Approaches for estimating and benchmarking costs for large scale water infrastructure projects

RAPID and OFWAT

22 June 2022

FINAL REPORT

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Document Suite

Workstream	Title	Doc Type
1	**Approaches for estimating and benchmarking costs for large scale water infrastructure projects**	**Report**
2	Water Infrastructure Cost Estimation Principles and Benchmarking – Cost Components, Drivers and Database Structure	Report
3	Water Infrastructure Cost Estimation Principles and Benchmarking - User Guide	Report
	Water Infrastructure Cost Estimation Principles and Benchmarking Appendix A - Inclusions and Exclusions	Report
	Water Infrastructure Cost Estimation Principles and Benchmarking - User Tool	Excel Tool

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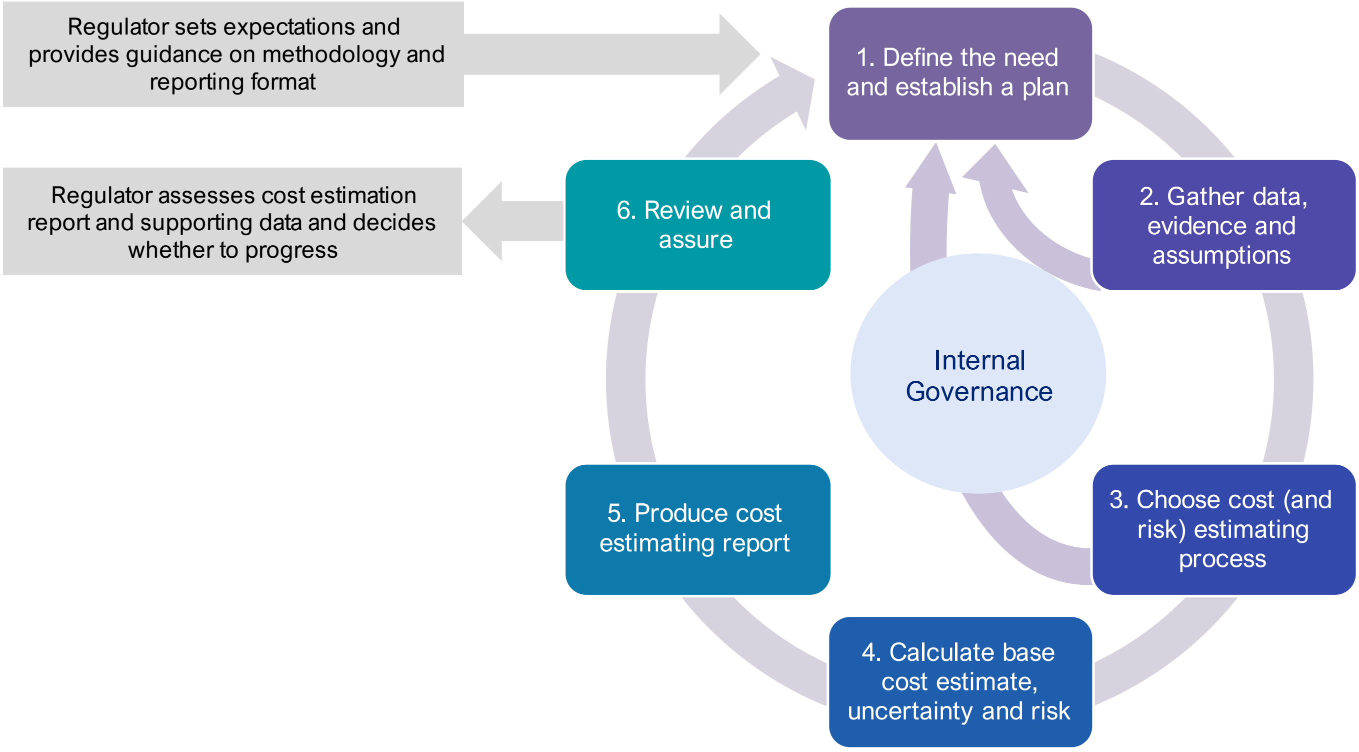
EXECUTIVE SUMMARY

The estimating of costs for large-scale, strategic infrastructure projects can be challenging, given they tend to be inherently risky, subject to greater uncertainty than smaller, less complex projects, and have fewer, relevant prior projects to benchmark from. Such challenges are likely to apply to the strategic water resources solutions being developed by water companies. Nevertheless, a large body of guidance has emerged on how best to estimate the cost of a proposed infrastructure project at each stage of the project's development, which we summarise in this report.

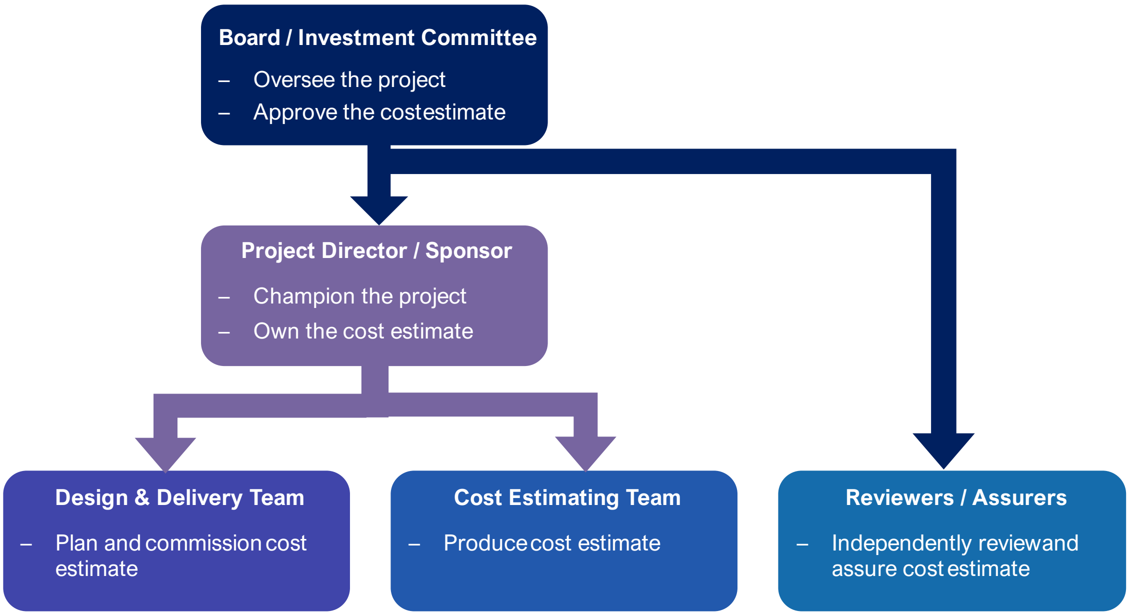
The diagram below, outlines the key steps in developing a cost estimate and outlines the potential role of Ofwat, as the economic regulator, in steering the development of the cost estimate, and using it to inform decision making. This is an iterative process, as the cost estimate is revised as a project evolves from inception, to design, to procurement, to construction and finally, to commissioning and operation.



Governance of the cost estimate

The governance of a cost estimate should be closely aligned with the governance of the project itself, with the project leadership ultimately owning the cost estimate. There will typically be a cost estimating team responsible for developing the cost estimate and reporting to the project leadership. And for larger projects there will also be a need for an independent reviewer, who can assure the cost estimate and review the cost estimating process. Where cost estimates are required for regulatory purposes, we would also expect the cost estimate to be reviewed and signed-off by senior leadership, such as the water company board.

