to costs in the range of 400 to 13.

1.1.2. Where is Real Options a Better Approach?

Traditionally resource decisions are made using deterministic or simple probabilistic models. For our discussion of options, we will call the strategy with the highest benefit based on a deterministic or probabilistic analysis the "base" scenario. The additional "option" value of a strategy can be defined as the difference in value between committing to the base strategy and adopting a "flexible strategy" that can be adjusted and updated as new information is revealed. With this new ability to adapt, the optimal initial investment is not necessarily the same as in the single, up front decision case because another initial alternative may offer greater downstream flexibility. Furthermore, since this switching is a right but not an obligation – ie, an option – the additional option value must always be non-negative. That is, the company making the investment always has the right to stay with the base strategy, so having an option to switch cannot decrease the net benefit associated with the project.

There are three necessary conditions for positive option value:

1. First, there must be **uncertainty**. Without uncertainty, there is no need to consider the possibility of switching strategies in the future. The future is known and the best decision under certainty can be made now.
2. Second, there must be **learning**; that is, the state of information regarding uncertainty must change over time. With uncertainty but without learning, the future may not be known but that state of knowledge (or lack thereof) remains constant. There is no reason to postpone any decision-making and the best decision under uncertainty can be made now.
3. Third, there must be **flexibility**; that is, there must be the possibility of acting on the basis of new information over time. With learning but without flexibility, there is no ability to take advantage of that learning and switch strategies.

A few examples of uncertainties, learning, and flexibility in a water planning context are:

- Uncertainty
  - Future rainfall levels
  - Cost of resources
- Learning
  - Better demand estimates
  - Better capital cost estimates
- Flexibility
  - Delay the project

  - Prepare for rapid, low cost expansion

"Option value" is captured when uncertainty, learning and flexibility are incorporated appropriately into the decision-making process. "Real options" is the technique used to calculate this option value and determine the appropriate potentially-flexible strategy on the basis of both the base and option values.

In practice, the term real options is used three ways

- A strategy of constantly seeking to enhance investments by the creation and utilization of flexibility
- The application of a set of tools that can quantify the value of options
- A method of pricing risk based on replicating portfolios or state space pricing[6]

1.2. The General Real Options Approach

The real options approach involves the following steps.

1. Create the *structure* for the problem.

Answer the following questions to create the building blocks for the real options analysis.

- What are the key metrics by which outcomes will be measured?
- What are the current or short-run alternative actions?
- What are the significant uncertainties that will impact the outcomes?
- Is there expected to be learning regarding those uncertainties?
- What longer-run actions will respond to the uncertainties? Do the current alternatives enhance or limit longer-run response to uncertainties? Can new current alternatives create more flexibility?

Is there no 'obvious' best alternative under most/all future outcomes? Or said another way, is there a significant "possibility of regret." (i.e., If I choose A and X happens, will I really regret not having chosen B in the first place?) Will there clearly be learning and significantly different responses? If the answers to these questions are yes, option value could be high and option analysis should be considered.

6 Much of the real options literature is not about uncertainty, learning, and flexibility; but, about the pricing of risk in financial markets. Options have significantly different risk characteristics than most business investments and information from options markets can provide significant indicators of the public's assessments of the risks of an investment or company. For both these reasons, the valuation of risks in options analysis has been a key topic in the literature. However, it does not appear to be of central importance for public water decision making. It will only be dealt with briefly in this report.

2. Develop a *model* of the decisions, uncertainties, and outcomes over time

- Define the decisions and uncertainties more precisely. Even in qualitative studies clear and unambiguous definitions are key to proper communication. Decide on appropriate level of quantification and the size of the model. (Measures of model size will be discussed in later sections of the report.)
- Prioritize the decisions and uncertainties and cut the problem to size. Consider what decisions and uncertainties are dependent (correlation is the most common form of dependence). Timing is a critical issue. Clearly layout the sequence of decisions, learning, and resource commitments. Incorporate the potential for staged investments, acceleration, delay and other flexibilities.
- For quantitative models, pick the tool that will be used to calculate outcome values. (Typically different tools are used to model the outcomes and the decision/uncertainty structure.) Typical tools for outcome modelling are spreadsheets, linear programs, or other models. Program the model keeping in mind the need to calculate outcomes for many different decision and uncertainty values.
- Additionally for quantitative models, pick the tool that will be used to describe the decision and uncertainty levels and interactions. Tools for decision/uncertainty structure are specialized decision tree or simulation software. Program the model keeping in mind the calculation speed of the outcome model.

3. Gather *data* for estimating outcome values in each scenario

- Identify appropriate sources of data considering the audience for the analysis, the resource constraints, and the time constraints for the analysis.
- Gather rough data from low cost and easily accessed data sources. Input this data to the model to perform sensitivity analysis. Focus further data collection on the variables to which the model is most sensitive.
- Gather detailed data for important variables. Analyse available statistics and conduct interviews with experts when statistics are unavailable.

4. Perform *analysis* comparing alternatives and identifying action plans

- Determine the range of value and the expected value of the costs or net benefits for each strategy.
- Confirm the recommendations by validating key results using alternative models.
- Document the results and the drivers of the results

1.3. Specific Approaches to Real Options

1.3.1. Alternative Degrees of Effort in Real Options Approaches

Figure 1.4 maps real options approaches on two axes. The vertical axis is Specificity/Quantification. Specificity/Quantification is low when the analysis provides information, general advice, and raises awareness but leaves the decision maker to weigh and balance the interactions of uncertainties and decisions. Specificity/Quantification is high when the analysis quantifies and combines all the elements of the problem and summarizes the outcomes in a single measure. The horizontal axis is size. A number of measures of analysis size could be used. We think that the number of outcomes examined is a useful measure. Though there are exceptions, number of outcomes generally correlates well with both how many decisions and uncertainties can be examined and how many person-hours are required for the analysis.

The large arrow in the centre of Figure 1.4 indicates that in our experience these two separate measures are highly correlated: the smaller the analysis, the more general the discussion and reasoning; the larger the analysis, the more specific and quantified the reasoning and basis of the recommendation. Assuming this practical correlation allows us to talk about alternative real options approaches along a single line. This is done in Table 1.2.

Figure 1.4
Alternative Real Option Approaches

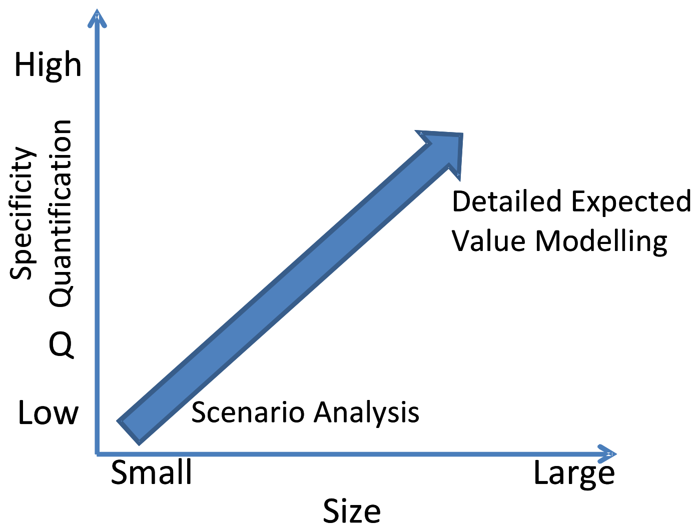

Table 1.2
Alternative Real Option Approaches

Analysis Approach	**Description**
Scenario Analysis	Initial decisions and uncertainties are formally identified. Uncertainties may be ranked and combined into scenarios. There is a formal discussion of the future response to each initial decision – scenario combination. The analysis is usually limited to four to twelve combinations.
Scenario Analysis with Quantification	The analysis is similar in process and size to Scenario Analysis, but some measure of the comparative likelihood of the scenarios and some measure of the comparative benefits or costs of the decision – scenario combinations are made. The CATALYST process is a good example of this approach.[7]
Small Structured and Quantified	The analysis is limited to less than 100 outcomes and only two decision periods are recognized (initial decision and response to one period of learning). Decisions and uncertainties are sufficiently well defined that a formal calculation of outcomes and expected value is made. It is recognized that the analysis is incomplete and that considerable judgment should be used in interpreting results. Specialized software for manipulating uncertainties is not needed.
Medium Structured and Quantified	An attempt is made to quantify all key uncertainties. Multiple decision periods may be examined. The analysis may have millions of outcomes calculated. Specialized software for the management of uncertainty data is utilized. Decision makers must rely on the structure of the model and the input data, because they will have limited ability to trace results in detail. Model outputs are assumed to accurately summarize a large number of relationships.
Large Scale Analysis	Large scale analysis is most often used to optimize resource portfolios. The modelling of individual portfolio items is similar to that for Medium analyses, but the portfolio analysis requires additional software capabilities. Often some customization of standard software is necessary.

1.3.2. Alternative Tools for Calculations[8]

Over the years, numerous tools have been used for real options calculations. These tools differ widely in the assumptions they make, the specific situations where they apply, and the mechanics required to implement them.

At a high level, there are four tools that are widely used for real options analysis. Listed roughly in their order of flexibility, these are:

- Analytic,
- Lattice,
- Simulation, and
- Decision Tree/Dynamic Programming.

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[7] EPRI, CATALYST-A Group Process for Strategic Decision Making: Facilitator's Guidebook, Prepared by Applied Decision Analysis and the Brattle Group, EPRI TR-100583, Research Project 2631, Final Report, Palo Alto, CA: Electric Power Research Institute, 1992

[8] The discussion of alternative tools draws heavily on material in "*Real Options and urban water resource planning in Australia*;" A. Borison, G. Hamm, S. Farrier, and G. Swier; WSAA Occasional Paper No. 20; April 2008; pp. 15-18.

1.3.2.1. Analytic

In the analytic or closed-form method, flexible investments are valued using an option-value equation with a limited number of parameters. This is by far the simplest and most-elegant method, but also by far the most restrictive. The famous Black-Scholes equation is the classic example. It reduces the option value problem to estimation of five (without dividends) or six (with dividends) parameters. Off-the-shelf software for implementing this method is ubiquitous; several Black-Scholes calculators are available online.

The analytic method applies only to simple calls and puts, and is based on very specific market assumptions. Some authors (particularly Luehrman[9]) have argued that this method can be used to value real assets, but the underlying assumptions are so restrictive and parameter estimation is so crude that the results must be used with extreme caution.

1.3.2.2. Lattice

Figure 1.5 illustrates the lattice model of an uncertainty, such as the price of electricity. Steps in the lattice almost always represent time, for example, a day or a month. A lattice is a special, simple form of a decision tree. The key assumption is that the uncertainty (for example, price) moves up or down the same amount at each step. This means that the lattice recombines or an up-down arrives at the same value as a down-up. This dramatically limits the number of output values that need to be calculated in a lattice. Lattices are generally limited to representing one to three uncertainties that evolve regularly over time. Off-the-shelf software for lattices is extremely common.

The lattice method has two advantages over the analytic method. It can handle a wider variety of option types and it is easier to explain. A lattice is somewhat more difficult to implement than an analytic model. Obviously, the lattice depends on very strict assumptions about the form of the uncertainties. Some authors (Copeland and Antikarov[10]) have argued that this method can be used to model a wide variety of real assets. We have found that the restrictions on the form of the uncertainties and decisions severely limit its application to real problems.

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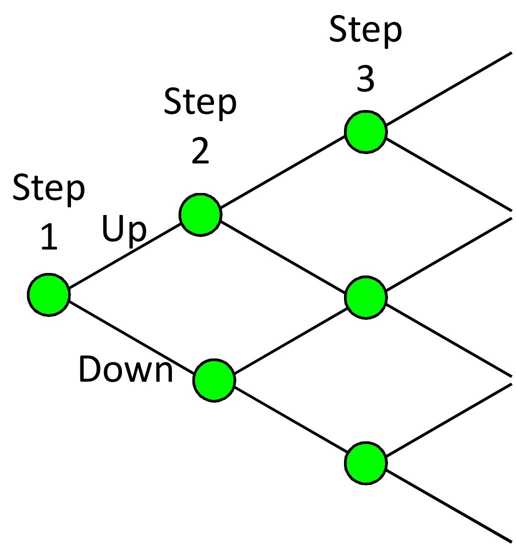
[9] "*Investment Opportunities as Real Options: Getting Started on the Numbers*;" T. Luehrman; Harvard Business Review; July-August, 1998; pp. 3-15 and "*Strategy as a Portfolio of Real Options*;" T. Luehrman; Harvard Business Review, September- October, 1998; pp. 89-99.

[10] *Real Options: A Practitioner's Guide,* T. Copeland and V. Antikarov, TEXERE, New York, 2001.

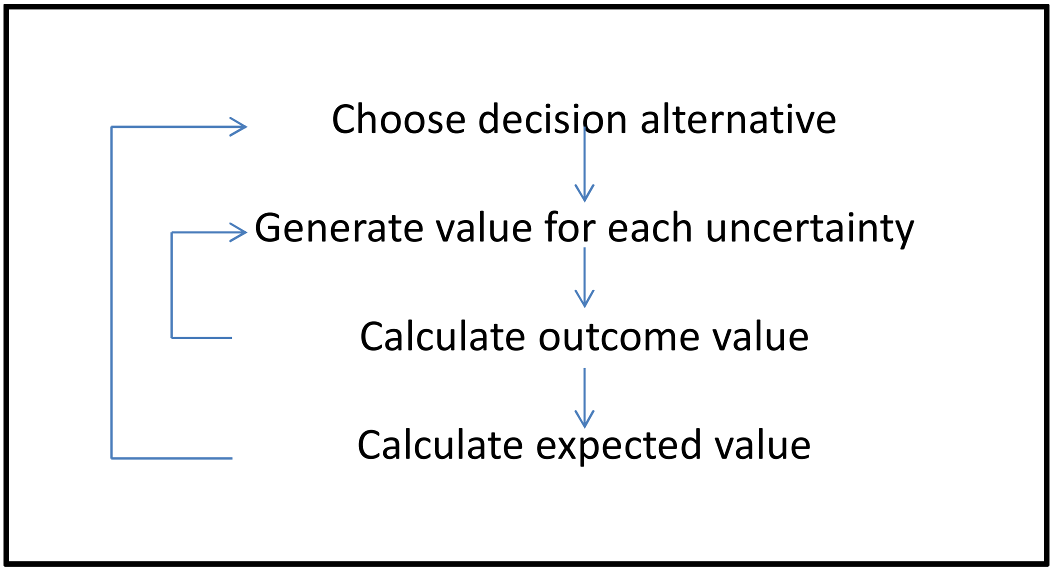
Figure 1.5
Binomial Lattice



1.3.2.3. Simulation

Figure 1.6 illustrates the simulation process. In Monte-Carlo simulation each uncertainty is described by a probability distribution. The outer loop is repeated once for each instance of the decision and once for each decision alternative. Each repetition of the inner loop is referred to as a trial. More trials result in greater accuracy – thousands of trials are typical. If the values for each uncertainty are generated to appropriately represent the underlying probability distributions, the outcomes will represent the probability distribution of their combined effects. When used for real options with multiple stages of decision making the number of outcomes that are simulated grows geometrically. If 1000 trials are used for each alternative, two stages of decision making will require 1 million trials, three stages will require 1 billion trials, and so on. Monte Carlo simulation is a very powerful and versatile approach to modelling uncertainty in decision problems. A number of software products are available to support Monte-Carlo simulation (@Risk, Crystal Ball, Risk Solver, and others).

Figure 1.6
Monte-Carlo Simulation Process



The simulation method is more general than the analytic and lattice methods, and can provide useful results that these methods cannot. But it is considerably harder to implement and to explain. Problem size grows very rapidly and limits its use to either very few trials per simulation or very few periods of decision making.

1.3.2.4. Decision Trees and Dynamic Programming

Decision Trees and Dynamic Programming are the most widely-applicable methods for real options analysis. Conceptually, they are quite easy to explain and understand. They are extremely flexible in their application. They have been applied for many years in the energy sector among other applications.[11] However, because of their considerable generality, they are cumbersome to implement in practice. Evaluating the tree produces an option value, along with a detailed action plan indicating what to do as each individual uncertainty evolves.

Off-the-shelf decision tree software (DPL, Treeage) is available; most dynamic programming applications are custom programmed.

Decision trees and dynamic programming are the most versatile of the tools, but these tools tend to require more expertise and time than other methods. (Note that there is a very significant time versus expertise tradeoff. Experience leads to much faster and accurate modelling.) On the other hand, the tree structure is quite intuitive. Generally, tree models can handle more steps in decision making with fewer calculations than Monte-Carlo simulations. Most importantly, the assumptions fit most potential applications of real options.

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[11] For an example of a simple application see Baker, W.R., Daellenbach, H.G., "*Two-phase optimization of coal strategies at a power station*", European Journal of Operational Research, Volume 18, 1984, pp. 304-314

2. Benefits and Costs of Real Options in General

We feel that virtually any investment problem of more than a few thousand pounds deserves some real options thinking, that is, at least a review of the flexibility, uncertainty, and learning associated with the decision. The difficult questions are how much additional real options analysis is worthwhile, and what kind is best?

For both asset owners and reviewers of asset decisions (regulators, financial investors, and other stakeholders), the "how much" and "what kind" questions are difficult to answer because 1) they will depend on attributes of the both the decision environment and the problem and 2) there are a variety of approaches and with each a range of possible formulations of the decision situation as a real options problem.

This section first describes a basic set of questions that will both lead to real options insights and help determine whether additional real options analysis is needed. The second part of the section outlines the costs and barriers that need to be faced and overcome if a potentially beneficial real options analysis is to proceed.

2.1. The Conditions for Real Options Analysis to have Benefits

2.1.1. Better Decision Making

For any investment larger than a few thousand pounds we recommend conducting the structuring phase of real options. This consists of answering the following questions:

- What are the key metrics by which the eventual outcomes will be measured?
- Are there multiple current or short-run alternative actions that affect these outcomes?
- Are there significant uncertainties that will affect the outcomes?
- Is there expected to be learning regarding those uncertainties? (Either by passage of time, or from deliberate research)

If there is a single short-run alternative, OR no significant uncertainties, OR no expectation of learning; there cannot be any positive option value, so a deterministic or probabilistic analysis will suffice. If however ALL of the three questions are answered yes, then there may be a positive option value, so the analyst should go on to ask the following questions:

- Is there a significant "possibility of regret?" (i.e., If I choose A and X happens, will I really regret not having chosen B in the first place? or vice versa….)
- In the longer-term, are there significantly different responses to different uncertainties? Do the current alternative actions enhance or limit the responses available in the longer-run? Could new current alternative actions be created, offering more flexibility?

If the answers to these questions are yes, option thinking can be significant to the problem and it is useful to record this reasoning as part of the documentation of the decision process. At this point, the first level of real options analysis as described in Table 1.2 is completed. Further option analysis should be considered if the problem is large, say £50,000 or more, and time and resources allow for further analysis.