The diagram below illustrates the key functions and their roles in relation to the cost estimate, and the lines of accountability.



Planning the development of the cost estimate

Whenever a cost estimate is being developed, it needs to be clear what the purpose of the cost estimate is and for that purpose to be communicated to the cost estimating team. This helps ensure that sufficient resources are invested in developing the cost estimate and the most appropriate techniques are used, such that the cost estimate that is ultimately developed is fit for purpose. Cost estimates are typically required for one of three reasons:

- Comparing the costs of several competing solutions against one another;
- Informing decisions on whether to proceed with a scheme for further development, or the final decision on whether to invest in the scheme; and
- Determining the budget for the scheme

Cost estimates are also most valuable when they follow a consistent cost structure throughout the project lifecycle. This allows users of the estimate to better understand how it is evolving with the project's development. It also enables comparisons of cost estimates across different projects. And it also allows the outturn costs from a project to subsequently be used to inform cost estimates of future projects.

Gathering data and evidence

The gathering of data and evidence to produce a cost estimate will be led by water companies at least initially. We expect in most instances, water companies will use their own cost data supplemented with other sources where proposed activities are outside the scope of their previous experience. The quality of data that is fed in will have a material influence over the robustness of any cost estimate.

Key issues for internal company oversight or regulatory oversight are likely to be:

- Receiving assurance that appropriate and sufficient sources of evidence are being used to underpin the estimate at each stage, and there is transparent presentation of assumptions given that there will always be compromises.

- Considering whether there are opportunities to facilitate data sharing between water companies and with relevant bodies outside the water sector noting that such data may be considered confidential.

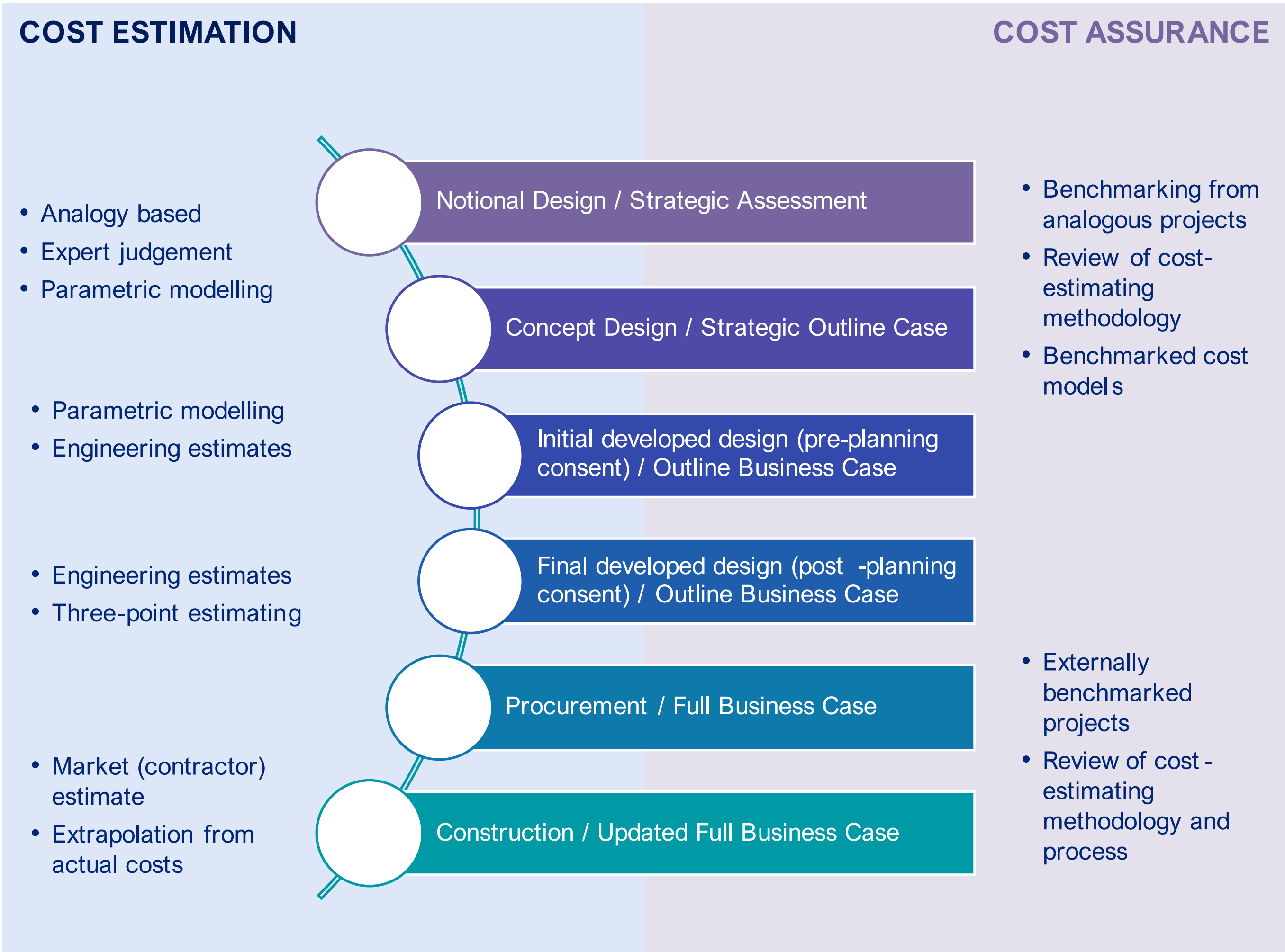
Estimating techniques

Cost estimating techniques can be broadly split into two categories: top-down and bottom-up estimates. Top-down is likely to be more appropriate for earlier stages of project development, with bottom-up estimates used as the project matures.

Water company senior oversight or regulatory oversight will be most applicable when checking that the cost estimating technique is appropriate to the context of the project, its stage of development and how the cost estimate will be used. The rationale for selecting a technique should be explained, with a discussion provided around any limitations. This should also feed into expectations around how cost estimates will be developed or refined at subsequent stages.

Also relevant is the method for undertaking an independent review or assurance of the cost estimate. This can be broadly split into either reviewing the cost estimating methodology and making sure it has been undertaken appropriately, or using an alternate technique (e.g. a top-down method) as a benchmark or sense-check against the main estimate.

The figure below summarises the choice of cost estimating and cost assurance techniques available, and their appropriateness at different stages of project development.



Bias and uncertainty

Cost estimates are likely to have varying degrees of uncertainty associated with them. These can be split into:

- The inherent uncertainty applicability of the input data to estimate the costs of a new scheme, or the inherent uncertainty related to the design of the scheme.
- Biases on the part of the estimators that may lead to cost estimates being overly optimistic.
- Discrete risk events that may or may not materialise, which may affect the cost of the scheme.

The key issues for internal company oversight or regulatory oversight are likely to be:

- Ensuring that companies demonstrate complete cost estimates that appropriately account for uncertainty at each stage. This will be particularly relevant once planning consent is obtained and a final investment decision is being made, as cost estimates at this stage will likely serve as the foundation for setting budgets. It is generally inappropriate to use earlier stage cost estimates as the basis of setting budgets, given the degree of uncertainty. At these earlier stages, costs should be presented as a range with a clear expectation that the budget estimate prepared later will fall within that range.
- Confirming that interactions between risk and uncertainty have been correctly identified and accounted for.

Early-stage cost estimates should be presented as a range to reflect the greater degree of uncertainty at that stage. At later stages, where point estimates are required for planning or budgeting purposes, there should be consideration of the appropriate p-value to use. This will be used to determine an appropriate contingency allowance.

1. INTRODUCTION

This report presents a summary of approaches to cost estimating and cost assurance for water and wastewater infrastructure projects, with a particular focus on strategic water resources solutions such as desalination plants, wastewater reuse plants, water reservoirs, and water transfer schemes. Given the focus on strategic water resources solutions, this report primarily discusses the issues related to estimating the costs of infrastructure projects that are large, complex and/or include a degree of innovation or novelty.

Large, complex, or novel infrastructure projects typically present more challenges and risks compared to smaller, simpler, and more routine projects. Such projects are inherently riskier, they are more challenging to cost benchmark, and there is a greater tendency for project teams to be over optimistic about what can be delivered.[1] As a result, greater care needs to be taken to develop cost estimates, and there needs to be an enhanced focus on cost estimates appropriately reflecting the inherent uncertainty. Nevertheless, the approaches outlined in this report can be applied to the cost estimation of smaller projects, but with activities appropriately scaled back to reflect what is proportionate.

The methods summarised in this report can be used by Ofwat to better understand the processes undertaken by water companies when costing water infrastructure at different stages of project development. The methods are generally applied to estimating project costs (i.e. the capital expenditure associated with the development of an infrastructure asset up to the point of commissioning). However, the methods can be extended to also estimate post-commissioning costs (e.g. operations, maintenance, renewals, and end-of-life costs) and to estimate carbon impacts. The methods presented in this report could also be used as a reference for the water industry more broadly when estimating and evidencing costs for large water infrastructure projects.

This report does not cover the estimating of social or environmental costs and benefits, as would typically be captured within cost-benefit analysis or other economic appraisal methods.[2] As per the water resources planning guidance, water companies are required to consider such environmental and social impacts, in addition to the financial costs as captured by the project cost and whole life cost estimates. However, relevant techniques for the estimating of such impacts, whether in monetised form or as a non-monetised assessment, is outside the scope of this report.

We have consulted numerous sources to develop this report, including:

- the HM Treasury Green Book;
- the Infrastructure and Projects Authority's (IPA) Cost Estimating Guidance and Best Practice in Benchmarking;
- the All Company Working Group Cost Consistency Methodology developed with Mott MacDonald;
- academic literature on cost estimating; and
- case studies of historical projects and associated National Audit Office reports.

As this document is intended to be succinct, it provides a high-level but practical summary of approaches for cost estimating. The sources we have drawn upon provide further detail.

The remainder of this report covers: the generalised process for developing and using cost estimates, ownership and governance structures, structuring and presenting cost estimates, cost estimating techniques and how they

[1] See National Audit Office (2018) Survival guide to challenging costs in major projects, available at nao.org.uk and Flyvbjerg, B. (2021) Make Megaprojects More Modular, available at hbr.org

[2] Environmental Agency, Natural Resources Wales and Ofwat (2022) Water resources planning guideline, available at gov.uk

should be used at different stages of project development, the treatment of risk and uncertainty, and techniques for cost assurance. It is structured as follows:

- Section 2 details the overall process for developing and revisiting cost estimates
- Section 3 introduces the concept of a consistent cost structure for presenting cost estimates
- Section 4 discusses governance arrangements for developing and using cost estimates
- Section 5 outlines sources of data and evidence
- Section 6 details the various cost estimating techniques and their appropriateness for the various stages of development
- Section 7 covers the treatment of risk and uncertainty
- Section 8 addresses methods for cost assurance.

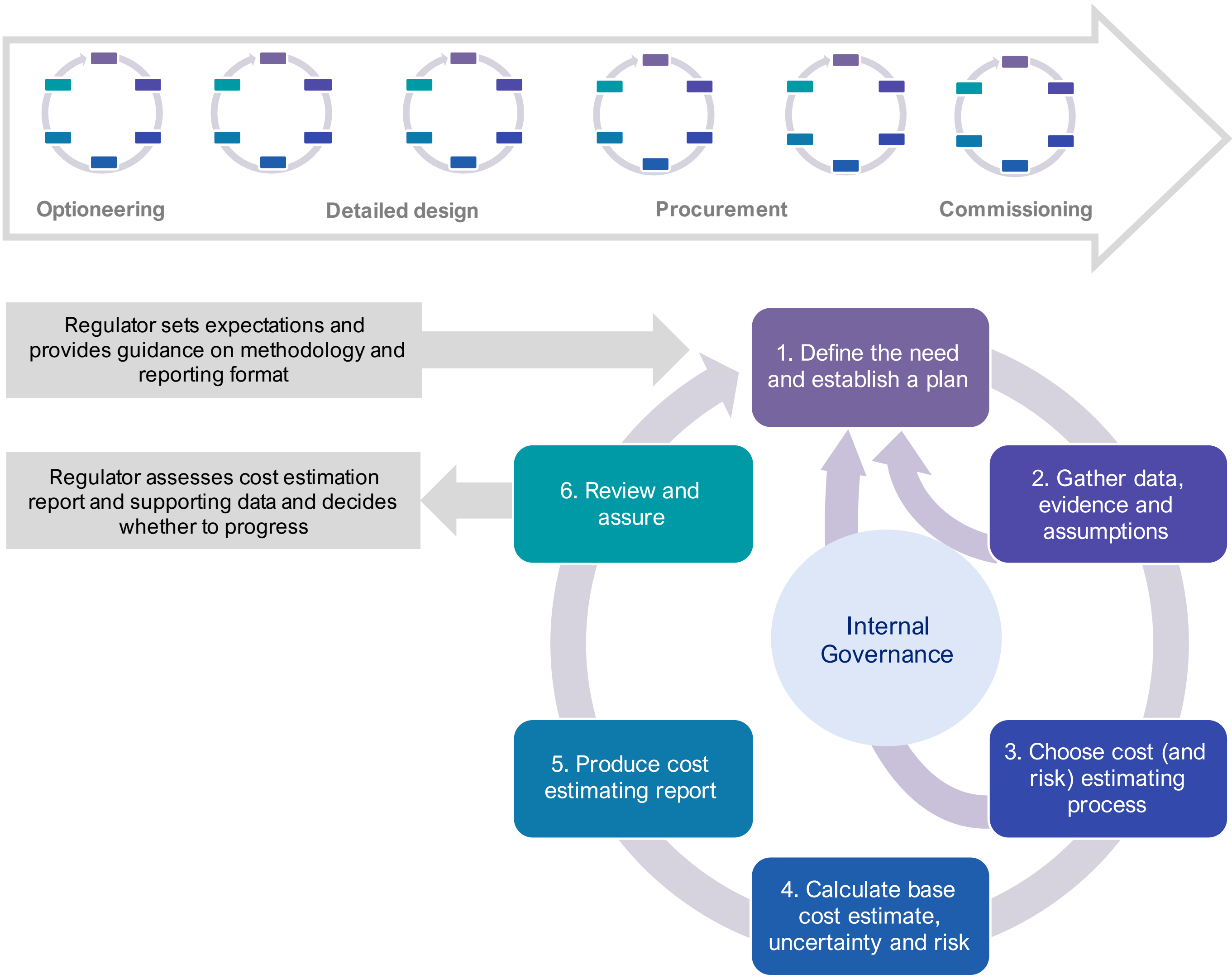
2. COST ESTIMATING PROCESS

The process for developing cost estimates is relatively well-established. It is an iterative process where cost estimates are continually refined as project develops from inception to execution. When presenting estimates to decision makers and reviewers, the methodology employed and the assumptions and data sources used, need to be clear and sufficiently detailed to understand the robustness of the cost estimate.