We note that there may be disagreement over whether undertaking the steps above should be simply labelled "good analysis practice" or labelled "a real options approach."

2.1.2. Additional Benefits

The prior section focused on situations where real options analysis may lead to new strategies with higher expected values or lower expected costs. This is the primary driver for real options analysis. However, real options analysis provides additional ancillary benefits. These include:

- The ability to determine and quantify the benefits of a flexible strategy rather than a single deterministic plan. Often the first step recommended after the options analysis coincides with the first step in the plan found in a deterministic analysis. A superficial accounting might then set the value of the real options work at zero. But many organizations find it valuable to have clear articulation of under what circumstances different paths will be taken in the future. Real options provides a clear indication to stakeholders of when and why actions may change in the future. It identifies key uncertainties to monitor that will signal the change. It provides a fuller description of what the future costs will be under a variety of circumstances.
- A clearer articulation of the basis for decision making. Based on risk, strategies may reasonably differ from the lowest cost plan given by a deterministic analysis. However, when the advantage is left couched in qualitative terms such as "avoiding high risk or large losses" for a "reasonable cost", stakeholders have vague and potentially conflicting understandings of the drivers of the decision. Real options analysis, by quantifying the assumptions around risks and rewards, provides a clearer and more auditable accounting of why decisions are appropriate.
- Ability to calculate value of information. A strength of quantified probabilistic decision analysis, including real options analysis, is the ability to calculate the value of collecting more information or refining a probability estimate. A detailed description of value of information analysis is beyond the scope of this report.[12] Value of perfect information is an extremely simple calculation that shows the maximum value that should be paid to eliminate an uncertainty. The value of perfect information places an upper limit on the amount to spend on information gathering. With an estimate of the accuracy of future research, a survey, a test, an innovative scheme trial or other information gathering activity, a more complex analysis can provide a more definitive estimate of the value of new information and thus support a decision to gather or not gather additional information.

2.2. The Costs of and Barriers to Real Options Analysis

Before committing to a real options analysis for a situation where the steps described under Section 2.1 above have shown it is potentially beneficial, the costs and barriers to the work need to be appreciated.

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[12] More detailed information on value of information can be found in most decision analysis textbooks. See, for example: Skinner, Cavid C. Introduction to Decision Analysis (3rd Edition), ISBN-10: 0964793865, Probabilistic Publishing, Gainesville, Florida 2009

2.2.1. Three Barriers to Probabilistic Analysis

Real options analysis is a subset of probabilistic analysis. The three biggest roadblocks to successful probabilistic analysis are:

- Unwillingness to deal with uncertainty
- Unclear or ill-defined objective functions
- Unwillingness to quantify uncertainty/lack of data

2.2.1.1. Unwillingness to deal with uncertainty

An unwillingness to deal with uncertainty is obviously incompatible with probabilistic analysis and therefore with options analysis.

One source of unwillingness to deal with uncertainty is an unwillingness to accept risks. A related attitude is that the proposer of action should always (and can) be clever enough and spend enough money to make the decision riskless. This is an unrealistic attitude in our view. Hopefully, it is seldom encountered and when it is an explanation of the high costs of attempting to avoid risks altogether can establish a more realistic perspective.

A second source of unwillingness to deal with uncertainty is the assumption that doing this is too complex. A major aspect of this is the assumption that the uncertainty is too complex to communicate to all the stakeholders in a decision. The communication difficulties should not be taken lightly, as it is true that explaining multiple uncertainties and multiple decisions, where both the initial rationale for flexibility and the need for adjustments over time under specific conditions must be conveyed effectively, is difficult. When stakeholders are first introduced to probabilistic analysis, significant extra time must be committed both to preparing the presentation and to the communication (and education) process. The better the analyst understands the analysis the simpler it can be made.

In most studies, a clear and simple rationale for the best path emerges from the analysis. Understanding and acceptance will be aided by identifying the value enhancement and risk reduction benefits up front, and showing how the flexible strategy meets the interests of the community. Finally, modern uncertainty analysis software provides many graphical tools for presenting probabilistic analysis. These need to be used.

2.2.1.2. Unclear or ill-defined formulations (objectives and constraints)

Developing a step formulation of the decision problem is often a challenge in any case, and this becomes more complex when real options thinking is employed.

As for probabilistic work, in real options analysis the objective function will implicitly or explicitly express an attitude to risk as well as to discounting over time, using perhaps the expected value, or using a more risk averse approach and in the extreme maximin.

In a multiple objective decision situation, the real options analysis may need to be undertaken for each objective alone and for various weightings of them, and the optimal strategy may turn out to vary widely with the objective.

When objective functions or constraints are rigid, probabilistic analysis or real options analysis may not be able to provide much extra insight, but it may not be immediately obvious why. For example consider the following problem:

Min E(cS), such that it is always true that Q + S > D

Where:

- E indicates expected value
- S is the new supply quantity, to be decided
- c is the cost per unit of new supply
- Q is the current supply quantity, an uncertain amount
- D is the quantity demanded

The hard nature of the constraint means that S will be chosen based on the minimum value that Q can take. The expectation operation in the objective function will be largely irrelevant. To put it another way, in this formulation the penalty for not meeting demand has been set at infinity even though the objective function is using the expected value.

2.2.1.3. Unwillingness to accept judgmental data

When good statistics are available on all the critical uncertainties, there is seldom an unwillingness to quantify uncertainty. With real problems, however, data on the uncertainties will often be scarce, controversial, expensive, or time consuming to collect.

If no direct sources of data are available sometimes a model based on other sources can be constructed. For example, if statistics on demand growth are unreliable, perhaps statistics on growth in number of customers and in demand per customer are available and can be used to provide a reliable estimate.

In other situations, expert judgments may be the best source of probabilities. It is important to use experts that are unbiased and trusted. It is also important to use a good process for assessment of probabilities.

Judgmental probabilities are generally developed using two well-established techniques. The first is to use a structured **probability encoding**[13] process to assess the opinion of individual experts. The second is to use a structured **expert aggregation**[14] process to combine these individual opinions. These two processes have been used in a wide range of applications both in the public and private sectors.[15]

The probability distributions must satisfy the audience for the analysis. For private decisions, this usually means satisfying one or a few decision makers who have a high understanding of the problem and understand that a decision is necessary (no action is a decision). For public decisions this may mean satisfying a larger number of stakeholders including some that see the explicit uncertainties as simply a weak point in the decision. Needing to meet their needs may increase the costs of data collection and statistical work significantly and in some cases this can make quantitative probabilistic or real options analysis infeasible.

2.2.2. Lack of training and experience in real options

Internal resources with some understanding of real options are needed because without basic understanding of real options it is difficult to determine what type and extent of analysis is justified. The best way to develop a basic understanding is through formal training backed up by case work. With experienced project managers and analysts, a basic level of competency can quickly be gained via study and a few days training with an experienced expert. Basic training should cover basic theory, problem structuring, and provide examples of simple models. More advanced training should cover probability elicitation, model construction, use of specialized software, and presentation of results.

The types of analysis that can be undertaken reliably depend on the level of expertise available.

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13 One of the earliest and best references on probability assessment is Spetzler, Carl S. and Carl-Axel S. Stael von Holstein, "*Probability Encoding in Decision Analysis*", Management Science, 22(3), November 1975, pp. 340-358. For more recent presentations, most decision analysis texts cover the topic, for example, Clemen, Robert T. Making Hard Decisions, 2004. ISBN 0534365973 and Winkler, Robert L. Introduction to Bayesian Inference and Decision (2nd ed.), 2003. ISBN 0-9647938-4-9.

14 Robert T Clemen and Robert L. Winkler, "*Combining Probability Distributions from Experts in Risk Analysis*", Risk Analysis, Volume 19, Number 2, 1999, pp. 187-203.

15 See Keefer, Donald L., C. W. Kirkwood, J. L. Corner, "*Summary of Decision Analysis Applications in the Operations Research Literature*", Technical Report, Department of Supply Chain Management, Arizona State University, 1990-2001, available at http://www.public.asu.edu/~kirkwood/Papers/DAAppsSummaryTechReport.pdf. Most of these studies use judgmental probabilities and many of the studies are by or for government or regulatory authorities. Studies that may be of particular interest are: Balson, W. E., J. L. Welsh, D. S. Wilson "*Using decision analysis and risk analysis to manage utility environmental risk*", Interfaces, 22(6), 1992, pp. 126-139; Borison, A., "*Oglethorpe Power Corporation decides about investing in a major transmission system*", Interfaces, 25(2) 1995, pp. 25-36; Keeney, R. L, D. von Winterfeldt, "*Eliciting probabilities from experts in complex technical problems*", IEEE Transactions on Engineering Management, 38, 1991, pp. 191–201.

Table 2.1
Real Options Capabilities and Skills

Capability	Minimum Training and Experience
Basic: Can construct models with one period, one uncertainty, and one option. Can identify when a fuller real options analysis is justified.	Has two or three days training from an expert. Understands real options concepts, can develop simple decision trees, can roughly structure problems and identify when real options has high potential.
Intermediate: Can independently conduct significant real options projects with multiple periods and thousands of outcome paths. Can very rapidly identify when real options is needed.	Has experience with three or more projects, can use at least one of the common software packages, has done a dozen expert assessments. Does quick back of the envelope analyses regularly.
Advanced: Can conduct real options projects involving portfolios. Can direct teams of analysts and provide training to others. Can solve problems requiring non-standard analysis tools.	Has experience with dozens of projects. Understands several tools and their limitations. Has experience with large scale assessment exercises. Has experience presenting real options analysis to varied audiences.

Lack of internal experience is not a necessarily a road block to more sophisticated real options analysis, as there are consultants with the skills to conduct sophisticated analyses. The disadvantages of consultants are often the costs, a lack of detailed understanding of problem specifics, and the firm not retaining a complete understanding of the analysis when the consultant finishes and departs. However consultants offer the advantages of rapid access to wide experience, an independent view of problems, and an opportunity for skill transfers to internal staff.

2.2.3. Cost (time and money) of real options analysis

Table 2.2 suggests some typical costs in terms of person days for analyses. For all of these estimates, it is assumed that the individual or team conducting the analysis is experienced. Scenario Analysis is often conducted as a team effort. In such cases, less than two person-days per participant is reasonable. The team needs a member for each main dimension of the scenarios, depending on the detail required.

In our experience the largest source of uncertainty in these time and effort estimates concerns data collection. Where extensive probabilistic analysis is already being undertaken, or/and elements for scenarios are available from other research efforts, the extra effort required to quantify a real options model may not be great. We have participated in Scenario Analyses with UK water companies where convincing and helpful scenarios have been developed by a small group in a few elapsed days. We have also participated in studies elsewhere where separate teams of experts have done extensive primary and secondary research on each scenario; the study required approximately 250 person-days. We have participated in a major arbitration in which data were supplied by a four person engineering team, a four person economics team, and a political expert. The project required approximately 450 person days. A project of similar scope with data supplied by internal experts of the organization could have been completed in 50 to 100 person days.

Table 2.2
Costs for Real Options

Analysis Approach	Typical Cost (person days)
Scenario Analysis (by a team)	< 2 per member
Scenario Analysis with Quantification	5 to 24
Small Structured and Quantified	4 to 25
Medium Structured and Quantified	10 to 150
Large Scale Analysis	100 to 1000

2.2.4. Other factors

Several other factors should be considered when determining the approach and extent of real options analysis:

- Many organizations already have standard models for the evaluation of resource decisions. The organization has high faith in these models and has become accustomed to their outputs as a guide to decision making. In these cases, it is often very important that real options analyses integrate with these models. Because of the large number of outcome values that must be calculated in a medium or larger real options model, if standard models are resource intensive or slow to solve, they cannot be used directly within the real options work. A common practice then is to create a simpler model that mimics the performance of the larger model over some region of interest. Also, it is important to check the results of the real options analysis with the standard model.
- Real options work is sometimes considered to be purely additional effort. Much of what is required for a real options approach should already be common practice so the incremental effort may not be great – but the incremental benefit needs to be elaborated. Also, real options approaches will provide a new perspective on the relative importance of different factors in decision making, and this new perspective may lead to significant simplification of prior work, ultimately producing a saving in analytical effort. For example, when probabilistic analysis indicates that the standard deviation is in the millions of pounds, organizations may decide to simplify currently detailed models that calculate quantities to the thousands of pounds.
- Organizations that have worked with real options for some time may very quickly identify that a particular decision needs a major real options evaluation. But more commonly, real options work proceeds by stages. First, a Scenario Analysis, or Scenario Analysis with Quantification, is done. If this indicates that regret could be in the millions of pounds, the organization moves on to discuss a quantitative real options analysis with their in-house or consulting expert. A preliminary analysis with readily available data might then be undertaken. This analysis might be conclusive or might indicate the value of additional data gathering or more detailed real options modelling, for example with more granular time periods or sizes of options.

3. ROA in Water in England and Wales

Our discussion of real options above emphasized that three elements must be present for real options value to exist: uncertainty, learning, and flexibility. The potential benefits also increase with increases in "size"; i.e. in the value or consequences of the decision. In this section we first briefly review the current water planning process in England and Wales to identify some prime situations where decisions about water supply and demand must be made. We then examine the level of uncertainty, learning, and flexibility that is present in these decision situations, leading on to a preliminary identification of where real options approaches are most likely to add value.

3.1. Supply Demand Decisions Requiring Substantial Analysis

In this section we provide a broad outline of the processes governing supply and demand decisions by water companies in England and Wales to help identify where moving to real options thinking might bring benefits. Consistent with our terms of reference our focus is on planning and decision-making by today's integrated water companies, not on any broader effort aimed at identifying the best plans or policies for the sector as a whole including other abstractors.

3.1.1. Forming long term plans

We first consider the formation of water company long term supply demand plans. Real options analysis allows a movement away from deterministic plans, towards setting long-term strategies in which water companies build the value of choice into their investment decisions.

The key documents in which water companies communicate their preferred plans to regulators and the public are the Water Resource Management Plan (WRMP) - which must be formed and submitted by each appointed water company according to statute law - and the Supply Demand Balance (SDB) submission. The specified WRMP planning period is 25 years (i.e. the WRMP must address how the company is going to balance supply and demand in each zone for the next 25 years), and a new WRMP must be submitted every five years.

The WRMP is an integrated plan covering all the company's decisions/options on both the supply side and demand side, relevant to their supply-demand balance. It must conform to the guidelines set out in the most recent update of the EA's "Water Resource Planning Guidelines" (1998, latest update April 2011).[16] A real options analysis could easily be adapted to these time frames with one or more strategy revisions at five year intervals and a 25 year time frame, as suggested in Case 1 below.

The WRMP guidelines cover links with some other relevant statutory approvals processes such as Strategic Environmental Assessment (SEA). They also cite other more detailed work on how companies can or should approach the supply demand balance, notably the joint

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16 Water Resources Planning Guideline, The Environment Agency, April 2011

EA/UKWIR reports "The Economics of Balancing Supply and Demand" (2002), and “An Improved Method for Converting Uncertainty into Headroom” (2002).[17]

As well, the water sector economic regulator for England and Wales, Ofwat, requires each appointed water companies to submit various reports in advance of its price cap review on a five yearly cycle[18]. Ofwat also requires companies to submit detailed business plans which justify all projected capital expenditures. While the main focus of business plans is on the next five or ten years, within the business plan there must be a 25 year supply demand (SDB) plan, setting out the projected expenditure on schemes or programs of work addressing the supply-demand balance, and showing the results in terms of levels of service for water customers. Bigger schemes or programmes may be phased so that the justification for proposed preparation or piloting work in the first five years can be examined separately.

Each appointed water company must therefore form a 25 year plan and convince the EA, the Minister, Ofwat, and potentially a Planning Inquiry and/or the Competition Commission (at least) that it is justified.

As stated above, in forming their 25 year WRMP and SDB plans the water companies conform with EA guidelines and Ofwat guidance at the time respectively, informed by a related set of more detailed materials which has evolved substantially over the last fifteen years. The materials are continuing to develop, with several projects (apart from this one) currently considering where new supply demand planning practices might be worthwhile.[19]

Currently the supply demand planning practice may be described in a stylised way as follows, though practice differs from company to company and situation to situation. Unsurprisingly, companies vary the scope and depth of their analysis to match the perceived complexity of the decision situation and the possible consequences in terms of customer service, environmental effects, or financial implications. This variation is reflected in the cluster of SDB guidance, for example the EA’s recent climate change report suggests a “risk based approach” which suggests that companies with a particularly sensitive and expensive SDB are carrying out more complex analysis.[20] This risk based “tailoring” approach is appropriate for real options in general, with fuller real options work required for those companies with SDBs with especially large possibility for regret.

To form its WRMP the company makes a plan for each water resource planning zone (WRZ). For each zone the company projects household and non-household demands for water, and projects the water available from existing facilities, over 25 years, on the assumption that defined dry conditions occur each year or occur in a defined “critical period” each year. The company also considers the uncertainties in these projections and from them calculates the “headroom”, or excess of projected supply capability over projected demand, that it considers it must have each year to provide adequate security of supply for customers.

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[17] Chapter 5 in Water Resources Planning Guideline, The Environment Agency, April 2011, pp. 2-4

[18] Currently (March 2012) the review cycles are being considered and may change in the future.

[19] See, for example “*Customer Behaviour and Water Use Project CU02*”, Working Paper for UKWIR Series, October 2011

[20] “*Climate Change Approaches in Water Resource Management Planning – Overview of New Methods*”, EA/HR Wallingford, (forthcoming), pp. 64 – 69.

However we have not seen use of the screening suggested in section 2.1 above, where flexibility, uncertainty, learning and regret are checked to see if a real options analysis might be beneficial for the zone. This screening is consistent with, but not specified in current WRMP guidelines. It could be introduced to the current process fairly easily using current data initially.

For zones where the projected water available is less than the projected demand plus headroom, meaning that a supply demand gap exists, the company looks for extra capacity or demand side reductions. Starting with a long list of options on both the supply and demand sides, the company applies filters for the feasibility of options and for their relevance to the particular gap identified. The company then seeks the set of options and implementation dates which will fill all supply demand gaps for the zone at least cost. This least cost solution may be modified in a refinement phase described below. This schedule of options to implement over 25 years is the company's preferred plan.

The use of headroom is a very simplistic and deterministic way of accounting for the possibility that uncertainty resolves in such a way as to require more future capacity. A full real options approach would anticipate possible future states in which there is a deficit, and, based on the likelihood of being in any given state, calculate the benefits and costs of waiting to learn that such a state has been realised or at least became more likely. A full real options approach could completely substitute for the use of headroom as it includes in its valuation the possibility of being in an unlikely state. However, such a full analysis would require many different scenarios which may be expensive and complex. Therefore instead a smaller number of relevant states could be identified. If some of the included states were the worst case scenarios for given uncertainties then this effectively does the job of headroom and would allow headroom to be dropped. However, a gradual introduction to ROA is advisable as it is a technique new to the industry, so an approach which combines real options and headroom would suit best at first.