Cost estimating is an iterative process, with cost estimates revised and refined as projects evolve from initial concept to detailed designs, construction, and live operation. The basic steps involved in developing and revising cost estimates at each stage of the project lifecycle are broadly the same.

In this section, we outline the general process for developing cost estimates in terms of the key steps involved, adapted from the IPA Cost Estimating Guidance. As shown in Figure 1, this is an iterative process with the evidence and insights gathered from each stage used to inform the development of increasingly mature cost estimates.

Figure 1: Cost estimating process diagram



Cost estimating in the context of the RAPID Gated Process

The Gated Process introduced by RAPID has been designed to accelerate the development of strategic regional water resources solutions. At each stage gate, Ofwat will decide whether companies should continue to be allowed funding to further investigate and develop a solution to the next gate. Consequently, there is an enhanced role for the regulator in both setting expectations for the cost estimate at each stage, and assessing the cost estimate produced by the water company for each proposed solution, to inform decision making.

In the remainder of this report, we outline where Ofwat (or in some cases RAPID) may wish to take an active role in steering the development of the cost estimate, what it may wish to consider when seeking assurance of a cost estimate, and how cost estimates should be interpreted when informing decision-making.

2.1. Key steps for developing cost estimates

Before companies commence Step 1, guidance should be provided around the format, outputs, inclusions and exclusions for the cost estimates which may apply at each stage. Depending on the type of project and the stage of development, this guidance may be provided by the regulator (i.e. Ofwat or RAPID), or it may be internal company guidance. [3]

A regulator may wish to provide such guidance where it intends to undertake enhanced scrutiny of cost estimates, where it intends to undertake benchmarking exercises, or where it expects to receive a certain level of assurance around the cost estimates. The guidance will need to include a cost structure, or 'common language', for how costs will be captured, to facilitate benchmarking and like-for-like comparisons between different projects, to better understand how cost estimates are evolving as a project progresses, and to support future cost estimating exercises. A proposed initial cost structure is presented in Section 3; it is likely that this will need to be refined and further developed over time.

Step 1: Define the need and establish a plan

For companies, the initial phase of the cost estimating process will be dedicated to preparing for and planning the approach to developing a cost estimate. This planning phase would typically cover:

- Developing a shared understanding of the context, scope and objective of the project and the implications of this for the estimate.
- Determining the resource requirement to deliver the cost estimates.
- Establishing a governance framework for the cost estimate, including lines of accountability, collaboration with internal stakeholders (e.g., design teams, project leadership), and assurance and sign-off protocols.

This topic is covered in more detail in Section 3, alongside broader commentary around ownership and governance.

Step 2: Gather assumptions, data, and evidence

Once the project has been scoped and planned, the work can begin on defining options for the solution and collecting the data and evidence which will inform the cost estimates. The starting point for this should be to understand the depth and breadth of the available evidence, keeping in mind that data and evidence may come from a combination of internal and external sources. The search for data should be guided by the cost structure defined during the planning phase. To the extent that there are gaps in the available data and other evidence, this should be fed-back into the project plan, with subsequent adjustments made to resourcing, expectations, and decisions around the target level of maturity.

[3] See RAPID (2022) *Strategic regional water resource solutions guidance for gate two*, for an example of such guidance. Available at ofwat.gov.uk

This step is covered in more detail in Section 5.

Step 3: Choose cost (and risk) estimating techniques

There are a range of different cost estimating techniques available; some of the more commonly used ones are introduced in Section 6. The appropriateness of different techniques will depend on the novelty and complexity of the project, its maturity and associated scheme design, data availability, and how the cost estimate will be used. The cost estimating technique for a particular project will have been identified on the interim basis during the planning phase but may need to be modified in light of the available evidence.

At later stages of project development, the choice of cost estimating technique would need to be considered alongside the technique used to estimate and adjust for risk. This is because certain cost estimating techniques implicitly address some sources of uncertainty.

Similar to Step 2, if there is a need for material amendments to the cost and risk estimating techniques after the gathering of data and other evidence, this should be reflected in adjustments to the project plan and resourcing assumptions.

Step 4: Calculate base cost estimate, uncertainty, and risk

With evidence collected and documented and a methodology bedded down, the base estimate of cost and the time required to undertake the project can be prepared. The base estimate will include a point estimate representing the most likely outcome based on the assumptions made up until that point, and should include an adjustment for optimism bias where appropriate. Alongside the base estimate, there should be a presentation of a likely range of costs based on the level of uncertainty, and an analysis of the risks. The level of uncertainty may be addressed implicitly through the cost estimating techniques deployed, or it may require making separate adjustments. This step is covered in more detail in Section 7.

Step 5: Produce cost estimate report

The cost estimating team should produce a report documenting the process they have undertaken and the outputs of Steps 1-4, including the cost and time estimates and the underpinning methodology, data, and assumptions. This report should also include an estimate of the cost and an estimated cost range, with a clear articulation of the associated level of confidence in the estimate and identification of any material areas of the estimate that are particularly uncertain.

Step 6: Review and assure

After the cost estimating team have produced an initial version of the report in Step 5, the steps for independent review and cost assurance that were built into the project plan can be undertaken and an assurance statement/report produced.

Sign-off and next stage

The completion of Step 6 means that the cost estimates can be submitted for evaluation and sign off. Each project will have an internal sign-off process through the internal governance processes detailed in Section 3, though certain projects may also require regulator sign-off. If the project progresses through to the next stage of development, this process will be repeated with a variation of Steps 1-6.

When planning the next iteration of the cost estimate, particular consideration should be given to:

- how the revised cost estimate will be used and what the aim is for revising the cost estimate,
- whether the same options will be estimated or whether some will be discounted,
- the extent to which the design of the options be progressed to reduce uncertainty, and
- whether further resources will be required to mitigate some of the data or methodology limitations of the existing cost estimate.

3. OWNERSHIP AND GOVERNANCE

The ownership and governance of cost estimates are important components of project development. For large projects with cost risk potentially borne by water customers (at least up to a certain stage) there is a need to establish good governance practice. This should include setting expectations for the process of producing the estimate and for independent assurance of it at each stage.

Key governance issues for large water infrastructure projects are likely to include:

- Ensuring that estimated costs are complete and realistic in the early stage of development and is business plan costings, and that there is sufficient provision for risk and uncertainty that is commensurate with project stage. There is pressure on project teams to minimise costs in order to obtain a positive investment decision. As a result, cost overruns are often the result of a failure to properly estimate costs in the initial stages of project development.
- Considering whether the project timeline is realistic. Large projects often come under significant pressure to deliver earlier than is really practicable, creating additional cost risks when these projects are inevitably delayed.

3.1. Governance of project cost estimates

In the initial stages of project development, we expect that a water company or perhaps multiple water companies will be in the lead in developing a potential scheme through early stages of project development, and providing associated cost estimates. We consider it unlikely that a third party will take risk on a project prior to planning consent being granted. As such, the water companies will ultimately own the cost estimates of any proposed scheme.

We would typically expect the sponsoring water companies to put in place an appropriate governance structure around the cost estimates that ties into the wider project governance structure (covered in the next section). For each proposed scheme, depending on the project maturity, we would expect there to be:

- A **Project Leadership** function. This may start off as a single **Project Sponsor** to champion and lead the project, or as projects grow in complexity and progress through the various stages, this may split into two roles with a Project Sponsor responsible for oversight and a **Project Director** responsible for day-to-day leadership. These roles will be responsible for reviewing and challenging the cost estimates produced and will, alongside the Senior Oversight function, be the ultimate users of the cost estimates in decision making.
- A **Project Delivery** function. At initial stages, this may consist solely of a **Project Manager** to oversee the work, but over time will expand into a larger **Project Design and Delivery Team** responsible for the delivery of day-to-day activities. These roles will be responsible for commissioning cost estimates and assurance, providing appropriate guidance.
- A **Cost Estimating** function consisting of either a single **Cost Estimator** or, more likely, a **Cost Estimating Team**, responsible for producing cost estimates using an appropriate mixture of internal and external resources.
- **Independent Reviewers and Assurers**, responsible for conducting independent reviews of the cost estimates, by reviewing the process or by undertaking benchmarking exercises or through a mix of the two. Such reviews and assurance would typically report directly to the Senior Oversight function.
- **Senior / Board Oversight.** At inception stage, this oversight role may be covered by the Project Sponsor. However, for projects that progress beyond the inception stage or for more strategic projects, we would expect senior oversight to come through the **company board** through an **investment sub-committee**. For

such projects, we would expect there to be a clear and enduring line of accountability between the Project Leadership function and the Senior Oversight function.

Planning the cost estimating exercise

The Project Delivery function will typically lead the cost estimating exercise by developing a project brief and a cost estimate production plan.

The project brief will set out the requirements of the cost estimate and the surrounding context, covering the need for the project, the options for meeting the need, how the options have been identified, and the decisions which the cost estimates will support. The project brief may also include key design features for each option where these are known. The project brief will need to be approved by the Project Leadership and will be used to guide the Cost Estimating team as well as Independent Assurers.

Although, the development of a project brief would typically be led by the Project Delivery function with oversight from the Project Leadership, Ofwat or RAPID may wish to provide high-level guidance around the requirements of the cost estimates at each stage, to provide a level of cost consistency across the different solutions.

A cost estimate production plan will capture the expected timescales for delivering the cost estimate, and the internal and external resources which may be required, such as benchmarking data, subject matter experts, etc. The plan should also cover expectations around communication between the Cost Estimating team and the Project Delivery function, particularly during later stages of project development where the size of project teams may not naturally allow for open communication. Finally, this exercise should consider what level of assurance is appropriate, such that roles for independent reviewers can be built into the project plan, as necessary.

The production plan will need to be iterated with the Cost Estimating team once they are engaged to provide advice on cost estimating techniques and data availability. The Cost Estimating team should provide a recommendation on whether the resources identified in the production plan meet the requirements of the project brief and where not, and what additional resources will be necessary.

Developing the cost estimate

The Cost Estimating team should have an appropriate range of skills, or access to such skills either from within the wider project team or externally. Care should be taken where a project being cost estimated includes activities that are outside of the scope of the types of activities typically undertaken by the lead water company. Additional assurance may be needed in this circumstance.

There should also be regular communication between the Cost Estimating team and the Project Delivery function to ensure there is a shared understanding of the assumptions that inform the cost estimates. Finally, there should be a regular reporting cycle to allow the Project Sponsor to provide sufficient oversight.

Review and assurance of cost estimate

Independent review and assurance should be carried out in line with the cost estimate production plan, commissioned by the Project Delivery function. A review will typically seek to evaluate the Cost Estimating team's adherence to the established methodology or methodologies, as well as the robustness of the sources and assumptions, and coverage/completeness of the cost estimate. An assurance exercise may also include independent top-down benchmarking of some or all cost components as a sense check against the estimate provided by the cost estimating team.

Following the review there should be the opportunity for a discussion between the reviewers and assurers and the Cost Estimating Team around the findings and recommendations from the review. The Cost Estimating Team should then take the steps necessary so that the accepted recommendations are reflected in future stages and/or iterations of the cost estimates.

We provide recommendations on appropriate levels of assurance for the cost estimates at different stages, in Sections 6.3 and 8 of this report. Ofwat as the economic regulator should consider how it obtains assurance of the cost estimates. This could be through attendance of project board meetings, through the sharing of papers/minutes, or through the commissioning of independent reviews and assurance.

Sign-off of cost estimate

Through the sign-off process, Project Leadership will apply a final round of scrutiny and formalise its ownership of the cost estimate. The sign-off process should encompass the cost estimate, risk register, assumptions register, and commentary and recommendations received during the review and assurance phase. Sign-off should be managed by the Project Director.

In providing sign-off, Project Leadership is indicating its satisfaction with the cost estimate in the context of the scope and schedule of the project, and the stage of development. Where the cost estimate is being reviewed by a regulator, the sign-off decision should be captured in a written statement provided to the regulator.

3.2. Wider project governance and regulatory oversight

Ultimately, the cost estimating exercise should not be considered an isolated component of project development. The cost estimate is used not just to inform decision making at each stage gate but instead, it also serves as a realistic baselined estimate for exercising cost control during project execution. As such, overall project governance should be aligned with the governance of the cost estimate.

As projects progress through the planning process, where the focus shifts from planning to execution, there are additional governance considerations:

- **An appropriate project structure –** When a project reaches sufficient maturity such that the sponsoring water companies are ready to start obtaining planning and regulatory consents, the project team will need to develop into a team that can manage a planning application[4] and large-scale procurement exercises, lead contract development and, where appropriate, arrange financing.

  The appropriate regulatory authority may wish to satisfy itself that the project has the right level of resource with sufficient expertise to effectively manage the next stage of the process based on the activities to be undertaken in that stage. The cost of these resources should be a discrete line in the project estimate and subject to the same level of scrutiny and assurance that is required for the cost estimate itself.

- **Have a practical/timely escalation process** – Throughout the project life cycle issues will emerge that require rapid resolution. There are likely to be peaks and troughs in activity i.e. during procurement and in the later stages when being financed. Establishing senior level oversight is important but there will be periods when key decisions have to be taken outside of a standing meeting cycle.

- **Reporting** – throughout the lifecycle the project should be reporting on progress and performance to the Senior Oversight function. As with other aspects of project development and delivery this will change over time, but we would suggest that Ofwat and RAPID keep in mind the key issues set out in the context section above when it sets its requirements and ensure that these requirements are built into project processes at an early stage. Ideally, reporting requirements would be common across projects and will include a degree of data gathering that enables cost benchmarking and allows the sharing of best practice across the portfolio of projects.

[4] Where the project is deemed a Nationally Significant Infrastructure Project as per the Planning Act 2008, this would include experience managing planning applications through the Development Consent Order (DCO) process

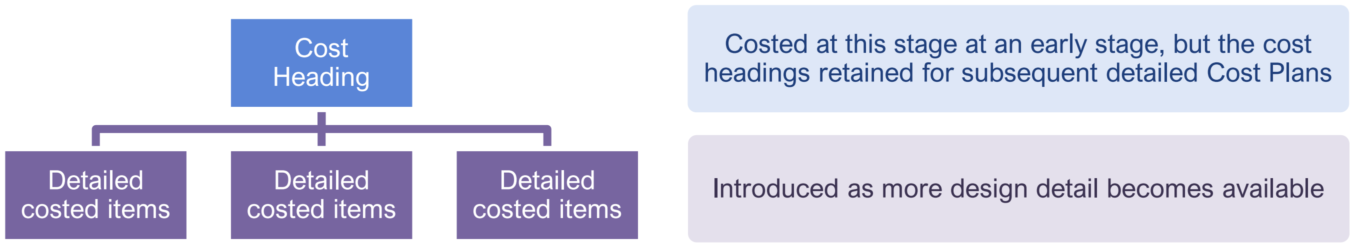
4. ESTABLISHING A CONSISTENT COST STRUCTURE

It is important to adopt a consistent cost structure throughout in terms of maintaining oversight and facilitating comparison as a project progresses. We provide an initial high level cost breakdown structure for consideration.