Table 3.1 contrasts the current process and a real options process. The real options assumptions on additional planning costs do not consider savings from reduced plan reworking over time which is expected with more flexible strategies, or savings from using less granular options. The assumptions on frequency and value of cost reductions are considered conservative.

Under the current guidelines the substantial uncertainty about water availability due to the weather (from month to month, and year to year) is taken account of by measuring the water available from each supply facility in defined dry conditions; i.e. the Deployable Output of a scheme is measured for (say) a one-in-fifty year return period, meaning that that much water availability or more will occur in 49/50 future years or critical periods. Generally the historical flow records or probability distributions fitted to them are the basis for this measure. Uncertainty about other factors, and about the projections – including whether the distribution of future water availability will be like that of the past - is taken account of through the headroom allowance.

When substantial new capacity is needed, generally the company follows the guidance and makes an exploration of variations on the preferred least cost program of schemes, starting with an "optimal" least cost program identified by simple AISC cost-ordering of schemes or by LP/IP optimization methods, including extensive sensitivity analysis covering all inputs.

Table 3.1
Current WRMP Contrasted with RO Approaches

Current Planning Step	Revised Step w. Real Options
Examines supply demand balance in each zone	Same process
Calculates headroom for each zone, increasingly this is calculated based on Monte Carlo simulation	Monte Carlo simulation and willingness-to-pay or revealed preference data used to determine expected value to exceed headroom and expected cost of any shortfall
Develops long list of potential supply increases and demand decreases	Same process
Gathers information on costs and likely supply or demand reduction levels	Same process
Screens list based on costs and implementation barriers	Same process
	Additional data gathering to determine probabilistic costs and supply or demand reduction levels.
Chooses options based on AISC benefit/cost ratio or mathematical programming solution	May be framed as a few scenarios with same analysis process over scenarios. May be framed as tree with many branches. If framed as tree, may require definitions of distinct alternative solutions to reduce the number of options examined.
Provide stakeholder report with qualitative discussion of risks and strategies	Provide stakeholder report with quantified assumptions about risks and specific strategies responding to risks over time. May also provide indication of value for additional information gathering.
Planning cost for small simple zone £50k Planning cost for large complex zone £500k	Assume 30% additional planning cost Added cost for small £30k Added cost for large £150k
"Typical" NPV plan cost for small £10m "Typical" NPV plan cost for large £100m	Assume 20% savings, 20% of the time. Cost saving for small £400K Cost saving for large £4M

The inadequacy of AISC ordering in complex situations is increasingly understood, with LP/IP methods increasingly used.

The current guidance does not stop at deterministic approaches. It suggests that in an advanced analysis a Monte Carlo simulation should be undertaken to identify the level of security of supply that the preferred program is projected to deliver year by year, so that this projected level can be cross-checked with the security level customers are willing to pay for. However, as far as we know this probabilistic step has not often been undertaken as part of WRMP work, though some companies at least simulate their operations under a range of weather conditions with each intended capacity increment.

Uncertainty is also implicitly allowed for in that a rolling planning approach is being applied, so that better measurements and new information about current and projected conditions is introduced at least every five years as the whole WRMP/SDB analysis is repeated.

The above discussion shows that it is not part of current general water planning practice to consider and optimise over explicit strategies for implementing schemes and programmes depending on evolving information, such as might be developed with decision tree structures or the like in real options fashion. Instead the work focuses on 25 year plans, derived in a deterministic way for a defined "poor case" situation, with a lot of sensitivity testing.

The Thames Water WRMP Planning Inquiry found some shortcomings of WRMPs in the current general water planning practice. The Inquiry did not view the treatment of long-term risk as sufficiently rigorous to justify investment, saying the company: "…should undertake a more sophisticated approach to sensitivity analysis.[21]" The Inquiry report called for a more robust approach to uncertainties: "The work required to implement EA4.2 (more sophisticated sensitivity analysis) would enable a range of scenarios to be tested, with a choice of options identified which could then meet the deficits identified within those scenarios. Those options which are identified as having the potential to meet different levels of deficit resulting from SRs, could then be subject to further work.[22]" Adopting a real options approach would help to meet this recommendation.

However some frontier long term planning work by England and Wales water companies, such as that undertaken recently by Thames Water as part of revising its WRMP and considering the merits of a large new reservoir or large inter-basin transfers, is in fact bordering on applying a real options approach. This work[23] took a similar basic approach to the formation of a WRMP as described above, but considered a much longer horizon, and drew on three scenarios for the distribution of water availability (i.e. the distribution of water available having a relatively low, medium, or high mean) created by UKCP to show long term climate change possibilities. Each scenario as to the water distribution is based on a global CO2 emissions path, and UKCP does not specify probabilities over these driving CO2 emissions paths. Thames identifies a good investment plan for each long-range scenario and considers how the plans differ between scenarios, noting that the early years' investments are the same in each plan.

However as far as we know the recent Thames work has not taken the extra step to a formal real options approach, which would require placing a subjective probability measure across the three CO2 scenarios, and then deriving the implied optimal supply demand strategy. For example it could be simplistically assumed that the climate path uncertainty will fully resolve, leaving us on one CO2 path or another, each with a postulated probability, in (say) 25 years time. The best strategy would then comprise the best single set of schemes before year 25, and the best set of schemes for each scenario after that time and after the initial schemes have been implemented. The sensitivity of the initial best step to the assumed climate path probabilities could be explored.

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21 Paragraph 13.2.13, Inspector's Report Thames Water, 13th December 2010.

22 Paragraph 14.7.2, Inspector's Report Thames Water, 13th December 2010.

23 See Darch, G., Arkell, B. and Tradewell, J. 2011. *Water resource planning under climate uncertainty in London*. Atkins Report (Reference 5103993/73/DG/035) for the Adaptation Sub-Committee and Thames Water. Atkins, Epsom.

3.1.2. Appraising implementation of individual schemes or programs

The second decision-situation we briefly examine is where the merits of undertaking an individual scheme need to be considered, with the prevailing WRMP providing context.

Specific resource schemes – whether they were in the WRMP or SDB plan or not – are likely to require further specific legal permissions, notably planning permission (for example to devote land to a reservoir or treatment works or pipeline), or permission to take water from groundwater or surface water sources. These permissions must be pursued separately and will require their own justifications to the relevant authorities. The scheme being an element of a company's WRMP may be treated as a necessary condition by the authority but is unlikely to be a sufficient condition for the permission to be granted.

Other supply demand schemes or programs, such as leakage reduction programmes (perhaps involving substantial road-works and traffic delays) and metering programs (perhaps involving change in the billing methods, tariffs, and bill levels for many households), may not require planning permission but still need to be justified individually by water companies to a range of parties including central and local government and consumer bodies.

In most water companies an increasingly rigorous sequence of internal investment appraisals is used to test the worth of each individual scheme or programme as the intended implementation date approaches.

New information may arise at any time, including suggestions for schemes or programmes to address supply demand issues which need to be appraised sooner than waiting for a full re-consideration of the WRMP.

In appraising individual schemes or programs, company practice varies substantially to match the justification required. For most significant supply demand schemes or programs, which will usually cost millions of pounds, companies tend to treat the appraisal similarly to the latter stages of a WRMP exercise, comparing the merits of the scheme with the main alternatives in the conditions of the relevant zone or zones.

Compared with WRMP more details on the implications of the option are likely to be developed and considered, for example the expected operating costs are likely to be estimated across the full range of weather conditions instead of just for a dry and a normal year. The position of the scheme within the regulatory frameworks will be considered – whether it was listed in the WRMP and SDB, how the expenditures on it will affect the company finances before and after any regulatory mechanisms operate, whether it will produce the anticipated service improvement for customers. Wider aspects and criteria such as impacts on capital maintenance schedules, carbon impacts or planning gains may be considered in much more detail. The timing of the option will be considered in more detail as well.

The impacts on the option of changes controlled by others are likely to be more fully considered, along with possible mitigations. For example the merits of a resource scheme may depend on the likelihood that "restoring sustainable abstraction" (RSA) abstraction license reductions will affect raw water availability in the medium-term, and further information on this likelihood may be sought from the EA.

Our understanding is that in these appraisals it is common practice for companies to treat uncertainties as described for WRMP above, and with further sensitivity analysis, with more use of expected values, and by deeper consideration of possible dependencies and ways of mitigating downside risks. Sometimes the consideration of timing dependencies means this analysis is effectively applying a real options approach.

However we do not know of any cases in England and Wales where the appraisal has been explicitly framed as a real options exercise.

3.1.3. Operational decision-making

The third context for water supply demand decisions where there may be potential for RO thinking is in operations. It is well known that some supply demand decisions arising in water operations inherently require substantial analysis of uncertainty due to the weather and its effects on rainfall and inflow to surface water storages or to aquifers.

Examples include proposals to change the control curves and thereby the yield of a reservoir, or the reservoir-stock-levels at which drought restrictions are invoked, or to change the rules governing abstraction from a stretch of river. These changes may have substantial effects on the environment, on security of supply, or on company finances, and so need substantial appraisal and possibly an application to the authorities.

Formal applications to the authorities by water companies wishing to use special powers in drought situations (e.g. to take more water from a river, or to restrict customers' demands) need to be accompanied by substantial analysis showing why the exercise of the power now is necessary to avoid a possible worse outcome later – with an explicit treatment of the changed likelihood of the poor outcome. The borders on a real options approach.

Water companies wishing to minimise costs will often need to balance possible immediate cost reductions with an uncertain range of possible future outcomes (e.g. some chance that maximum use of a cheap source immediately will lead to more use of a much higher cost source in a few months if there is low rainfall or inflow in the interim period). This implies real options thinking will be beneficial.

In approaching these operational decisions companies in England and Wales typically apply simulation modelling to understand the uncertainties. Simulation of operations across a distribution of possible weather outcomes, with derivation of extreme value likelihoods and expected values, is commonplace. So is optimisation of operating rules and decisions through many iterations which examine the change in the simulated effects when the rule or decision is changed.

However structuring decisions in a tree for solution by backwards recursion, and other variants of dynamic programming methods, are not in general use as far as we know. Water operations practitioners rightly have substantial scepticism about any operating solutions derived from "black boxes" – companies take a highly risk averse approach to the possibility of inadvertently adopting rules or decisions which might lead them to need to invoke severe water restrictions more often than otherwise – so simulation of any such rules is the norm. In our view this is wise, nevertheless real options approaches can help find good rules.

3.1.4. Contexts where in some cases real options may bring benefits

We have considered above three contexts for water supply demand decisions: forming long term WRMP or SDB plans; appraising substantial individual schemes or programs; and operating water supply systems. In each context there may be situations where there is sufficient flexibility, uncertainty, and learning for real options thinking to bring substantial benefits over and above applying deterministic or probabilistic approaches. That is, in each context there are situations where adopting a strategy – where the projected optimal decisions explicitly depend on what is learned in the interim – might be notably better than adopting a set plan. In those situations there may be substantial benefit from moving from considering plans with deterministic models and sensitivity analysis, to considering strategies with a real options approach.

As noted in section 2.1.2 Additional Benefits, real options provides a fuller description of uncertainty and strategy, a better documented strategy argument, and can clarify the value of information. The fuller description of uncertainty may make stakeholders more comfortable with lower levels of headroom. Certainly, making uncertainties explicit and making the assumptions about the costs and benefits of higher and lower levels of headroom explicit should lead to greater clarity in discussion of appropriate levels of risk for under-supply.

Real options thinking could also help clarify the importance of uncertainty regarding climate impacts on headroom and the value of better climate information for water utilities (via value of information analysis), though a longer horizon is probably needed to reflect the likely slow resolution of climate uncertainties over decades rather than years.[24]

3.2. Water Supply Demand Decisions and Uncertainties

Table 3.2 below lists examples of decisions that we think will often involve sufficient flexibility, uncertainty and learning to make real options thinking beneficial.

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[24] See, for example: Arnell, N. W., Charlton, M. B., *"Adapting to the effects of climate change on water supply reliability"*, in Adger, W. N., Lorenzoni, I., O'Brien, K. L., Adapting to Climate Change, pp. 42-53, 2009

Lopez, A., Wilby, R. L., Fung, F., New, M., *"Water for people: Climate change and water availability"*, in Fung, F., Lopez, A., New M., Modelling the Impact of Climate Change on Water Resources, pp. 128-135, 2011

Lopez ,A., Fung, F., New, M., *"The case studies"*, in Fung, F., Lopez, A., New M., Modelling the Impact of Climate Change on Water Resources, pp. 136-182, 2011

Lopez, A., Fung, F., New. M., Watts, G., Weston, A., Wilby, R., "*From climate model ensembles to climate change impacts and adaptation: A Case study of water resource management in the southwest of England"*, Water Resources Research, Volume 45, 2009

Von Christierson, B., Wade, S., Counsell, C., Arnell, N., Charlton, M., Prudhomme, C., Hannaford, J., Lawson, R., Tattersall, C., Fenn, C., Ball, A., "*Climate change approaches in water resources planning – Overview of new methods"*. A study for the Environment Agency.

Watts, G., *"Water for people: Climate change and water availability"*, in Fung, F., Lopez, A., New M., Modelling the Impact of Climate Change on Water Resources, pp. 86-127, 2011

Table 3.2
Water Supply Demand Decisions

#	Example	#	Example
	Long term strategy examples		**Demand management examples**
1.	Identify (& implement best early steps in) optimal long-term strategy. Strategy is company's, or statutory WRMP, or SDB	10.	Implement the next tranche of leakage reduction; e.g. real time pressure control, pressure reductions, mains replacement
	Resource management examples	11.	Sign price reduction contract where a large customer agrees to be interruptible for three months in a drought
2.	Acquire land and apply for statutory Planning Permission for a large reservoir	12.	Implement household water metering and volumetric charging programs
3.	Give construction go-ahead on a large new reservoir		**Flexibility scheme examples**
4.	Renew an "ordinary" resource scheme (abstraction, treatment, connection to the network) where RSA reductions may occur	13.	Build a new interconnector between neighbouring resource zones or with the neighbouring water company
5.	Cut annual abstraction by 10 Ml/d on a particular river	14.	Implement "resilience" schemes such as twinning or ringing of trunk mains to lower non-supply risk (rather than provide capacity)
6.	Take a lease, with an early termination clause, on an extra water abstraction right		**Operations examples**
7.	Appraise an innovative scheme e.g. for the water company to build on-farm storage, used by farmers most years but by the company in drought years	15.	Identify control curves for operations, or for drought plans e.g. as stocks dwindle in a drought, at what point do you: start to use more expensive sources such as desalination or long distance pumping; start savings campaigns etc.
8.	Appraise a desalination plant intended for occasional last-resort use to cut risk	16.	Initiate service reduction for large customer under interruptible contract
9.	Construct a desalination plant	17.	Introduce water use quantity restrictions

Most of the examples above have occurred recently in England and Wales with decisions involving millions of pounds of capex or/and opex, or involving customer service or environmental impacts valued in millions, in each case. They will often involve sufficient flexibility, uncertainty and learning for there to be potential benefits to a real options approach. We draw attention to just a few aspects of the numbered examples:

- Case 1. Forming any long term plan for water supply, including the statutory WRMP, will require choices among a variety of flexible and inflexible options.
- Case 2. Land acquisition and permitting are examples of actions that "buy" future flexibility. These may be particularly important when sites are limited or regulation may change permissible land use.
- Cases 3 and 9 are large, capital intensive actions to develop significant resources. Development of these large resources might be staged with some extra cost: both by staging the commitments as suggested by Cases 2 and 8; and perhaps by allowing initially for extra capacity upsizing at a later stage, not shown in the cases. Is the flexibility of the

staging worth it? The more granular capacity from Case 10 may be more expensive - is the extra timing flexibility worth it?

- Case 5. The cost and benefits of a permanent reduction might be compared to a flexible reduction where a lower average abstraction is imposed but higher levels may be taken in some years. How much is the extra flexibility worth?
- Case 6. Termination flexibility is very comparable to a financial put option.
- Case 7 and 8. Appraisals and research are often low cost opportunities for learning. Such actions can have very high option value versus cost.
- Case 10. Demand management actions can often be made very incremental in nature. Thus even when they look expensive on a cost per m^3 basis, option value may make them a preferred choice.
- Case 11. Again, a contract with volume flexibility is a clear option: what is the flexibility worth?
- Case 12. Price signals are extremely flexible. It is difficult to compare their value to other approaches without recognizing the differences in flexibility.
- Case 13 and 14. While not addressing the supply-demand balance directly, flexibility created by higher levels of interconnectedness creates value than can be estimated by real options. So can the flexibility created by extra storage.
- Case 15, 16, and 17. Operations that preserve resources, preserve flexibility. What is the value of the flexibility?

As suggested in 2.1 The Conditions for Real Options Analysis to have Benefits above, some consideration of real options is appropriate for most significant resource investments. While emphasizing the uniqueness of each situation, we understand the desire to identify the most likely cases where more formal real options might provide value. Based on our experience, there are two areas where value is highly likely.

1. Quantitative real options analysis often provides new perspectives on major investments such as reservoirs, desalination plants, and large pipelines. These large investments with up to 80 year lives tend to be highly committing, or very **inflexible**, which implies substantial possibility for regret It is important to determine if more flexible alternatives, even if more costly, provide greater value.
2. A significant investment whose main purpose is to create options or flexibility is often hard to justify without real options analysis. These investments would include acquisition of property for later use, investment to speed or lower the cost of resource expansion, R&D or other activities specifically targeted at learning, and contracts with options clauses such as rights to terminate or extend, and perhaps a desalinisation intended to run occasionally.

We illustrate this first situation in section 6.2 Case 1 for England and Wales Water, and the second in section 6.3 Case 2 for England and Wales Water.

Table 3.3 below lists a number of important uncertainties, where learning opportunities may make a real options approach worthwhile.

Table 3.3
Relevant Uncertainties

Category	Example Uncertainties		
Water availability	Weather or inflows up to two years ahead, from any starting year	Climate change "trend effect" on inflow mean and/or variance	Impact of abstraction reduction policies such as RSA
Water demand	Base Population and Forecasting growth	Change in household composition in future	Growth in public, commercial and industrial activity in future
	Change in seasonal use patterns	Impact of water sector structural changes such as competitive retail	Efficiency of water using appliances and processes
	Price level changes and responses to them	Pricing signal changes: metering, rising block, seasonal etc.	Responses to conservation messages and drought reduction requests
Water supply feasibility and capex	Construction work required and input costs	New technology feasibility and cost; e.g. membranes	Cost of capital
Water supply opex and capital maintenance	Taxes including abstraction taxes or shadow prices	Operating input costs including energy costs in future	Savings in system-wide opex and capital maintenance
Regulatory and social factors	Planning permission and abstraction licenses	Recovery of costs of investments & of optimal but unused options	Carbon costs and permits

Many of these uncertainties are in the base numbers or are inherent in the need to make forecasts. In many cases, the uncertainty will resolve if we wait to observe the outcome – but we may not be able to react very quickly or costlessly to the revealed situation. Real options analysis does not reduce the level of uncertainty, but it provides insight into how much should be invested in the ability to respond to different possible outturns, and how much spending to reduce the uncertainty is worthwhile.