A key principle for cost estimating is structuring costs in a consistent manner throughout the development of a project. As presented in Figure 2, cost estimates developed at earlier stages of a project's development should be presented under key headers that are then retained as the costs become more defined and more granular. This has two key advantages:

- **It allows easy comparison for how cost estimates for a project are developing over time.** For example, for construction costs, there should be a simple read across from the high-level Order of Cost Estimates (OCE) to the more detailed Work Breakdown Structures (WBS). This ensures that the key drivers underpinning any change to the cost estimates can be understood easily.
- **It allows easier comparison of costs across projects.** A consistent structure for presenting both cost estimates and actual costs enables the comparison of such costs across projects. This aids benchmarking and cost estimating exercises for future projects.

Figure 2: Stylised illustration of cost structure



Below, we propose a generalised cost structure for water resources assets, drawing on the literature we have reviewed and our understanding of existing water company practices. This presents the key headers under which we would expect costs to be presented. We propose using this structure for Stage 2 of this assignment.

Table 4.1: Proposed cost breakdown structure

Level 1	Level 2	Description
Project inception		Concept and initial designs, stakeholder engagement, obtaining planning and regulatory consents.
Acquisition	Land and compensation	Site and land acquisition costs, compensation, administrative, finance, legal and marketing expenses.
Capital expenditure	Direct	Permanent works, including all assets, materials, plant, equipment, and labour required.
	Indirect	Preliminaries, accommodation, construction management and supervision, temporary works to facilitate the construction of the Direct works.
	Administrative	Project management, design, surveys and investigations.
	Escalation	Inflationary costs to construction date.
	Contingency	Allowance for risk
Optimism Bias		

Level 1	Level 2	Description
Operation and Maintenance		Power, maintenance, servicing, replacement of small parts, labour, sludge, chemicals.
Renewals		Replacement of assets beyond life.
End of life		Removal and disposal, reinstatement.

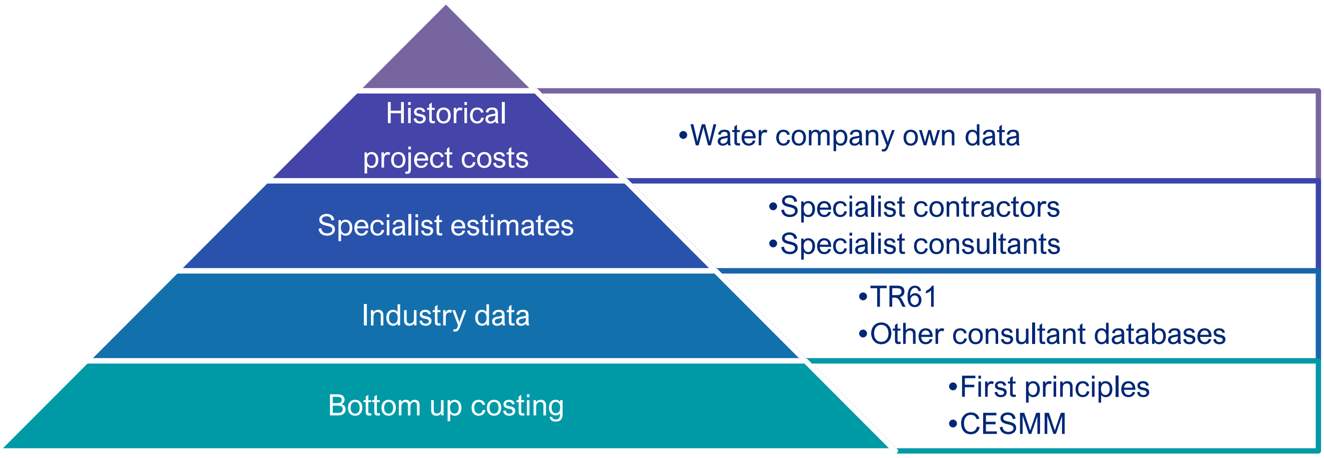
5. GATHERING DATA AND EVIDENCE

The gathering of data and evidence to produce a cost estimate will be led by water companies at least initially. We expect in most instances, water companies will use their own cost data supplemented with other sources where proposed activities are outside the scope of their previous experience. Key issues for internal company oversight or regulatory oversight are likely to be:

- Receiving assurance that appropriate and sufficient sources of evidence are being used to underpin the estimate at each stage, and there is transparent presentation of assumptions given that there will always be compromises.
- Considering whether there are opportunities to facilitate data sharing between water companies and with relevant bodies outside the water sector noting that such data may be considered confidential.

The following figure presents a hierarchy of data and evidence sources for estimating the costs of water and wastewater projects. The hierarchy represents the order of preference when selecting cost data, based on the likely robustness and relevance of the evidence sources. The hierarchy works from top to bottom with regards to greater preference on cost data. Water company's own historical project cost data has the greater preference, as they have a good knowledge of the projects, understand the relevance and is reflective to their operating area, procurement strategies and delivery.

Figure 3: Cost Data Sources Hierarchy



Note 1: The Water Research Centre (WRc) work with a number of the water companies to develop a series of parametric cost models for capex and opex, known as TR61, which may can be used to support cost estimation and benchmarking.
Note 2: The Civil Engineering Standard Method of Measurement (CESMM) supports the building of bottom-up costs by providing a standardised approach

Water companies are likely to have a strong understanding of and prior experience in the type of work typically undertaken in the development of a water infrastructure asset. We expect that water companies will have captured historical cost data from previous projects which could be used as the starting point for predicting the cost of future works. As such, we expect this will be the best starting point for cost estimate data. However, we note that a single water company's experience may not extend to strategic water resource or wastewater solutions, or to the full scope of a project's design, in which case other data sources should be consulted.

Where a project includes a large component of activity that is specialised or outside the scope of a water company's experience, it will be necessary to procure data or commission cost estimates covering those activities from firms who are able to produce a better-informed costing of works. Cost estimates can be directly procured from consultants that specialise in the cost estimation of such projects, or through a process of market engagement with specialist contractors. This will be particularly relevant for multi-sector water resources solutions, which may include activities such as canal restoration or wetland creation. Cost estimates for these activities may be directly procured from specialist contractors or from organisations with experience of undertaking such activities (e.g. the Environment Agency and Canal & Rivers trust).

Alternatively, wider industry data could be used to support the cost estimation of water and wastewater solutions. Such data might be used in several ways:

- Data from the wider sector may be able to supplement a water company's own dataset where the internal database has few data points to inform a cost estimate. Using such data as a supplement would increase the robustness of any cost estimates derived from the data.
- Alternatively, data from the water sector may provide outturn cost data for larger scale projects than exists in the water company's own dataset. This would increase the external validity of the cost estimates.
- Finally, where the other water companies have experience delivering certain assets of types of activity, such data may be a more proportionate alternative to procuring specialist estimates.

Some of this data exists in databases such as WRc TR61, and in databases managed by water industry cost consultants. Where data is owned by water companies or subject to contract, confidentiality issues may arise.

In the absence of any benchmark data, the alternative would be to develop a bottom-up cost estimate from first principles using supplier prices. This is explored further in the following section. We consider this should be considered a last resort unless the bottom-up estimate is provided by a contractor as part of a tender process.

For particularly novel activities (such as those that involve the use of new technology), it may be possible to collect data by undertaking a small-scale pilot, to better understand the activities undertaken and the resources required to deliver those activities.