In England and Wales the importance of the uncertainties listed above varies from zone to zone: raw water is already very scarce in some places today; the main source is groundwater in some places, surface water in others; growth in population and in economic activity is expected to be much higher in some places than others; some of today's zones are large and well connected, others small and isolated. The potential for learning varies a lot accordingly. Despite this variation we draw attention to a few aspects of uncertainty and learning that seem generally important:

- Water availability. In this area there are at least two layers of uncertainty about the weather. The first and obvious point is that water availability varies unpredictably with rainfall and inflows. We do have a long record from which to predict the characteristics of the uncertainty, but predicting the risk of the extreme events in the tails of the distribution has always been a challenge, and these drought events are ones that matter a lot to supply demand plans.

- Climate change has introduced a second layer of weather uncertainty to water availability. This layer is uncertainty about the continued relevance of the historic record. A great deal of effort is being committed to studying climate change, as for example in the UKCP projections of the distribution of rainfall events over 80 years[25], so we might think that learning in this area is likely to be significant in the coming years. However, the timing and nature of this learning is not at all clear. UKCP provide scenarios for the distribution of rainfall, each driven by a global CO2 emissions path, but do not provide probabilities over those CO2 paths.
- Also, predicting future rainfall distributions at the local/seasonal degree of granularity ideally required for water planning is a massive scientific challenge – the best current global climate models are based on much larger regions, and there are some dynamic processes such as storm tracks which are very important to local rainfall but which are amongst the hardest things to model. We cannot presume that advances in climate science to better model the climate processes will lead to a "narrowing down" of the relevant rainfall distributions, and on the contrary it is possible that for the next 20 or 30 years or more the best view of the ultimate rainfall distribution possibilities will widen, even though passage of time must narrow down some important associated information such as the CO2 emitted to date.[26]
- Real options analysis does have a very important role to play in ensuring WRMPs are fit to deal with climate change uncertainty, as was noted by the EA who effectively called for real options analysis labelled as "adaptive management processes" in their review of climate change approaches. The EA stated that adaptive management processes are needed to ensure "that decisions made now about the future can be adapted in time as the future becomes more certain[27]" which is the key attribute of a strategy found by applying real options.
- EA analysis suggested that looking forward to 2040 about a third of supply uncertainty in target headroom would be due to climate change.[28] This suggests that at least some water resource planning should occur over a longer horizon such as 50+ years, which would allow real options with long-term decision points to value the impact of learning and flexibility in light of climate change paths.
- From the point of view of many water company zones, there is substantial uncertainty about continued or further water availability for two reasons to do with policy, both of which appear to be likely to resolve more quickly than climate change understanding.

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[25] Murphy, J.M., Sexton, D.M.H., Jenkins, G.J., Boorman, P.M., Booth, B.B.B., Brown, C.C., Clark, R.T., Collins, M., Harris, G.R., Kendon, E.J., Betts, R.A., Brown, S.J., Howard, T. P., Humphrey, K. A., McCarthy, M. P., McDonald, R. E., Stephens, A., Wallace, C., Warren, R., Wilby, R., Wood, R. A.,*UK Climate Projections Science Report: Climate change projections*. Met Office Hadley Centre, Exeter, 2009.

[26] Watts, G., The Environment Agency, **a** communication for EA WRMP Real Options Project, March 2012

[27] Page 62, "*Climate Change Approaches in Water Resource Management Planning – Overview of New Methods*", EA/HR Wallingford, (forthcoming).

[28] Ibid. page 61.

First, it is not clear how and when the workings of policy to improve the water environment (enacted through the mechanisms of CAMS, RSA, buy-backs, shadow or actual abstraction taxes, etc) will limit the company's ability to abstract water or make it substantially more expensive to do so. The EA recognise this as potentially important in their new consultation on the WRMP guidelines, stating that an aim for new guidelines would be to *"help reduce the uncertainty around the sustainability of existing abstraction licenses, enabling water companies to plan strategically to meet public supply needs and reduce damaging abstractions.*[29]*"*

- Secondly it is not clear how or when proposed reforms to the nature of abstraction licences and to the opportunities to trade them will proceed, or how proposed reforms to encourage other parties to enter the water supply chain will proceed. So it is not clear to a water company how the policy reforms will affect the company's optimal supply arrangements – though it may be possible to frame the effects, define scenarios, and use varying probabilities to explore the implications for optimal near-term decisions.
- Water demand. Two areas of uncertainty stand out. First, it is difficult to predict gains and losses in individual large customers, who may be very important in a zone, but work with them may reduce the uncertainty. Similarly, if demand additions from possible population growth are on the horizon, this may be uncertain but the pattern of learning about this should be able to be researched and understood – over what minimum time frame could the possible population growth in the zone occur in practice? How has this panned out in the past?
- The second area of particular water demand uncertainty is customer reaction to new conservation measures and new pricing signals, in the longer term. Here trials and or the experience of other utilities should provide learning opportunities allowing a resolution much faster than simply waiting for the passage of time: and the value of the research to produce that earlier resolution should also be able to be gauged.
- Water facility costs. Desalination and other innovative treatment technologies, for example based on advances in membrane capabilities and production methods, may have particularly uncertain and difficult to predict costs. Innovations applying technology to operations such as real time pressure and flow controls have uncertain yields relative to costs. Learning can come from both the experience of others and research. While traditional technologies have better understood costs, construction costs for major engineering schemes are still widely regarded as having significant uncertainty. Most models of construction cost evolution suggest that waiting has learning value.
- The cost of capital demanded by investors in water companies is a function of wider infrastructure opportunities - which are growing globally – and of the comparative risk of water in England and Wales - which is a function of the regulatory regime, where substantial reforms are currently proposed. This may be expected to resolve to some degree over five or ten years.
- Water O&M costs. Energy costs have been particularly volatile and the trend globally is quite uncertain with advances in demand and in supply (e.g. from shale gas), as well as political factors. Again, waiting usually has some learning value.

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[29] "*The guiding principles for developing a water resources management plan*", EA WRMP Guidelines Consultation, Page 5. available at https://consult.environment-agency.gov.uk/portal/ho/waterres/draft/plans?pointId=1330093623228

- Regulatory and social. New quality regulations, particularly in the environmental area, are a significant source of uncertainty, quite apart from the water policy development uncertainties discussed above. Waiting and monitoring the regulatory environment are the major routes to learning. Social acceptance of water recycled from waste to non-potable use, and even more so to potable use, is an important future uncertainty.

3.3. Summary of Potential for Real Options to Provide Benefits

The benefits from applying real options analysis are perhaps most obviously considered in financial terms but can be enjoyed by customers and the community in different ways, for example: by achieving the same security of supply and environmental impacts for less financial outlay, or later financial outlay, hence lower water bills; or by gaining enhanced security of supply or enhanced environmental standards for the same financial outlay.

The general potential benefits of moving to real options approaches are difficult to scale because they are so situation dependent, and are so dependent on the quality of the analysis that would otherwise be done, but in aggregate the benefits could be substantial.
For example, if moving to a real options approach enabled the water companies of England and Wales to delay their commitments in such a way that it put all their supply-demand capex programs back by one year, this would save some £4,200 million out of the total projected £65,600 million of England and Wales WRMP capex in NPC terms. If instead a shift to a real options approach allowed water companies to reduce all their WRMP capex spending by 2% over the life of the WRMP, this would reduce the NPC by a figure in the region of £1,300 million.[30]

On an alternative view, imagine that moving to a real options approach improved service standards in some zones, by reducing the statistically expected amount of severe water restrictions by one tenth of a day per household per year. Valuation work[31] suggests that on average households value that service improvement by a figure of the order of £5.00 per household per year.

If the improved security was only in some zones so was enjoyed by (say) 10 million of the households in England and Wales, the value increase is about £50 million pounds in the first year. The security benefits to businesses and in later years would be additional, as would the value of any associated reduction in the chance of lesser restrictions such as hosepipe bans.

The WRMP process is designed to ensure that water companies can effectively communicate and justify their investment plans over the planning period. A shift towards strategic thinking through the use of real options analysis will allow water companies to justify their investment plans more effectively. Real options therefore by improving the efficiency and dialogue of the regulation of planning could reduce the number of planning inquiries necessary, with a substantial cost saving for companies and regulators, and allow regulators to engage more

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30 NERA analysis of WRMP expenditure projections

31 Baker, W. R., Metcalfe, P., "*Estimating customers' willingness to pay for service quality: the example of water service reliability in London, UK"*, in Voll, S. P., King, M. J., The Line in the Sand: The shifting boundary between markets and regulations in network industries, pp.485-497, 2007.

with companies' plans. It should satisfy the requests of the planning authorities for a better approach to uncertainty[32], and make the regulators' jobs easier.

Table 3.4 below summarizes the flexibility, uncertainty, learning, and cost (size or value) attributes of some relevant option categories and particular examples of each. The alternatives are listed in the first column with the more flexible alternative first. Other columns show relevant uncertainties, modes of learning, and project size.

Table 3.4 classifies learning into three modes:

- Dynamic Processes. We hypothesize that future values obey a process that we can learn about over time. For example, market prices for commodities (energy, gas) are modelled by specific markets. We learn simply by time passing and monitoring the process. We might also be building this new knowledge into our forecasting models.
- Other Passive. There are many other uncertainties that we can learn about with little or no effort, simply by waiting and observing, such as what regulations or laws are enacted, how many utilities build desalination plants, etc.
- Active. There are some uncertainties that are very hard to learn about without action on our part. For example, determining the productivity of an aquifer may require drilling a set of pilot wells. Learning customers' reactions to a conservation program (as distinct from the effects of the weather they are experiencing and the many other messages reaching them) may require active market research or trials.

The option categories we list in the Table include:

- Delay vs. build; and small vs. large. Delaying, building resources in incremental stages, and building smaller facilities all lower the commitment and provide option value that may offset higher unit costs. These methods allow time for learning prior to committing larger cash outlays (or not). They may also have the advantage of being able to match the capacity more closely to demand, thus reducing the cost of carrying excess capacity. Developing methods for building resources with short lead and construction times may have similar impacts.
- Invest to lower future costs or assure availability vs. not doing so. Sometimes current investment is required to enhance or acquire future flexibility. Land acquisition, gaining planning permission, and building allowing for expansion are all common ways of securing options about what to do next. Similarly, doing research or analysis may cost money but can be seen as an important way to learn and to lower the cost or assure the future availability of an alternative.
- Flexible termination vs. fixed term contracting. The ability to cancel a contract or shut down a facility is almost always negotiable and can be an important option. Determining the costs or payoffs from termination is important in evaluating the termination option. Contracts that specify termination rights may lower and clarify the cost of termination. It is important to recognize the value of the option both when you get the option and when

[32] Paragraph 13.2.13, Inspector's Report Thames Water, 13th December 2010.

you grant the option to a counter party. We also include the option to terminate or mothball and restart a project in this category.

- Multi-source flexibility. Having multiple sources of inputs is an important flexibility when the sources vary over time in their cost or availability.
- Save water vs. using it now. The most common type of operations option is to save or holdback resources in storage for future use.

All the examples in Table 3.4 have one or more types of flexibility, face significant uncertainty, and provide opportunities for significant learning with regard to the uncertainty. Further, we consider that a large number of these situations in England and Wales concern investments of over £10 million. In our view water supply demand planning clearly involves a lot of decision situations in which real options analysis has the possibility of providing significant benefits over deterministic or probabilistic planning.

Table 3.4
Option Evaluation

Flexibility Category *Example*	**Uncertainty**						**Learning**			**Cost/Value** (Millions £)			
	Water availability	**Demand**	**Supply cost**	**Commodity**	**Regulatory**	**Other**	**Dyanamic Processes**	**Other Passive**	**Active**	**<1**	**1 to 10**	**10 to 50**	**>50**
Multiple option categories													
WRMP	X	X	X	X	X	X	X	X	X				X
Delay vs. build; or small vs. large													
Build big new reservoir	X	X		X	X		X	X	X				X
Build a mixed resource scheme	X	X	X	X	X	X	X	X	X			X	
Invest to lower future costs or assure availability vs. not doing so													
Gain Planning Permission for reservoir	X	X			X		X	X	X				X
Appraise a desalination plant	X	X	X	X			X	X	X				X
Flexible termination vs. fixed term													
Implement volumetric charges	X	X			X	X	X	X	X			X	
Value an abstraction right w. termination	X	X					X	X			X		
Multi-source vs. single source													
Build new interconnector	X	X			X	X	X	X				X	
Implement “resilience” schemes	X	X				X	X	X			X		
Save vs. Use (Operational)													
Identify control curves	X	X					X	X				X	
Invoke interruptible arrangement	X	X					X	X			X		

4. Barriers to and Costs of ROA for Water in England and Wales

4.1. Discussion of Possible Barriers

The revisions to the WRMP and SDB guidance (broadly considered), and to the HMT Greenbook[33], as well as the comments in the Thames Water WRMP Planning Inquiry, and the direction of several current or impending studies[34], all suggest that a need for well-structured ways of dealing with uncertainty is increasingly being recognized at many levels in water supply demand planning.

However water companies will rightly be wary of doing substantial extra analysis where this adds little, and wary of producing situations of "paralysis by analysis", where genuinely richer new results raise many new questions in the minds of decision-makers, who freeze or who ask for further explanations in rounds which prevent decisions being made in timely fashion. This could occur internally, or by interaction with authorities who react by freezing or requesting more explorations. Careful development to avoid pointless work and delayed decisions will be required.

An aspect of the last point is that there will be some, perhaps many, zones currently not facing a supply demand gap, or apparently not having the flexibility, uncertainty and learning possibilities that make real options thinking worthwhile. Real options analysis will in those cases add little insight to the actions a company should be taking over the next five years. Applying the current basic planning methods should then be sufficient. However there are two substantial caveats to this important point in our view. The first is the current policy uncertainties may warrant a real options approach even where to date no current or prospective supply demand gap has been seen – for example, possible RSA reductions or shadow prices for abstraction in 10 years time may make a big difference to optimal plans for the next 5 years. A second caveat is that aspects of the standard method may be found to be inadequate in the face of new information or revised approaches – for example, if climate change uncertainties over rainfall distribution trends are very large but will only noticeably resolve over (say) 30 years, then WRMP may need a longer horizon than 25 years – and in that revised WRMP framework real options thinking may be valuable or indeed essential for a wider set of zones.

Real options analysis should be developed with probabilistic analysis, not ahead of it. As discussed in the general introduction above, if expert judgment is not accepted as a source of probability distributions, it is going to be hard to make much progress on a lot of issues where real options appears to have a lot to offer.

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33 See Chapter 2 of HM Treasury Supplementary Green Book guidance on the environment, Accounting for the effect of climate change, available at http://archive.defra.gov.uk/environment/climate/documents/adaptation-guidance.pdf, July 2009, pp.5-13.

34 See, for example: UKWIR, *WR27 Water Resources Planning Tools Project: Interim Technical Report No. 3*, December 2011; *UKWIR Resilience – Making a Business Case for PR14* – work in progress; Darch, G., Arkell, B. and Tradewell, J. 2011. *Water resource planning under climate uncertainty in London*. Atkins Report (Reference 5103993/73/DG/035) for the Adaptation Sub-Committee and Thames Water. Atkins, Epsom.

The water companies of England and Wales have considerable experience with making and using expert judgments about supply demand matters. They are well used to employing probability distributions based on historical stream-flow records, and accustomed to needing to make expert judgments in forming measures of future extreme value risk based on the history. Expert judgments about probability distributions have also been used for many years by water companies to form the Headroom assumption which is currently critical to supply demand planning. Expert judgment has also been used for many years to form the probability distributions over individual items which are the basis for the Maximum Likelihood adjustments necessary to derive a coherent water balance. More broadly, some water companies have made extensive Monte Carlo analyses of their financial projections using expert judgments to form probability distributions over each of many uncertain inputs – as embodied in the LiquidRisk model employed by some companies before the two most recent Periodic Reviews.

There may be a particular issue to address about how best to allow for risk aversion in water planning. Approaching planning with hard supply demand constraints or Minimax type decision rules may mean that the step to real options is less able to provide further insight – the constraint dominates the solution selection. However we regard this as a more general question about the appropriate formulation to use in supply demand planning, which should be addressed irrespective of whether the approach is deterministic, probabilistic, or strategic as in a real options approach. For example, in work for an English water company NERA has applied a formulation replacing the hard (S>D+H) constraint with a graduated penalty function calibrated to drought order costs and customer valuations of non-supply events, and using two weather states (dry and normal) each year in parallel, so that the sensitivity of the solution to the probability of a dry event can be explored. This is only a real options formulation in the minor sense that operations are assumed to vary between the two weather states each year, but the extra flexibility of the formulation may make it a better platform for real options explorations.

As noted in Section 2.2.1.2 real options may be harder to apply informatively when key issues, though still applicable, are determined by hard constraints. Thus headroom as a hard constraint limits the extra worth of applying real options, and indeed of applying probabilistic methods too. However, measurement of willingness-to-pay and simulation of under-service events is becoming more common. Such simulations can lead to a quantification of the benefits of higher and lower supply-demand balances. In turn this leads to a reinterpretation of headroom as a critical shortfall breakpoint, above which additional supply has limited expected value and below which supply has high expected costs. This trend in the pricing of the supply-demand balance will tend to make real options less difficult to use and its results more valuable.

Uptake by water companies will be helped by demonstrations that the analysis is beneficial to them within the prevailing incentive arrangements. A shift towards real options thinking seems well aligned with the current interest in addressing the capex/opex incentive balance and in moving from an outputs to an outcomes focus.

Gaining acceptance by the water utility planners, managers and investors – who are used to making sophisticated financial analyses with many parallels to real options approaches – may be less of a challenge than acceptance by government and the community at large. The latter parties include the regulators (EA, Ofwat and their Reporters, DWI, CCW, Competition

Commission), government departments (Defra, HMT), Ministers, the planning authorities including perhaps the Infrastructure Commission, local government, auditors, consumer groups, environmental groups and individual citizens. Section 2.2.1.1 discusses the added complexity of probabilistic analysis. The introduction of real options to stakeholders should be a gradual and ongoing process. Initially, real options might only be introduced where it has the highest and clearest benefits. Gradually, it can be introduced wherever it has positive benefit. Also, it should be anticipated that communication will require more effort and will have higher costs when real options is first introduced.

As part of a real options optimum in some cases preparation expenditure or risky innovative schemes will be worthwhile even where the associated projects have a significant possibility of never being completed. A traditional perspective may view such decisions as being wasteful or as poor management, and wish to log down or deduct the expenditures ex-post. It may also fail to identify that there is time to try a new method. But where they form part of a real options optimum such expenditures are a form of prudent hedging or buying insurance that adds value and reduces risk in the face of uncertainty. If real options approaches are to be employed by water companies, the incentives and financial and service measurement as governed by economic regulation, and the associated reporting and auditing arrangements, will need to recognize and facilitate the use of the approach. Investors will be concerned about this.