5.1. Data quality

Developing a credible and robust cost estimate relies on high quality data being fed into the benchmarking or cost estimating models. While there will inevitably always be some limitations to the data being used to inform a cost estimate, these limitations should be explicitly documented and the impact on the uncertainty of the cost estimate assessed. Several considerations apply to data quality:

- **Appropriate normalisation of input data.** Project cost data should be presented in a consistent price base and, where appropriate, converted to a single currency. Similarly, technical data should also be presented in consistent units. It is likely that other normalisation adjustments will also be required, such as adjusting for taxation, which should be transparently documented. Finally, data should be structured in a consistent format that is neutral to the procurement method used in the relevant project. For example, the cost for an activity should be reflected in the same way irrespective of whether it is performed in-house or contracted out.
- **Internal validity.** The cost models or cost databases developed using previous project data need to have sufficient internal validity. In other words, the relationship between the technical or design elements and cost (e.g. the relationship between the length of a pipeline and its cost) needs to be statistically robust. One of the key sources of poor internal validity will often be insufficient data. However, poor internal validity may also arise from inappropriate statistical analysis of previous project data, or from the use of outdated data that is no longer relevant (e.g. due to changes technology, standards etc.).
- **External validity.** It is important that the data being used to inform a cost estimate for a new project are, as far as possible, from previous projects that are comparable in scale and scope. When the projects are less comparable, the applicability of cost data to the new context is likely to be limited. This is likely to be a major challenge for strategic water resources solutions. As we discuss in subsequent sections, tackling the issue of external validity may require the use of an alternate cost estimating technique, or the use of adjustments to account for the differences in scale or scope, or it may simply be appropriate to document the issue for consideration at later stages of cost estimation.

5.2. DOCUMENTING ASSUMPTIONS

The process of gathering and interpreting the data will inevitably involve various assumptions which may have a material impact on the cost estimates. This could include engineering assumptions, cost assumptions (i.e., prices, efficiencies) and commercial assumptions (e.g., contracting decisions, risk appetite). It is important for such assumptions to be carefully documented and communicated to all levels of the governance structure. Transparency around assumptions provides opportunity for internal challenge and helps to ensure that data and evidence is used correctly in producing cost estimates.

Visibility around the assumptions is particularly important for the consideration of uncertainty and risk, and independent review. If assumptions are made in lieu of robust evidence, this should be reflected in methodological choices and adjustments for uncertainty.

6. COST ESTIMATING TECHNIQUES

Cost estimating techniques can be broadly split into two categories: top-down and bottom-up estimates. Top-down is likely to be more appropriate for earlier stages of project development, with bottom-up estimates used as the project matures. Key issues for internal company oversight or regulatory oversight are likely to be:

- Checking that the cost estimating technique is appropriate to the context of the project, its stage of development and how the cost estimate will be used. The rationale for selecting a technique should be explained, with a discussion provided around any limitations. This should also feed into expectations around how cost estimates will be developed or refined at subsequent stages.
- Understanding data quality.
- Choosing an appropriate method for undertaking independent review or assurance of the cost estimate. Top-down techniques are also relevant for benchmarking of cost estimates and should be used to sense-check cost estimates produced using alternate methods.

6.1. Choosing the most appropriate cost estimating techniques

Cost estimates are typically presented in the following form:

There are several techniques available to estimate the cost of a water infrastructure scheme, each with different merits. Most techniques are typically focused on the development of a base estimate. However, the choice of cost estimating technique should be considered alongside the separate methods used to estimate and account for risk and uncertainty. We cover this in more detail in the following section.

One way of differentiating between cost estimating techniques is whether they take a top-down approach or a bottom-up approach, as shown in the figure below:

Figure 4: Top-down and bottom-up cost estimating techniques

Top down

- Cost of scheme, as a whole, is estimated and then broken down into major work elements.
- Or more commonly for larger schemes, project scope is broken down into smaller, non-overlapping (but still high-level) components which are then individually cost estimated and aggregated.
- For example the construction cost of a reservoir project may be estimated solely based on the anticipated reservoir capacity (using data from historical reservoir projects), and then adjustments are made to include other costs such as planning, design, and project management.

USE: Better suited to earlier stages of scheme development when a scheme sponsor is unlikely to have access to detailed designs. Also useful for validating bottom-up estimates at later stages of project development.

Bottom up

- Generally developed when there is more detailed project scope information available, but often more resource intensive
- Cost estimates are built up based on the individual tasks that make up a work element, assigning resource requirements (e.g. labour, materials) and costs to each individual task, and aggregating up
- Can be built up from more detailed rates similar to Civil Engineering Standard Method of Measurement 4th Edition (CESMM4), or built up from a first principles basis

USE: Works best when the design of the scheme is sufficiently mature to be broken down into a series of tasks, each with well-defined resource requirements. Can also be used for discrete components of a broader project, and then combined with top-down estimates of other components.

Choosing the most appropriate methodology or methodologies will depend on a number of considerations:

- **The novelty and complexity of the proposed scheme(s)** – For novel or complex schemes, it is likely to be more challenging to find comparable benchmark or historic cost data. This means benchmarking exercises will need to be interpreted with caution, with a greater focus on uncertainty related adjustments. Estimating methodologies that do not rely on directly comparable projects (e.g. parametric cost estimating) are likely to be more suitable in this context. There may also be an advantage to using two different cost estimating methodologies to validate each other.
- **The maturity of the scheme design** – As projects progress through the various stages of development, we would expect the design of a scheme to mature allowing a more detailed understanding of the scheme requirements. Cost estimates during concept development and initial design stages, where scheme designs are less mature, are better suited to top-down estimating. Nevertheless, a consistent cost structure should be maintained throughout, so that over time top-down estimates can be replaced in part (or in whole) by more detailed bottom-up estimates.
- **The availability of benchmark or historic cost data for similar schemes, or for specific activities within the scheme, and the quality of such data** – From a practical perspective, certain data intensive cost estimating methodologies would not be workable where the required data does not exist is insufficiently detailed or has limited reliability. Consideration needs to be given to the quality of the data available, and the implications for using such data for cost estimating on the certainty of the estimate. While it may be necessary to use data that is less robust or less directly comparable, this should be reflected in any uncertainty related adjustment.
- **The objective of the cost estimate.** Cost estimates are typically used for three purposes:

- Comparing the costs of several competing solutions against one another;
- Informing decisions on whether to proceed with a scheme for further development, or the final decision on whether to invest in the scheme; and
- Determining the budget for the scheme.

In the context of comparing schemes against one another, choosing a consistent cost estimating methodology across the various schemes is recommended. Where cost estimates are being used to inform investment decisions, efforts should be made to reduce uncertainty as far as possible and for remaining uncertainty to be identified and quantified as discrete risks.