Water utilities operate within an environment where decisions on water supply are inevitably a political concern, so communication with the community at large is critically important. A single, fixed plan can be explained and defended using a fairly straightforward message. This is perhaps less true of a flexible strategy, where both the initial rationale for flexibility and the need for adjustments over time under specific conditions must be communicated effectively. Community understanding and acceptance will be aided by identifying the value enhancement and risk reduction benefits of a strategic approach up front, and by showing that the flexible strategy is being undertaken in the interests of the community.

The uncertainty about some variables such as climate change, interest rates, electric power costs, and construction input costs, may be the same for all or many water utilities. In such cases it will help to develop national default probability distributions, to reduce costs and increase consistency in the analyses presented – though a downside is that over-reliance on centrally developed figures will mean that all users will make the same mistakes. There are already some sets of national scenarios developed by the EA, Ofwat, and UKCP, for example, which could be adapted to form a national framework for companies to draw on for real options supply demand analyses. An important part of the adaptation would be to carefully delineate which elements are outside company control and which elements are to be decided as part of the analysis.

4.2. Training and Expertise

In-house capability for water supply demand planning varies substantially from company to company. Some have highly qualified experts who are already knowledgeable about the modelling needed for real options analysis, and are conducting analyses bordering on this approach already. Other companies have little in-house resource for supply demand planning of any type. All companies use engineering consultancies when extra skills are needed or extra work loads must be covered. That will no doubt be true of the use of real options analysis as well, with consultants used more initially, and used later for critical phases and where peak workloads require it.

Staff can be taught to apply real options thinking and undertake real options modelling, but in our experience specific training is valuable. Training is very helpful in the tasks of structuring the problems and identifying options, and for the more quantitative aspects of the analysis. Demonstration projects are a key part of training.

Similarly, early workshops for Boards and regulators to introduce the richer real options analysis, and to anticipate and answer many of the questions that will otherwise follow when the first real options results are tabled, are important "training" events.

4.3. Cost of Analysis

A key issue with the cost of moving from deterministic and probabilistic analyses to real options analyses is how simple the extra data collection can be kept. Our view is that the appropriate first step is to limit this extra cost greatly, by using very simple scenarios for real options framing, and using expert judgment for the probabilities over the scenarios, with exploration of the sensitivity of results to the probability judgments made.

This exploration will identify the value of having better probability figures, which can be fed back to the research community. For example, what difference would it make to the expected NPC of optimal real options-based WRMPs, to know what probability should be placed across the CO2 paths which underpin the UKCP long term rainfall scenarios?

The data collection costs can easily go from a small part of a real options project cost to 90% of the costs, if company internal judgments and explorations cannot be used.

Where multiple zones and companies face the same uncertainties then standard probabilities developed centrally or by joint-commissioning organizations such as UKWIR can help reduce the extra analysis costs. There are several existing sets of scenarios which could be drawn on in creating a single set of scenarios suitable for a lot of longer term real options supply demand framing.

4.4. Other Factors

Water companies currently use a number of fairly large complex simulation and optimisation models for water supply demand planning, each model with its own scope and attributes. Integrating a real options approach with these models may require establishing different modelling interactions in each case, some more difficult than others. A few demonstration projects that would illustrate how this could be done would be valuable. So would establishing a "set of principles" that should be complied with to be able to claim that a robust strategic or real options approach had been followed.

Modelling, of any kind, finds an optimal solution within a simplified world. It is not unusual in water resource planning to have hundreds of potential actions under consideration. Mathematical programming methods are gaining popularity in water resource planning because of their ability to deal with these many actions and the millions of ways they can fit together, but they often ignore uncertainty and the ability to adapt to future events. Real options cannot deal with very high numbers of individual actions. The list of actions needs to be pruned by some preliminary analysis and it may be necessary to group actions into major strategies structured around key potential resource investments. Real options can deal with thousands of potential futures and thousands of potential combinations of responses. Modellers need to balance the detail across the dimensions of actions, uncertainties, and responses. We suggest that a simple real options analysis can be used within the existing WRMP framework of mathematical programming in our first case study below. In our second case study, we illustrate how real options can resolve selection among a relatively small number of compound competing alternatives.

5. Example Applications

Summarising and restating our discussion of possible real options for water supply above, we can identify groups of typical real options applications:

- Call options
  - Delay or make more granular investments
  - Build expansion capability
  - Technical research, market research, pilot projects, small investments
- Put options
  - Close down or sell equipment
  - Add contract termination possibilities
- Others
  - Change inputs or outputs
  - Change operating facilities

5.1. Real Options Approach in Other Jurisdictions

The field of real options clearly began with an emphasis on wealth maximization, and most early applications were in the private sector where this is the dominant paradigm. However, there has been increasing interest in applying the concept and methods in the public sector. In recent years, there have been applications in public works, such as airports, energy facilities and roads, research and development and public health.[35] A notable UK example is the application of real options thinking to flooding protection in the Thames Estuary (the TE2100 study).[36]

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[35] See, for example: Ge, L. Mourits, M., Huirne, R., "*Valuing Flexibility in the Control of Contagious Animal Disease*", Working Paper, Wageningen University, 2005.

Long, D., Kostiuk, P., "*An Application of Real Options to Government R&D Portfolio Management*", Conference on Systems Engineering Research, Paper #67, 2007.

Mahnovski, S., Robust Decisions and Deep Uncertainty: An Application of Real Options to Public and Private Investment in Hydrogen and Fuel Cell Technologies, RAND Corporation, 2007.

Moreno-Hines, F., Real Options Applications for Public Sector Investment and Acquisitions, MITRE, 2007.

Pereira, P., Rodriguesy, A., Armadaz, M., "*The Optimal Timing for the Construction of an International Airport: a Real Options Approach with Multiple Stochastic Factors and Shocks*," Working Paper, University of Minho, 2006.

Saphores, J., Boarnet, M. G., "*Investing in Urban Transportation Infrastructure Under Uncertainty*," Working Paper, University of California – Irvine, 2000.

Williams, D.R, Hammes, P. H., Karahalis, G. G., "*Real Options Reasoning in Health Care: An Integrative Approach and Synopsis*," Journal of Healthcare Management, Volume 52, p. 170, May/June 2007.

[36] A discussion on the TE2100 is outlined in Ranger, N., Millner, A., Dietz, S., Fankhauser, S., Lopez, A., Ruta, G., "Adaptation in the UK: a decision-making process", available at http://www2.lse.ac.uk/GranthamInstitute/publications/Policy/briefs.aspx#generated-subheading2

There are a few published examples of actual or proposed real options applications in water resource planning.[37]

5.2. Case 1 for England and Wales Water

A water utility has revised its supply, demand, and headroom estimates and finds itself with the possibility of a significant future deficit in a large zone. It has examined hundreds of supply alternatives. A simple screening procedure was used to reduce the list of alternatives and then an integer programming approach was taken to select the optimal mix and the optimal timing of resource, leakage, and demand-side additions to fill the deficit. The final plan includes moving to universal metering, continuing successful leak reduction and water efficiency programs, and the addition of one significant new groundwater abstraction resource. We will refer to this as the base plan.

The utility is concerned about the uncertainty around medium-term demand growth in the zone, and also the appropriate figure to use for headroom, given some other uncertainties. It's been suggested that they should move rapidly to develop the new water groundwater abstraction and/or develop a reservoir which would provide significantly more supply in dry years.

Figure 5.1 summarizes a "real options" view of the situation a water company is facing in the context of the current regulatory regime. In the figure, the utility is compiling the WRMP for AMP6 starting 2015. It will have to commit to one set of actions during AMP6 but it is uncertain as to which demand it will have to meet over the medium-term. There are four possible demand scenarios, each of which requires different actions to deliver the optimal outcome. The scenario uncertainties will (by assumption in this view) be resolved at the end of AMP6, after which the company can revise its WRMP given what has been learnt about the scenario for the remaining planning period.

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[37] See, for example: Ramirez, N., Valuing Flexibility in Infrastructure Developments: The Bogota Water Supply Expansion Plan, 2002.

Reid, S., "*Demand Management: A Real Option?"* Water Markets Perspective, ICF Consulting, 2007.

"Decision Support Planning Methods: Incorporating Climate Change Uncertainties into Water Plannine" – A report prepared for Water Utility Climate Alliance, January 2010

Zhao, J., Uncertainty, Irreversibility and Water Project Assessment, Iowa State University, Department of Economics, Staff General Research Paper 5269, 2002.

Zhang, S., Babovic, V., "*A real options analysis of Singapore's water supply system*", Water Utility Management International, September 2009, pp.22-25

Figure 5.1
Decision Process

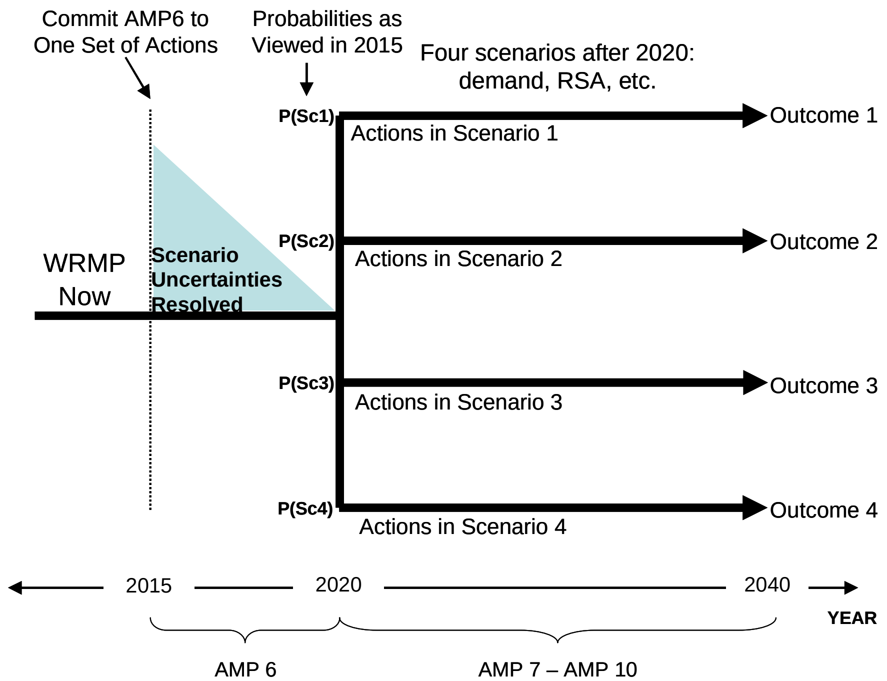


Figure 5.2
Supply Gap

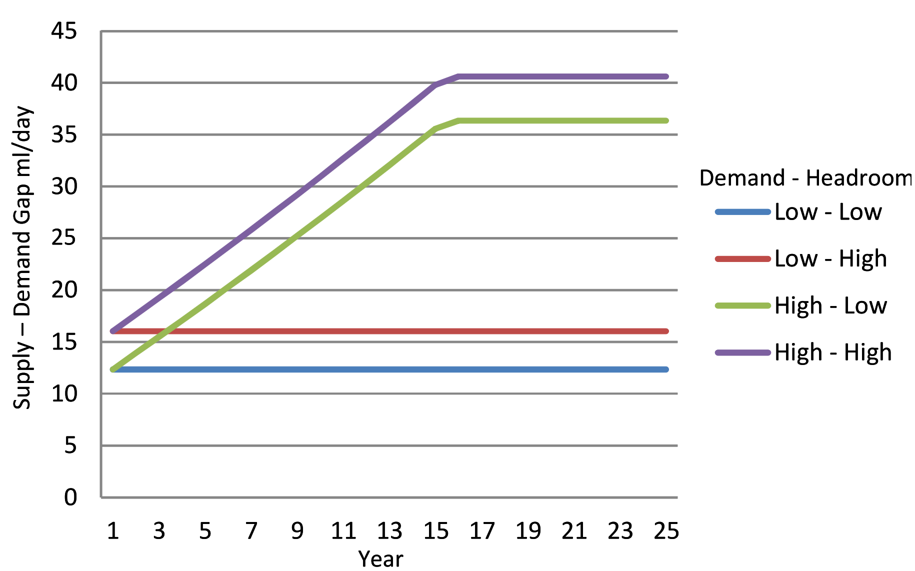


Figure 5.2 shows alternative future scenarios for the deficit, considering ranges for both the demand and the headroom estimate. The vertical scale is million liters per day (ml/day). Low – High indicates a Low demand forecast and a High headroom forecast.

A group of quick and low cost metering, leak control, and efficiency measures are planned to be implemented in all cases to close approximately 9 ml/day of the gap. Table 5.1 is a list of the other resources under consideration.

Table 5.1
Alternative Resources

Source Table		Construct Years	Size (*ml/day*)	Capital (*£Million*)	O&M (*£Million/yr*)
Metering 1	1	0	3.00	1.50	0.15
Metering 2	2	0	3.00	1.70	0.40
Leak and efficiency 1	3	0	3.00	2.00	0.40
Leak and efficiency 2	4	0	3.00	2.00	0.40
Leak and efficiency 3	5	1	3.00	2.00	0.50
Leak and efficiency 4	6	2	6.00	2.50	1.00
New abstraction	7	3	11.50	9.00	0.35
Reservoir	8	8	21.00	25.00	0.30

The utility believes that a real options analysis might give them insight into the best path forward, but they want to keep the analysis very simple and grounded in the tools with which the water resource planning analysts, Board, and regulators are familiar.

5.2.1. Step 1. Deterministic Modelling

The utility's standard planning model is run to determine a best plan for each future illustrated in Figure 5.2. The model builds a best plan for each demand situation out of the resources listed in Table 5.1. Table 5.2 briefly describes the plans and lists their costs. This analysis is similar to the analysis that many water utilities currently do.

Table 5.2
Deterministic Plans

Scenario Demand - Headroom	Plan Description	NPV Cost £Millions
Low – Low	Implement Metering 1.	£3.68
Low – High	Implement Metering 1 & 2	£13.74
High – Low	Begin development of New Abstraction immediately, followed gradually over time by the metering and top 3 leak and efficiency programs	£35.82
High – High	Begin development of New Abstraction immediately, and progress rapidly on metering, leak, and efficiency programs	£48.61

If one of the deterministic plans must be committed to now, and being short of water is unacceptable (i.e. a hard constraint is used), then a risk averse planner would need to implement the strategy associated with High – High at a cost of £48.61 Million.

5.2.2. Step 2: Simulation Analysis with Fixed Plans

The four plans developed above can be used in the probabilistic modelling, or modifications that might perform better across the range of futures might be defined. (The prior step of creating optimal plans for each future is not always necessary. For example, there may be only a small known set of plans to be examined, that the planner can just write-down.) The four plans examined in our example are shown in Table 5.3.

Table 5.3
Plan Descriptions

Plan	Name	Actions
1	Small	Metering 1, No additional
2	Abstraction only	Abstraction immediately, No additional
3	Abstraction plus	Abstraction immediately, Additional metering, leak reduction, and efficiency on accelerated schedule
4	Reservoir plus	Reservoir, metering, leak reduction, and efficiency immediately, Additional leak and efficiency

For this analysis, each of the four deficit scenarios was assumed to have the same 25% likelihood. The model does not use a supply-demand balance constraint. Instead, it penalizes shortages (below target headroom) at about 10 times the levelised cost of supply and adds a small reward (of about one third of the levelised cost of supply) for any surplus (above target headroom). Thus the model places a very high value on meeting the headroom target.

The model was then run in simulation mode, for each of the plans to be examined, keeping each fixed while the demand and headroom scenarios are varied across the four cases. The expected cost of each fixed strategy is then calculated, based on the probabilities of each path and the costs under each.

Plan 2, Abstraction only, the plan of developing the new groundwater abstraction as quickly as possible, but delaying any other actions, had the lowest expected cost at £36.18 Million. The Small plan cost was £43.69 Million, the Abstraction plus plan cost was £40.29 Million, and the Reservoir plus plan was £51.80 Million. The cost of the Abstraction only plan in each scenario is shown in Table 5.4. The portion of the costs attributable to supply shortages varies dramatically by scenario. In the Low – Low scenario shortage costs are £0.78 Million; in the High – High scenario shortage costs are £52.00 Million.

Table 5.4
Cost of Plan 2, "Abstraction Only", under Each Scenario

Scenario **Demand – Headroom**	**NPV Cost** **£Millions**
Low – Low	£13.93
Low – High	£17.45
High – Low	£48.20
High – High	£65.12

Faced with the probabilistic results, the utility concludes that assuming that the future is known and that a perfect plan can be chosen as in Step 1 is unrealistic, and the costs associated with any individual plan-scenario combination are very misleading. Similarly, it is unrealistic to assume that a fixed investment program with £52.00 Million in shortage costs would be maintained. Even a simple real options analysis will provide a more realistic picture of the future and the probable costs.

5.2.3. Step 3: Simple Real Options Analysis

The model is run with actions fixed for the first five years, the same length as the standard planning cycle. Three alternatives for the first 5 years are considered:

1. Small, implement only Metering 1;
2. Abstraction, begin development of new groundwater abstraction immediately; and
3. Reservoir, begin development of the reservoir, metering, leak reduction, and efficiency immediately.

They are chosen to bracket the likely best initial solution, for the five year period of learning about demand and headroom. At the end of the five years there is the opportunity to revise the strategy in response to what has been learned; i.e. in response to the revealed-scenario.

Each of the three initial actions can be followed by one of four actions after 5 years. These are named Small, Medium, Large, and Large Fast. The names indicate the ultimate target level to adopt for the resources. Descriptions of the twelve combined initial and long term strategies are found in Table 5.5. If the initial resource is abstraction or reservoir, because of their substantial size, additional resources are not added in some cases. Note that with optimization software, such as a mathematical programming routine, thousands of optional paths for the long-term can be easily examined.

Table 5.5
Strategy Descriptions

Plan	Initial	Following	Actions
1.1	Small	Small	Metering 1, No additional
1.2	Small	Medium	Metering 1, Then Metering 2
1.3	Small	Large	Metering 1, Reservoir and metering 2, leak reduction, and efficiency over time
1.4	Small	Large fast	Metering 1, Reservoir and metering 2, leak reduction, and efficiency on accelerated schedule
2.1	Abstraction	Small	Abstraction immediately, , No additional
2.2	Abstraction	Medium	Abstraction immediately, No additional
2.3	Abstraction	Large	Abstraction immediately, Additional metering, leak reduction, and efficiency over time
2.4	Abstraction	Large fast	Abstraction immediately, Additional metering, leak reduction, and efficiency on accelerated schedule
3.1	Reservoir	Small	Reservoir, metering, leak reduction, and efficiency immediately, No additional
3.2	Reservoir	Medium	Reservoir, metering, leak reduction, and efficiency immediately, No additional
3.3	Reservoir	Large	Reservoir, metering, leak reduction, and efficiency immediately, No additional
3.4	Reservoir	Large fast	Reservoir, metering, leak reduction, and efficiency immediately, Additional leak and efficiency

Figure 5.3 shows the decision tree for only the initial Small branch. The full tree would spread out similarly for the Abstraction and Reservoir branches and be three times as large. (Displaying full decision trees is cumbersome even for very simple structures. Therefore, unless information is being provided for individual branches, decision trees are almost always shown in reduced form. In reduced form if the later tree structure is identical for branches, it is only shown once.)

Figure 5.4 shows the tree from Figure 5.3 in the reduced form.

Figure 5.3
Partial Decision Tree for Case 1

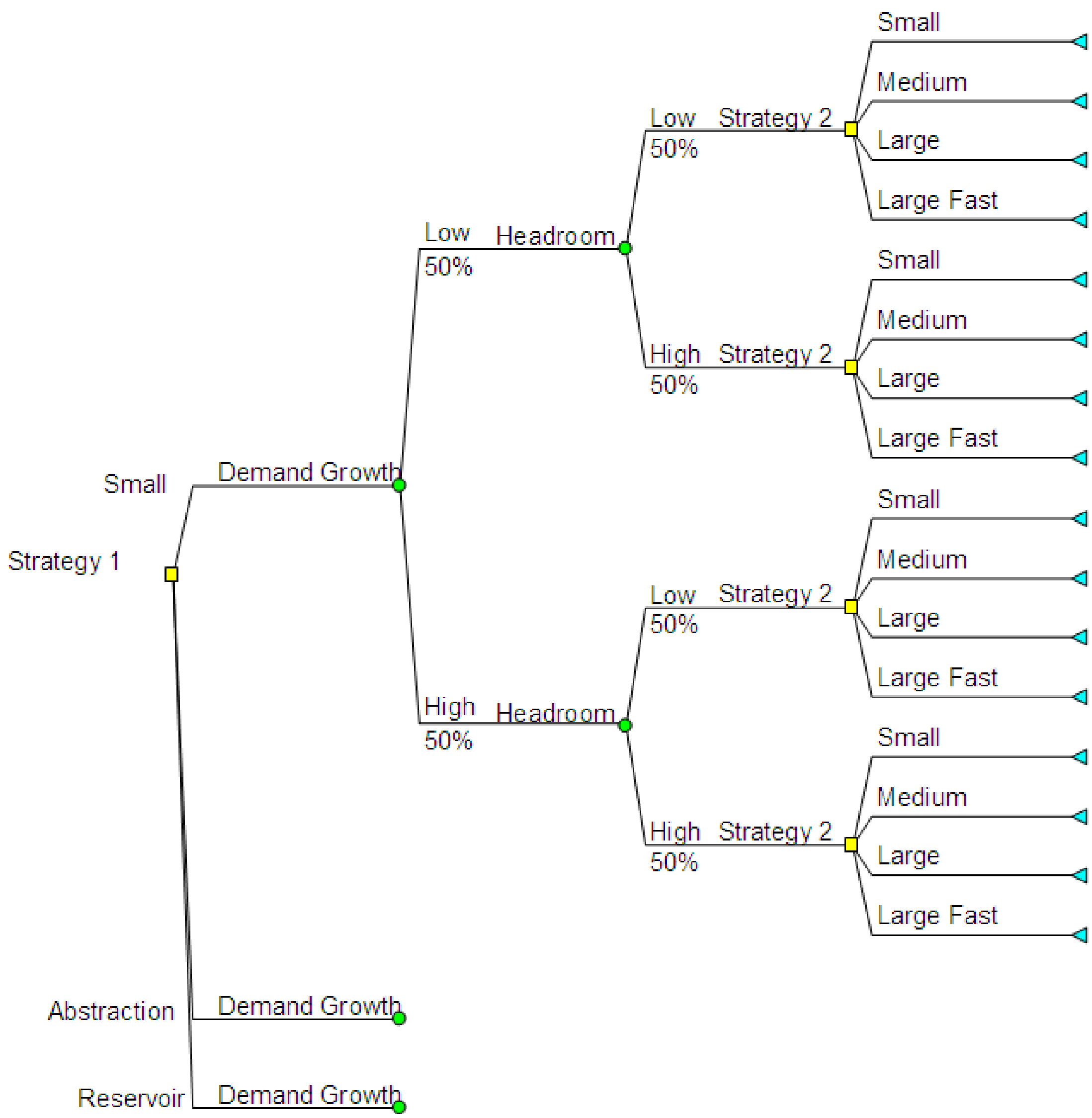
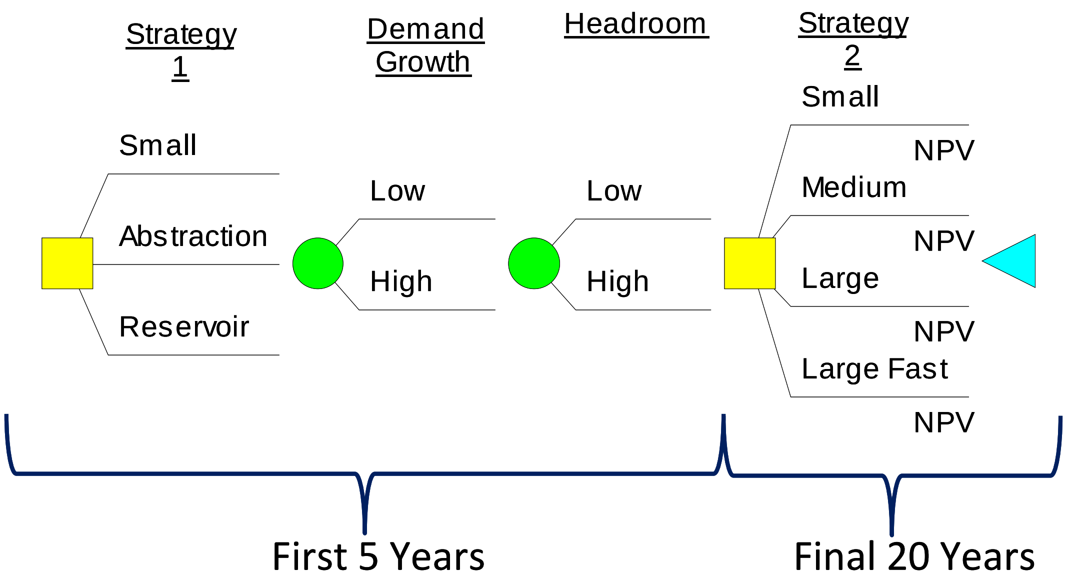


Figure 5.4
Tree Diagram for Analysis



The tree is analyzed fixing the plan in the first 5 years to one of the three initial strategies. In the later years, the model is allowed to optimize resource additions for the remainder of the period for each scenario. The value of each strategy is again the expected cost based on the probabilities of each demand and headroom combination, but now the strategies are committed-to for the initial period only and we assume the actions can differ after year five.

Typically, WRMP planning optimizations are run with the assumption of perfect knowledge of every future period. Here we assume that during the first five years, we are uncertain of the future. Then at the end of five years, we go back to the assumption of perfect knowledge of future demand. This is a very strong assumption, but it seems a better assumption than either the assumption that the future is perfectly known, or the assumption that there is no learning about the evolution of the supply-demand balance.

Figure 5.5 shows the results when the strategies are only fixed for the first 5 years, and able to adapt after that. The real options analysis shows that the best strategy is to adopt the Small actions initially, and that doing so will lead to an expected cost of £27.60 Million. (To allow a simple diagram we have not detailed the branch of the tree after initial "Abstraction" and after initial "Reservoir" strategies, because they both have a much higher expected cost than "Small".)

Figure 5.5
Analysis with Flexibility

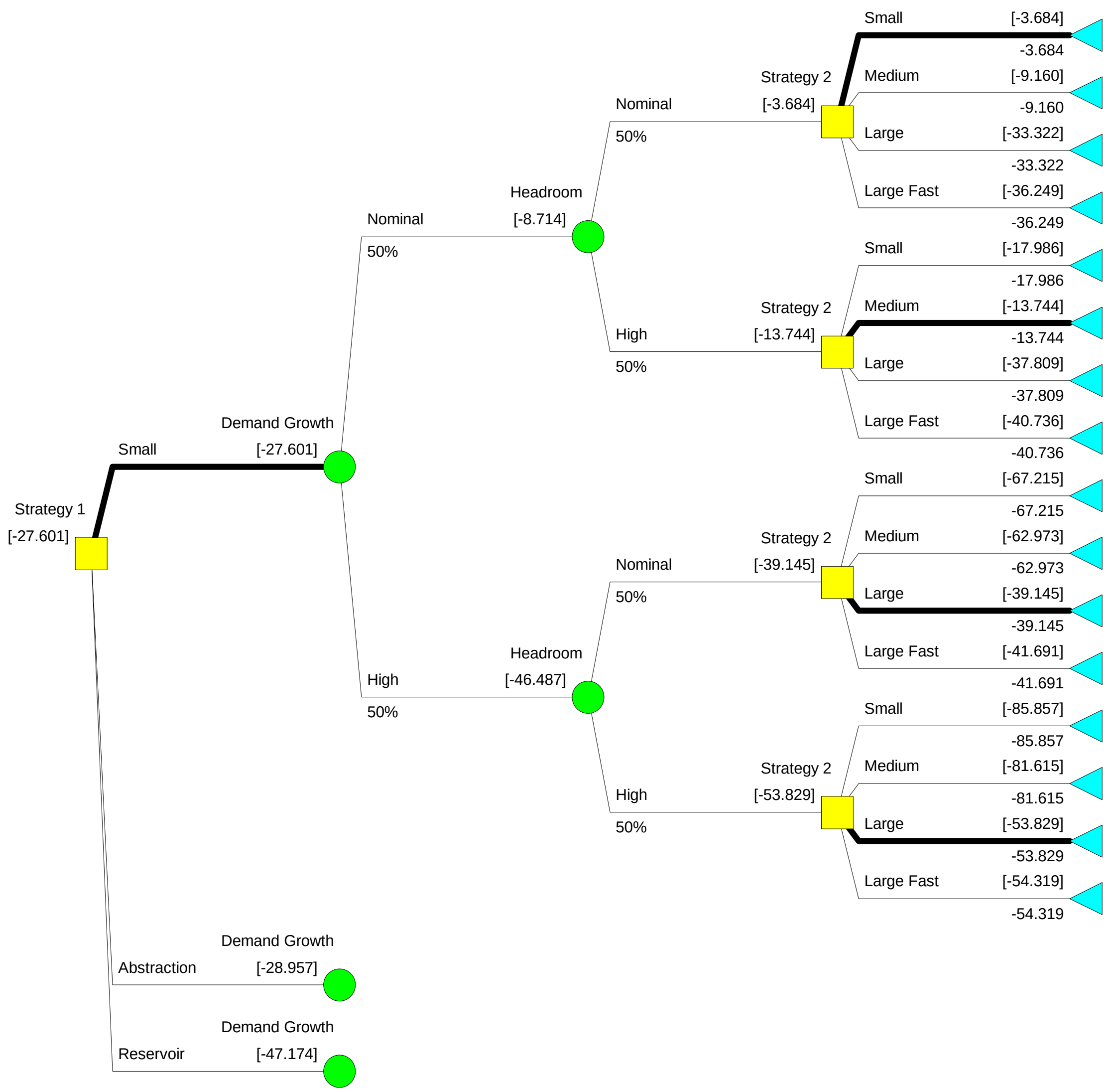


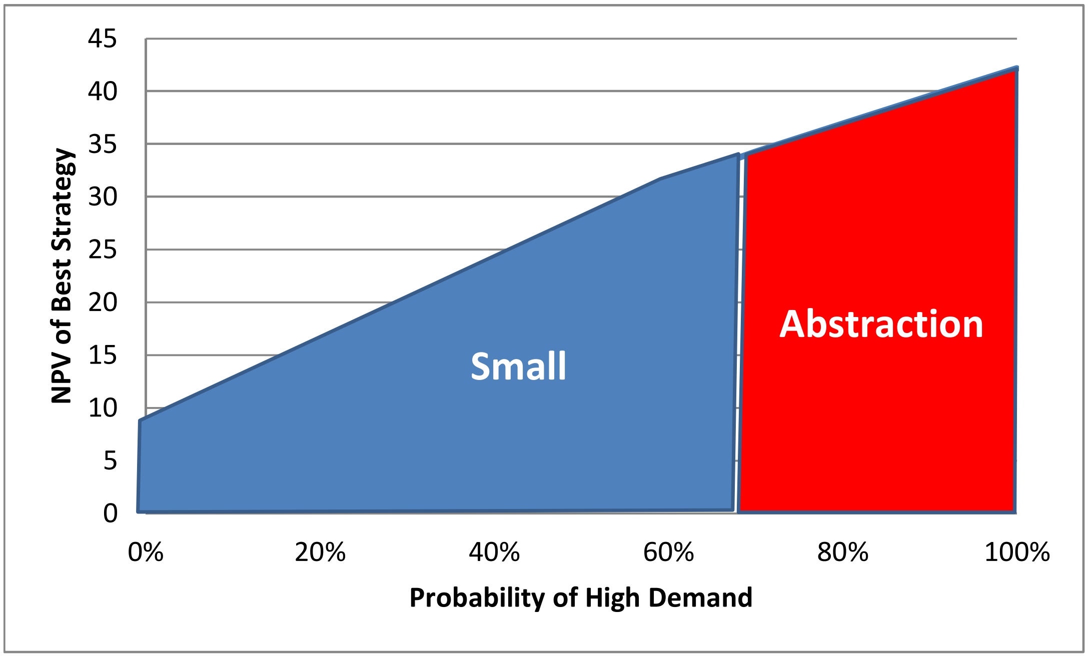
Table 5.6 below shows what the 2nd Period actions will then be, after adopting Small initially, and after the demand-headroom scenario becomes known. In the Low-Low case, the Small actions continue to be taken after five years; if after five years the scenario turns out to be Low-High, the Medium actions are taken; and in both the High demand cases it becomes best that the Large actions are taken. The cost along each whole path is shown: if things turn out most favourably the cost is much lower than the expected cost of the best single path found by probabilistic analysis. That is why the expected cost of the optimal real options strategy as a whole is at £27.6 Million much lower than the expected cost of the best fixed plan, which is £36.18 Million. As frequently happens, the options analysis highlights the potential value of waiting and learning and suggests a difference in the following actions depending on how things turn out.

Table 5.6
Cost and Actions Under Each Scenario

Scenario Demand - Headroom	2nd Period Action, After Small Initially	NPV Cost (£Millions)
Low – Low	1.1 Small	£3.68
Low – High	1.2 Medium	£13.74
High – Low	1.3 Large	£39.14
High - High	1.3 Large	£53.83

Various types of sensitivity analysis can performed to understand the results in more depth. It may be of interest to test how the decisions change with respect to different capital costs, operating costs, and probabilities. To illustrate, in Figure 5.6, the sensitivity to changes in the probability of High Demand is examined. We know that at 50% probability of High Demand the best initial alternative is the Small strategy with an expected cost of £27.60 Million. The figure illustrates that as the probability of High Demand increases the best expected cost also increases. At approximately 70% probability of High Demand, the best initial strategy switches. At this point Abstraction becomes the best initial action.

Figure 5.6
Sensitivity to Probability of High Demand



5.2.4. Summary of Case 1

This analysis has been kept simple so that it can be run within the utility's current WRMP modelling framework.

The real options analysis was conducted in three simple steps:

1. Find a best deterministic plan for each scenario.
2. Create alternative fixed plans, examine each of them against a set of possible future scenarios, and calculate its expected value and any supply infeasibility or shortage cost.
3. Fix the alternative plans for the first 5 years, optimize the following actions under each scenario, and calculate each initial plan's expected value.

Two important assumptions were made to accomplish this simplification:

- It was assumed that the key demand and headroom-level uncertainties about the future could be approximated by four alternative scenarios; obviously, many other futures could occur.
- It was assumed that there was only one break in the horizon, so that after 5 years the utility would hold perfect knowledge of the future; obviously, this is not true.

Because of these assumptions, the real options results should be considered indicative but not conclusive regarding the future strategy.

In addition to indicating that a waiting strategy is preferred before a commitment is made to a costly and irreversible groundwater abstraction or reservoir resource, this analysis has provided the utility with a much clearer picture of both future actions and costs. While this picture may be harder to explain to boards, regulators, and the public, it is a much more realistic picture of the future.

It should be a better platform for a discussion of the uncertainties and of willingness to take risks, allowing analysis of the questions "how probable does high demand need to be before it is best to commit to a major scheme in the first five years?", and "if we wait another five years before deciding to implement a major scheme, how much more costly could that be?" It should hopefully also reduce the conflicts that arise when stakeholders say, "But you told us last time….".

5.3. Case 2 for England and Wales Water

A large water utility sees significant increases in demand in the future. The water company has determined that under its standard planning approach either a large new reservoir or a large desalination plant will be needed. With the standard conservative growth assumptions, ground will need to be broken in 4 to 5 years on one of these projects to have the capacity available in time.

The utility recognizes that there are a number of significant risks. Demand is uncertain; and, if high demand does not occur, the utility will have spent hundreds of millions on a resource unnecessary for a decade or more. The capital costs of the desalination plant are especially uncertain. Technology is advancing rapidly, few plants have been built, and plants have different requirements depending on the brackishness and makeup of the water resource. The utility expects to understand the demand and costs better in 5 years.

The utility is also concerned about permitting the reservoir. The utility is confident that if it commits now it can get planning permission for the reservoir. The utility has a strong belief that land use changes will make it more difficult to get planning permission in 5 years than it would be today. However, the utility also believes that there are some actions that can be taken today that will raise the probability that permits can be obtained in the future. These include acquisition of some critical pieces of land around the reservoir site, additional work with residents, and some early site preparation to demonstrate how the environmental effects can be mitigated.

5.3.1. Deterministic Analysis

Table 5.7
Results of Deterministic Analysis

Scenario	Plan	Cost (£ millions)
Standard Demand, Most Likely Desalination Cost	Large – implement small projects and begin reservoir construction in four years	£1681
Standard Demand, Low Desalination Cost	Large – implement small projects and begin desalination construction in four years	£1671
Most Likely Demand, Most Likely Desalination Cost	Small – implement a number of smaller supply, metering, efficiency, and leak reduction projects.	£935
Low Demand, Most Likely Desalination Cost	Small – implement a number of smaller supply, metering, efficiency, and leak reduction projects.	£587

The utility generates cost and volume estimates for hundreds of potential actions. Simple screening criteria reduces this list to about a dozen practical measures. The utility initially conducts a deterministic analysis for the standard demand and most-likely costs case. This analysis is completed using the utility's standard resource planning software and spreadsheets. This analysis suggests it is best to implement a number of low cost, small projects immediately and to begin construction of the reservoir in four years.

In light of the risks, the utility outlines a number of additional scenarios for demand and costs. The company also looks at the optimum for each of these other cases. Four of the cases examined are shown in Table 5.7. The costs vary by a factor of three across the cases, depending on the assumption made about the rate of demand growth: the standard assumption is above the modal case and it is possible that demand could turn out to be lower still. While, on this analysis, the cost consequences of a wrong decision on reservoir versus desalination does not appear large, there is substantial possibility for regret if the standard optimum of the reservoir is adopted - if demand turns out to be lower, a much lower cost solution would have been enough to avoid problems in meeting demands.

5.3.2. Simulation Analysis

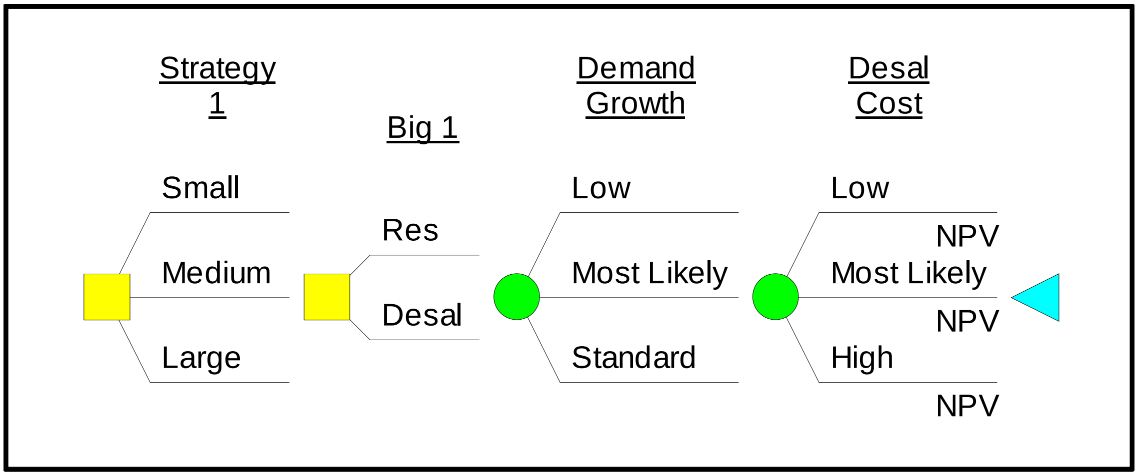
The utility decided a probabilistic simulation analysis would be undertaken to see if that added insight to the choices. This analysis required several steps beyond typical planning procedures for the utility. These included:

- Structuring the uncertainty model. Determining what variables would be considered uncertain. Deciding on their representation as discrete or continuous probability distributions. Deciding on the pattern of change in these variables over time. Deciding how many alternative plans of action would be examined. With demand uncertain, meeting a headroom constraint could not be assured, economic costs and benefits were assigned to shortfalls and availability of excess water. Establishing these costs and benefits required willingness-to-pay information and detailed simulations of water supply and demand patterns.
- Gathering data. The utility needed to gather uncertainty data. This meant either statistical analysis of demand, supply, and cost data or interviews with experts competent to make judgments about the likelihood of future values. Assessing judgments required the use of interview techniques new to the utility. The new data and sources were documented to allow review by outside stakeholders.
- Implementing the uncertainty model. The utility chose an uncertainty analysis software package to aid them in the analysis. While the package worked with standard spreadsheet software, the utility found that several of their cost and benefit calculation spreadsheets needed to be significantly modified to work well with the new software. The new software also required some programming and, of course, the probability data needed to be entered.
- Conducting the analysis. In addition to providing the expected value of each plan, the software provided a number of tools for analyzing the alternative plans. The sensitivity of the values to each variable could be tested. Graphs illustrating the risks of each alternative could be produced. Estimates of the value of collecting additional information could be made. Because many of these outputs were unfamiliar to management, regulators, and stakeholders, analysts and planners spent significant time considering the best methods of presentation. Initial presentations generated questions that led to a second round of analyses.

Figure 5.7 illustrates the final form of the simulation analysis. The strategy could be Small, Medium, or Large representing different paces and quantities of new resources added. The Big1 decision between Reservoir and Desalination is only relevant to the Large plan.

Two uncertainties were considered: Demand Growth and Desalination Cost. The diagram is simplified in that both Demand Growth and Desalination were allowed to vary over two 5 year periods. For example, the model considers patterns such as Demand Growth high for 5 years followed by Demand Growth low. There is no hard supply-demand constraint in the model, but the model is driven toward the headroom target by high assumed shortage costs when supply is below the target.

Figure 5.7
Schematic of Probability Analysis Structure



The plan which met demands with the lowest expected cost was to build the large reservoir beginning in the fourth year. This is the same plan that was preferred under the standard demand assumption and deterministic optimisation. The expected cost with this strategy is £1182 Million versus £1681 Million. Selection of this plan is driven by the high shortage costs if there was insufficient supply in the conservative standard demand case. The expected value is lower than the deterministic case with the Standard demand assumption mainly because the shortage costs are lower during the construction of the reservoir and at the very end of the planning period in the Low and Most Likely demand cases.

Figure 5.8
Risk Profile of Large Strategy

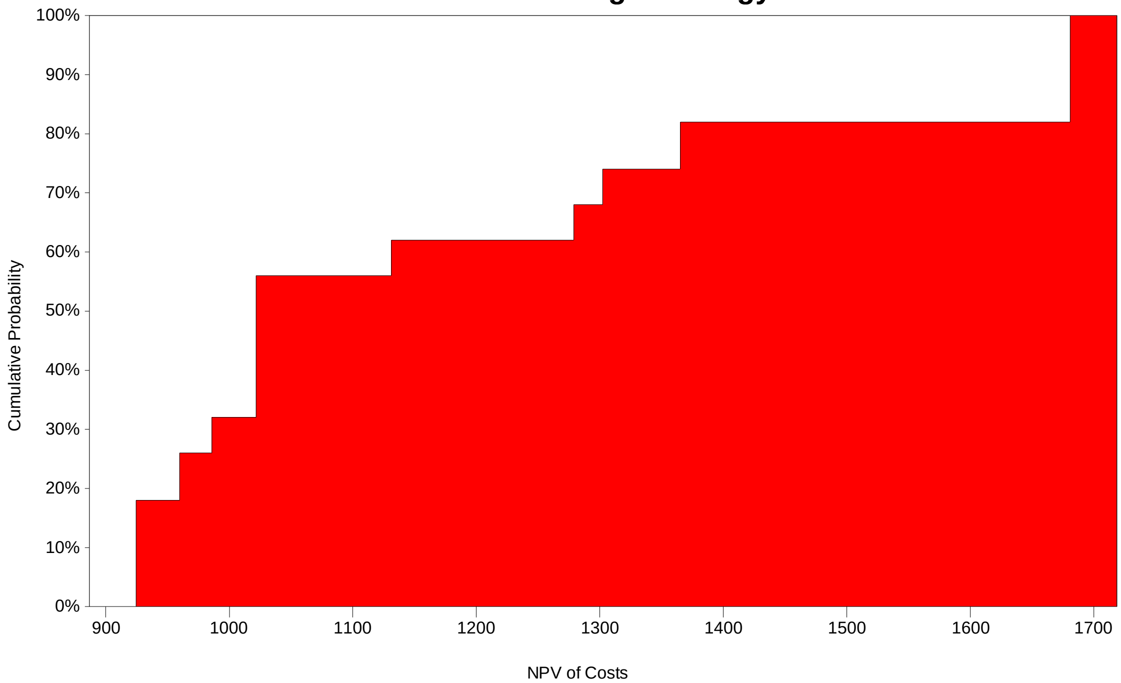


Figure 5.8 shows the range of cost outcomes possible under the large strategy. This is a cumulative probability or risk profile curve. It shows the probability that actual NPV of costs will be less than the cost on the horizontal axis. For example, there is a 62% chance that the costs will be less than £1200 Million. The worst case is £1681 Million, the cost found earlier under the deterministic model with the standard assumptions. The best case is a cost of £900 Million. This represents a situation in which the utilities' customers suffer virtually no shortages during the period and the company benefits from low operating costs and some sales of surplus water to neighbouring utilities.

However, given the substantial uncertainties, large upfront commitment, and substantial figures for regret if demand turns out to be low (£925 Million versus £587 Million in the low demand deterministic case), the utility decided to go further and analyze the problem in a real options framework.

5.3.3. Real Options Analysis

The real options analysis require additional effort, but the effort in moving from the simulation analysis to real options analysis is not so great as the jump from deterministic to simulation analysis.

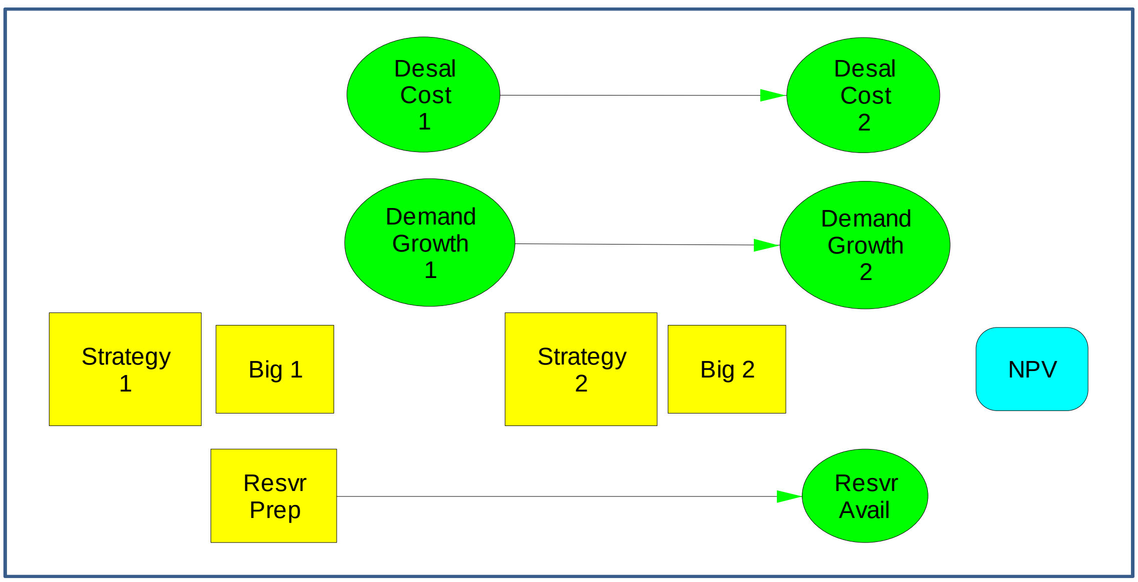
- Structuring the uncertainty model. The utility chooses the detail on the time dimension that will be examined. Problems get very large if more than two or three time periods are considered. Careful attention must be paid to the timing of decisions and learning.
- Gathering data. Some additional analysis or interviewing is needed to establish how learning occurs. Stated another way, the utility will determine how each potential outcome at the end of the first period (5 years in our example) will change the view of

uncertainties in the following period. For example, how much would very low demand in the first five years change the estimate of demand in following periods.

- Implementing the uncertainty model. Some software packages used for simulation are extremely difficult to use for real options analysis. Generally, tree based software is the easiest to use for real options. Real options analyses can be computationally intensive. Models need to be as simple as possible.
- Conducting the analysis. The analyses and results are more complex than simulation results, but very often they make more intuitive sense. Communication may take more time, but the results are usually seen as more realistic often reducing rework and debate.

Figure 5.9 illustrates the decisions and uncertainties in the problem and their probabilistic relationships when viewed in a real options way. There are two Strategy and two Big decisions in yellow representing a current decision on size and on reservoir/desalination respectively, then the possibility of delaying that decision to be made only after 5 years.

Figure 5.9
Influence Diagram of Real Options Analysis



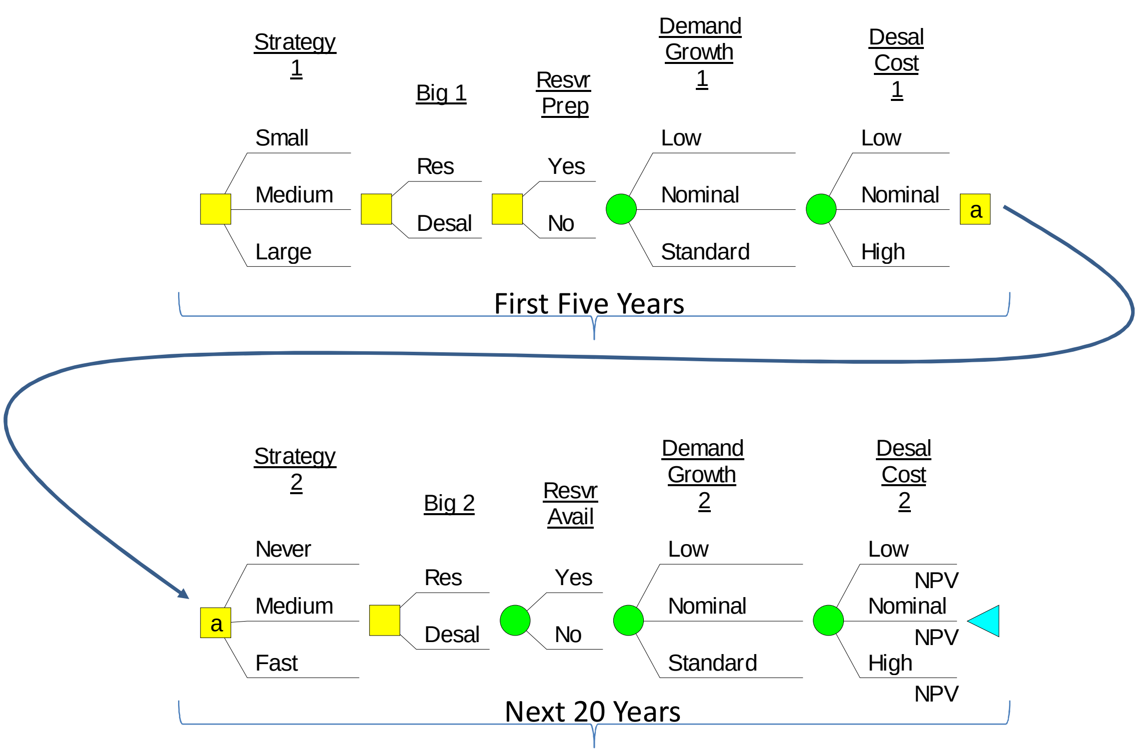
The utility also considers taking initial actions that will help preserve the right to build the reservoir, or not. These are represented by the decision “Resvr Prep.” Helping preserve the reservoir site will be costly, and the utility may ultimately not use it. But if desalination turns out to be more costly than current estimates, the utility could greatly regret not "buying insurance" on the reservoir site.

Figure 5.10, a reduced form decision tree, shows a number of uncertainties in green. The firm has a current uncertainty about desalination costs that is represented by Desal Cost 1. It is expected that current and future desalination costs are positively correlated. If costs at plants built in the next 5 years are higher than currently expected, the costs following that period are also expected to be high. This probabilistic dependence of future costs on present costs is indicated by the arrow in the figure. A similar relationship exists between the demands in period 1 and 2.

Dependence relationships can also exist between a decision and an uncertainty. "Resvr Prep" represents the decision to either spend or not on activities that will make getting planning permission the reservoir more likely. If the activities are undertaken it will raise the likelihood that the reservoir will be permitted.

The optimization was made again, but now with the multi-stage structure shown in Figure 5.10.

Figure 5.10
Real Options Decision Tree



Initially three decisions are made:

- Should the size of the initial capacity investment be Small, Medium or Large? Large includes the construction of a big resource in the fourth year.
- Under Large, should the big resource be a reservoir or a desalination plant?
- Under Small and Medium, where no big resource is built in the first five years, should an investment be made in reserving the ability to permit the reservoir?

The utility then has a five year period in which it undertakes the initial actions and learns about desalination costs, demand, and the ability to permit the reservoir. Following this five year period, the utility makes its final decisions on whether and when to develop the reservoir or the desalination plant. It has learned, but its knowledge is imperfect and uncertainty on the ability to get permission to build the reservoir, demand growth, and desalination cost all still exist.

The option structure analysis provides interesting insights. First, the preferred initial strategy is Medium, a strategy that was not preferred in either the deterministic or probabilistic analysis. The expected cost of doing this initially then whatever is best after that is £1162 Million. The second best initial option is the Large variant where the reservoir is built in 4 years – and which was the best strategy in the deterministic analysis and the probabilistic analysis. The expected cost of this option is £1182 Million, as it was under the probabilistic analysis. The best strategy found with a real options approach therefore achieves £20 Million expected cost savings over the best strategy found with deterministic or probabilistic methods.

Figure 5.11
Strategy Chart

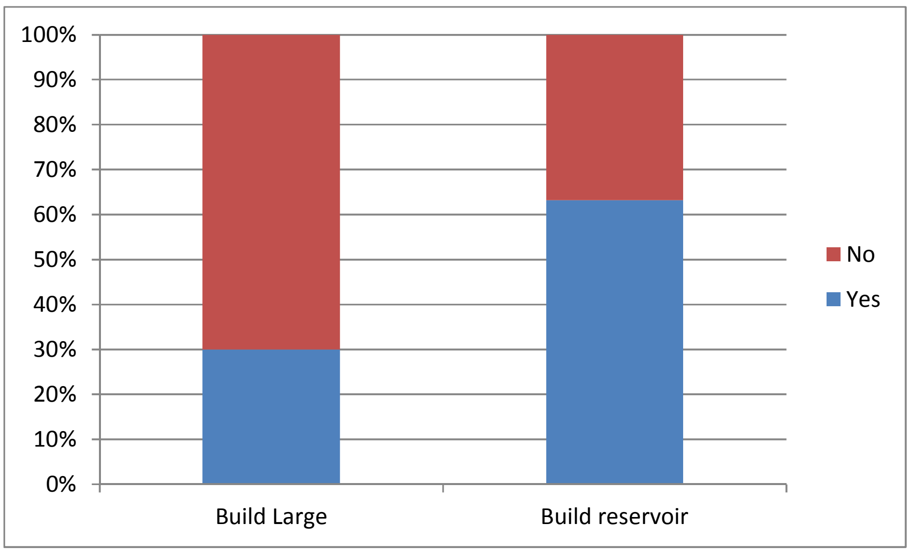
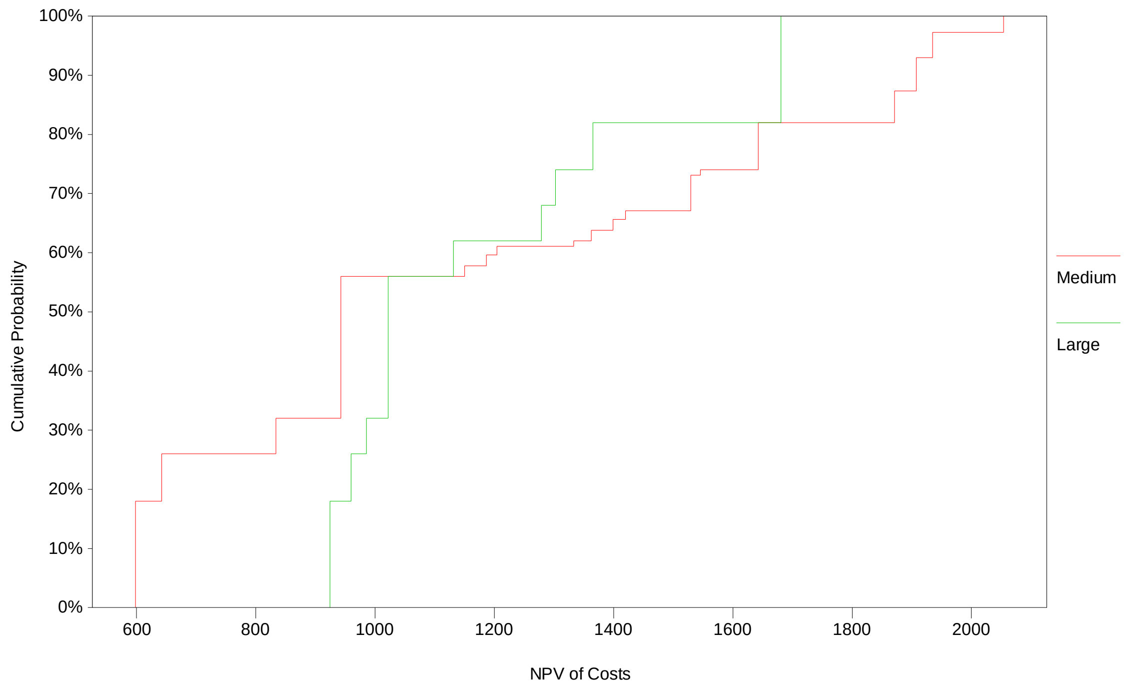


Figure 5.11 shows the relative frequencies of different options strategies. When we delay to learn, we believe there is a 30% probability that we will eventually build a large resource. That is, the sums of the probabilities of all the cases in which we build a large resource is 30%. If we build the large resource, there is a 63% probability it will be the reservoir.

Given the assumptions about the effectiveness of work to preserve the reservoir option, it is worthwhile to invest just over £4 Million in the initial period in preserving the reservoir option. If the cost of preserving the reservoir option is zero, our decision is of course "Yes" preserve the option. The utility finds this by starting the cost at zero and increasing the cost of preservation until the answer flips from "Yes" to "No." This is the maximum we will pay to preserve the reservoir option.

Figure 5.12 shows the probability distribution of costs associated with the flexible initial Medium decision and the inflexible initial Large decision. The profiles of the two decisions are unusual. Typically, a more flexible alternative that has lower expected cost will also have the least risk. However, that is not the case in this analysis; the initial options have different flexibility attributes. The Medium investment allows more flexibility in terms of the total investment and the type of investment. This leads to the opportunity of much lower costs over many scenarios. The lowest cost with the Medium strategy is about £600 Million as compared to £925 Million for the Large. However, the Large investment creates another kind of flexibility - that of responding quickly to increases in demand. This leads the Large investment cost distribution to have a shorter right hand tail. In the worst case after selecting Medium, costs reach almost £2055 Million. In the worst case after selecting large, costs reach £1681 Million. In this case the company might want to consider not only the modest difference in the expected cost values, but also whether it wants to avoid the high cost tail of the distribution – knowing this will cut off the low cost possibility as well.

Figure 5.12
Cumulative Probability Distribution of Costs



5.4. Example from NERA's Work with Australia's Water Service Companies

NERA undertook a review of real options for the Water Services Association of Australia. The purpose of this project was to introduce the real options approach to water services companies in Australia. The project included an extended hypothetical case study, an analysis of a realistic water investment problem.[38]

- Background
  - Firm with diverse asset portfolio to deal with hydro variability, climate change and other risks
  - Concerned about long-term risks and choosing among many alternatives for large near-term investments
- Approach
  - Understand drivers, especially hydro variability and climate change
  - Quantify risk associated with alternative strategies
  - Develop and document benefits of multifaceted strategy
- Benefits
  - Buy-in from management, customers, regulators
  - Investment roadmap for use as conditions evolve

Some of the figures showing the structure of the analysis and results appear below.

[38] For a full explanation of the case beyond this outline and summary figures, see: Borison, Adam; Gregory Hamm; Sally Farrier; Geoff Swier. Real Options and urban water resource planning in Australia. WSAA Occasional Paper No. 20, Water Services Assciation of Australia, April 2008.

Figure 5.13
Option Analysis Structure

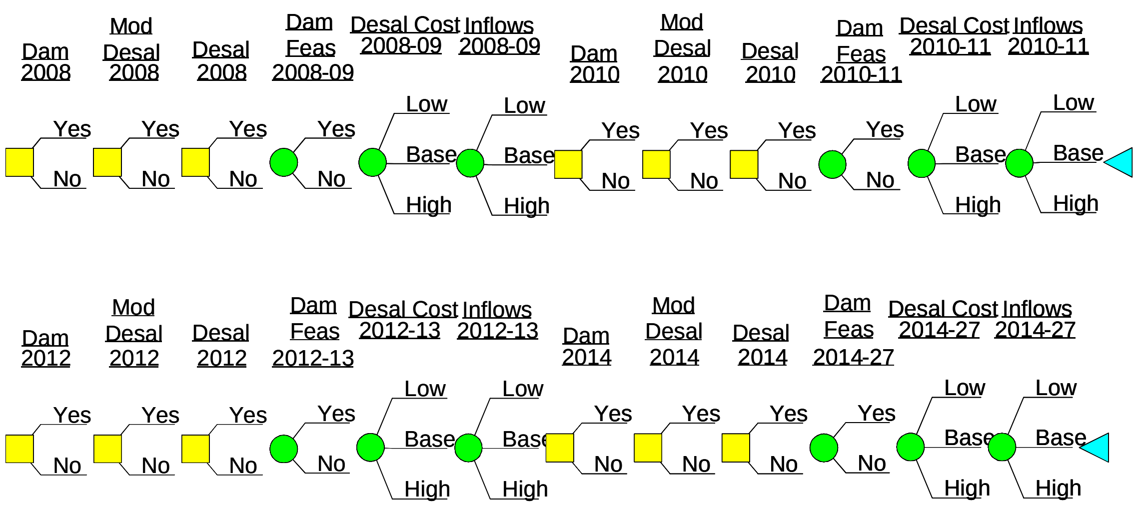


Figure 5.14
Uncertainty Data: Desalination Cost (2014-2017) Learning

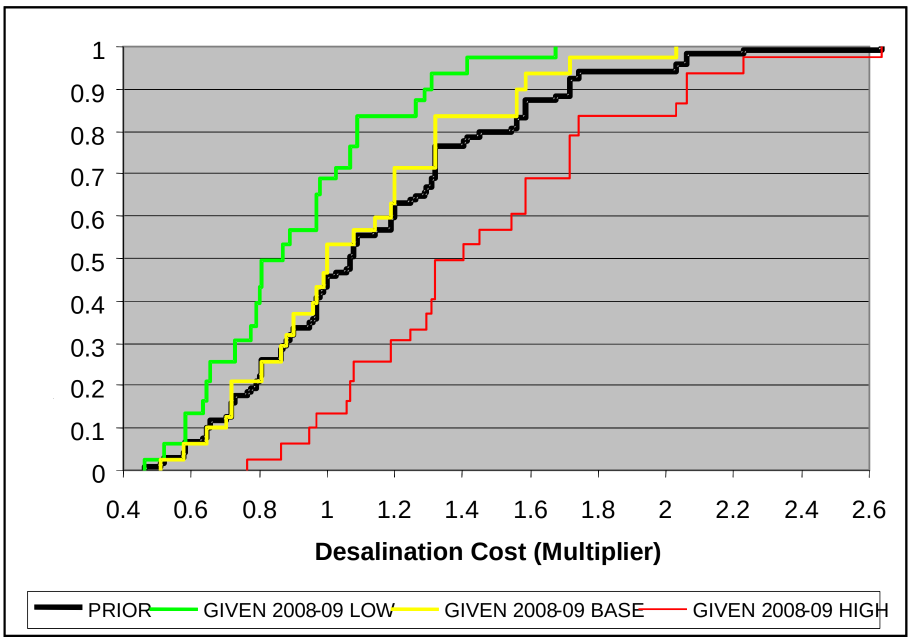


Figure 5.15
Likelihood of Management Plan

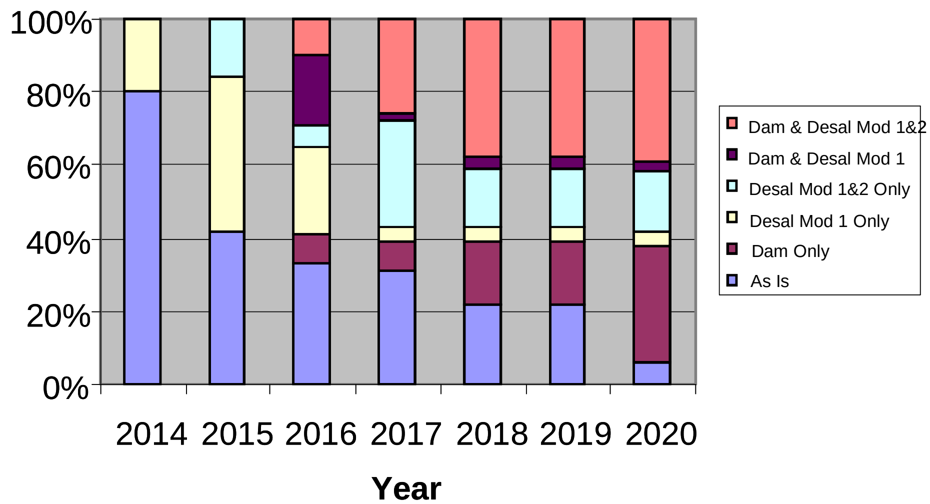
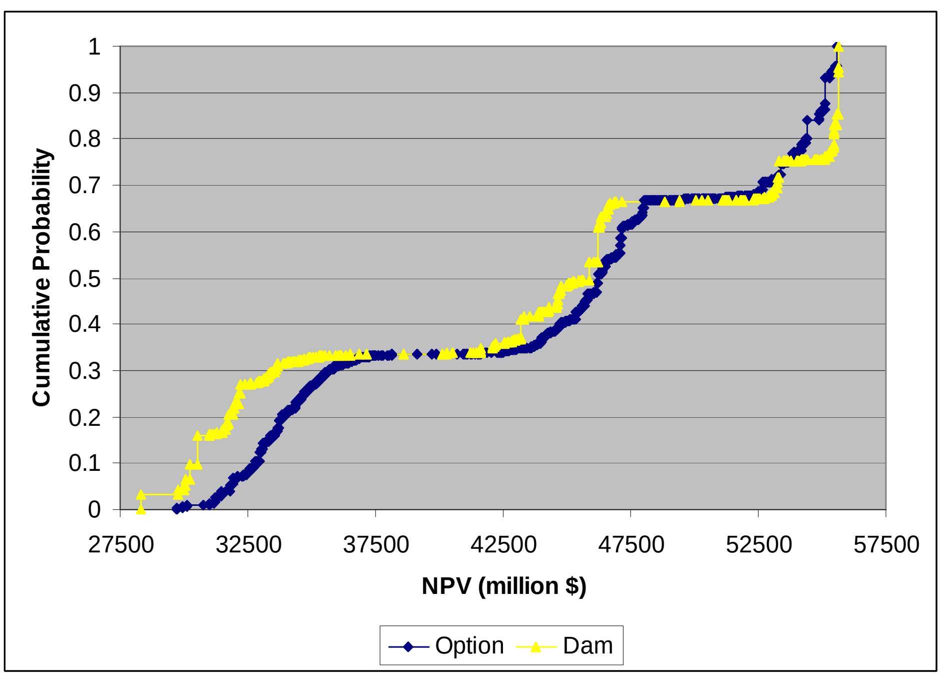


Figure 5.16
Option Analysis: Portfolio Risk Comparison



6. Summary and Assessment of Feasibility and Applicability

6.1. Summary of the Content of the Report

Real options analysis is an approach to decision making that formally recognizes uncertainty and examines how current decisions limit or expand our ability to learn and react in the future.

There are three necessary conditions for real options analysis to be of value:

- **Uncertainty:** Without uncertainty, there is no need to consider the possibility of switching strategies in the future.
- **Learning:** With uncertainty but without learning, there is no reason to postpone any decision-making.
- **Flexibility:** With learning but without flexibility, there is no ability to take advantage of that learning and switch strategies.

Real options thinking may be applied in optimising at least three types of decisions in water planning in England and Wales:

- Formation of water company long term supply demand plans
- Examination of the merits of undertaking an individual scheme, within the prevailing WRMP context
- Decisions on water operations, such as optimizing control curves for use of stored water, or for instigation of a hosepipe ban.

The potential benefits of moving to real options approaches are difficult to scale because they are situation dependent, but in aggregate the benefits could be substantial.

The costs, public and regulator unfamiliarity, and lack of staff skills and experience are all significant potential barriers to the adoption of probabilistic methods and, specifically, real options analysis. The barriers can be addressed through training and communications, and demonstration projects.

6.2. A Comparison of Real Options to Current Approaches

Table 6.1 compares current planning approaches to real options across the dimensions of decision quality, cost, and communication and acceptance.

- Decision Quality. The real options approach models the decision environment of water utilities more realistically. Its chief benefit is more accurate valuation of alternatives; and therefore, better selection of alternatives, saving customers money or providing better services at similar cost. The advantage will be small when uncertainty, learning, and flexibility are small; conversely, it will be large when those attributes are large. An exception to the rule can occur when detail with respect to resource alternatives is important. For computational practicality, real options sometimes requires simplification or aggregation of alternatives.
- Costs. In our experience, real options usually costs more than traditional analysis. Its use requires additional training and additional data gathering. The cost differential can be large on initial applications, but drops rapidly as both producers and consumers of analysis become more familiar with the approach. There are two cases where real options can produce significant cost savings. 1) After adopting a real options approach, many organizations find that they are spending excessive sums on meaningless details of analysis. When an organization realizes that irreducible uncertainties, with regard to such factors as climate change, input costs, and future demand, result in standard deviations of future costs that are 20%, 50%, or 100% of the mean, they may rethink and streamline their whole analysis process. 2) Because real options develops a more realistic view of the future, conflicts and inquiries about long-term plans are often reduced; thus, reducing rework and other costs of controversy.
- Communication and Acceptance. Traditional forms of analysis develop simpler results and are more familiar to stakeholders. Use of real options will necessitate more time and effort in communication in the short run. However, real options analysis produces results that are more complete and more realistic. Once stakeholders understand real options results their clarity, completeness, and logic enhance communication with stakeholders.

Table 6.1
Current Approach Versus Real Options, Issue by Issue

Issue	Current	Real Options
Issues related to decision quality		
Does the method lead to appropriate answers?	Basic method is satisfactory for low uncertainty and low flexibility. Advanced method is satisfactory for some uncertainties only.	Superior in situations with high uncertainty, flexibility, and learning. Recognises the value of flexible solutions.
Uncertainty and learning	Largely ignores learning. Will provide inaccurate NPV estimates where probabilities of events are significantly skewed.	Explicitly recognizes flexibility and learning. Takes into account shapes and interactions.
Detail	Addresses a high level of detail in alternatives. Mathematical programming approaches in particular are capable of looking at millions of combinations.	Addresses a high level of detail in future events, often requires simplification of the range of alternatives.
Issues related to cost of analysis		
Cost of analysis vs. its benefits	Usually less costly. May miss better solutions.	Generally more costly, though an approximate ROA may be cheaper (and better) than very “exact” LP/IP SDB.
Data	Requires a known data set.	Requires additional estimates of probabilities and of costs under alternative scenarios.
Training	Most organizations have skills in place. May need outside support for mathematical programming or other sophisticated analyses.	Requires acquisition of significant new skills or use of outside consultants. The most basic skills can be obtained in combination of 2-3 days training and 1-2 joint projects.
Issues related to communication and acceptance		
Comprehension	Stakeholders familiar with present methods of analysis and presentation. Authorities not always convinced.	Stakeholders may find probabilistic concepts and flexible strategies difficult to understand. Level of comfort rises with experience of both presenters and reviewers.
Completeness	Plans are incomplete and may provide unwarranted assumption of future certainty.	Plans clearly indicate potential future actions and drivers of change.
Clarity	Assumptions regarding risks are not quantified and can be misinterpreted.	Assumptions regarding risks are explicit, lessening chance for miscommunication.

6.3. Recommendations on Real Options for Water Decisions in E&W

There are many water supply demand decisions in England and Wales which exhibit the flexibility, uncertainty and learning characteristics necessary to make real options thinking valuable above and beyond deterministic and probabilistic single-plan approaches. The financial benefits, which correspond to lower customer bills, could be substantial in particular cases and in total.

Much of the information and modelling capability needed to apply real options thinking is already held by water companies, and in some cases water company analyses are bordering on a real options approach. A number of parties are looking for a more robust and coherent approach to incorporating uncertainties into supply demand planning – which is what real options modelling provides. Ways to limit the costs of the extra steps necessary and to build experience focusing on the most promising applications are available and should be adopted. Our case examples for stylized situations in England and Wales demonstrate that even very simple applications of the real options approach can generate a richer understanding of the problem and solutions, and find a better overall result.

We consider that the water regulators and companies should begin deliberately to build experience of real options approaches, in a stepwise fashion, by:

Immediate actions

- making it clear that a convincing real options analysis will be well received by the regulators, particularly on large, complex, and contentious decisions;
- encouraging real options analysis of decisions about strengthening links between water companies; and
- undertaking joint training exercises and demonstration cases.

Intermediate actions

- considering how the WRMP guidance, and the SDB scrutiny and incentives which will determine the effects on customers and investors, need to be revised to foster real options thinking where appropriate;
- making preliminary checks, zone by zone at the appropriate point in the next WRMP round, for the presence of the flexibility, uncertainty and learning possibilities that make a real options approach worthwhile. If some companies can use real options thinking to produce optimal strategies in the next round that should be welcomed;
- for subsequent WRMP rounds, revising the WRMP and SDB guidance to suggest application of real options analysis in specified categories of zone-situations; and
- jointly developing common scenario frameworks and common probabilities to use for longer term WRMP work such as climate change uncertainty.

Supporting actions

- developing real options and probabilistic analysis in parallel. Quantitative probabilistic analysis and quantitative real options analysis go hand-in-hand;
- considering long-horizon real options work for long-lived investment, e.g. introducing climate change learning in scenarios for climate drift over several decades after year 25;
- expanding medium-term uncertainty analysis beyond supply and demand forecasting into regulatory, technological, commodity price, and customer response factors. The appropriateness of addressing these other uncertainties should be affirmed; and
- recognizing that placing an economic value on water, in the environment, and on customer water shortage, will lead to formulations which make real options easier to apply, and will also result in more potential for value creation via real options analysis.

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