6.2. Cost estimating techniques

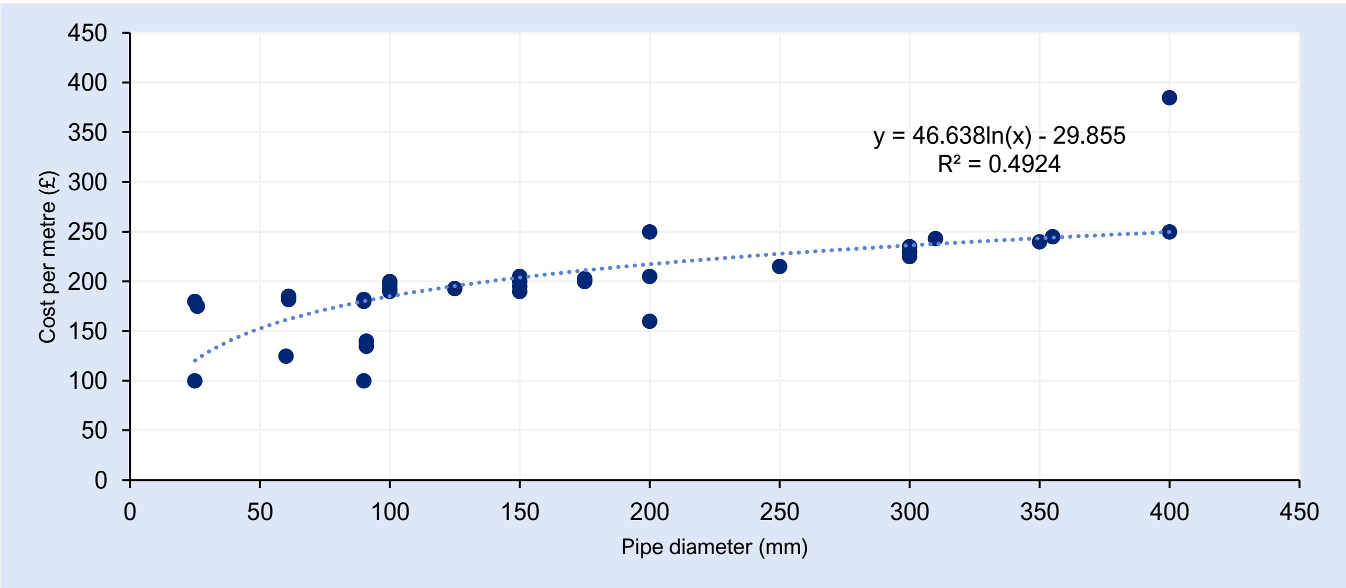
There are six common estimating techniques, these are:

- (Top-down) / Parametric modelling
- Expert judgement
- Analogy-based or comparative estimating
- (Bottom-up) engineering estimating
- Three-point estimating (3PE)
- Extrapolation from actual costs

Parametric modelling is a top-down technique that uses outturn costs from previous projects to inform the costs of future projects. Parametric modelling relies on the use of a cost model, where for each asset class or asset type, there are a series of cost drivers (typically four to six drivers) and a parameter that determines the relationship between the cost driver and cost. The cost of future projects can then be estimated by inputting the design features associated with each cost driver. As a simple example, the cost of a new pipeline may be determined by a combination of the diameter of the pipe, its length, and the material used.

Parameters within a cost model are estimated through regression analysis of previous projects, with standard errors presenting an uncertainty range around the parameter. This is illustrated in the figure below. The choice of projects used to populate the dataset can often require judgement, particularly where certain projects are considered outliers. So this choice provides important context for the estimate.

Figure 5: Example of parametric modelling using dummy data



Expert judgement involves relying on the experience and 'gut feel' of experts to estimate projects. It tends to be quick and easy and most useful when you're planning a standard project that is similar to ones a team has completed before. However, the specific expertise maybe limited to a limited section of a project and would still require one of the other approaches to complete the estimate.

It is likely that where expert judgement is used, it would be in respect of a line item within the estimate for a specific piece of work, referencing the source. It is expected that cost may be refined as the project is developed, as the expert's judgement is likely to change, as more information becomes known.

An example of this would be a priced quotation or estimate report from either a specialist contractor or consultant, where the final cost is used in the water companies estimate.

Bottom-up engineering estimating is a more detailed approach to costing construction work. Work items are identified at a much granular level, typically following a Work Breakdown Structure. Typical examples of this would work that is identified, measured and costed following the standardised rules of measurement in CESMM4 or the Royal Institution of Chartered Surveyor's New Rules of Measurement 2 (NRM2). Standard rules of measurement identify how the work should be measured, and the costing of these items is likely to be historical project cost data matching these items. This can be broken down further and costed on a first principles basis, i.e. measured, and costed based on a labour, plant, equipment and materials requirements.

This more granular costing offers more detail around the costs of different components, and can provide more confidence where it is able to address project specific details and complexities. However, it relies on the existence of a well-developed design, such that the more granular work items can be identified and measured accordingly, otherwise the estimator will have to make assumptions, based on their own experience which will impact the confidence of the estimate. This approach tends to lend itself better to the later stages of the development process e.g. preconstruction costing.

Figure 6: Example of a bottom-up costed estimate

	Description	Quantity	Unit	Rate	Cost
	CLASS E: EARTHWORKS				
	General Excavation				
E411	Topsoil maximum depth: not ex	5.22	m^3	£ 4.08	£ 21.30
E422	Material other than topsoil, rock or artifical hard material: maximum depth; 0.25 to 0.50m	10.44	m^3	£ 4.02	£ 41.97
	Excavation ancillaries				
E522	Preparation of excavated surfaces; material other than topsoil, rock or artifical hard material	34.8	m^2	£ 1.16	£ 40.37
E531	Disposal of excavated material;	15.66	m^2	£ 4.59	£ 71.88

Analogy-based (or comparative) estimating looks at past project data combined with a top-down approach to estimating projects. It takes the average position of norms for similar projects and applies these to current estimate.

Three-point estimating is another technique used for creating bottom-up estimates that accounts for uncertainty. Rather than assuming a single cost for a task, an engineer would consider the costs associated with three possible outcomes: optimistic, pessimistic, and most likely. Assuming a triangular or PERT distribution,[5] the uncertainty surrounding each task can be aggregated using Monte Carlo analysis, giving a distribution of total costs before

[5] See Appendix A for further detail on such distributions.

accounting for risk. It effectively allows for the creation of a cost envelope at different degrees of confidence. However, as with standard bottom-up estimation, this approach requires a well-developed design.

Figure 7: Mocked up example of a three-point estimate

Best Case		Most Likely		Worst Case		Weighted Average	
£	5,000	£	6,000	£	7,000	£	6,000
£	4,000	£	5,000	£	8,000	£	5,333
£	3,000	£	4,000	£	6,800	£	4,300

Extrapolation from actual costs is used to refine and calibrate cost estimates once construction has commenced. Under this approach, the cost estimates are refined to reflect actual in-project experience. This may mean that for labour resource requirements, estimates are updated to reflect actual labour costs. While for time-related construction activities, cost estimates are adjusted to reflect actual run rates rather than estimated run rates.

The box below summarises the specific issues related to cost estimating in the context of environmental considerations.

Cost estimating in the context of the environment

Taking a more environmentally conscious approach to developing strategic water and wastewater resources solutions, or developing such solutions to maximise environmental benefits, may affect the cost of the development. At a minimum, planning rules require schemes to take relevant action to mitigate environmental impacts.

Incorporating environmental considerations within cost estimates can be thought of in four ways:

- The size of an asset could be adjusted to reduce associated carbon emissions (whether embedded or operational) or to reduce the impact on biodiversity, noise, or water quality. This would likely be captured within existing parametric models, but there would need to be proactive consideration at early stages as to how such considerations are incorporated into the scheme design.
- A new technology could be applied, or a different asset type or material used, as a way of mitigating environmental impacts. Such technologies or asset types may have been used in the past; in which case the associated costs would likely be captured within the databases used to develop bottom-up cost estimates. For top-down cost estimates, this would either require adapting parametric models to account for associated levels of embedded and operational carbon, or using expert judgement to apply adjustment factors.
- Additional activities could be undertaken to create additional environmental benefit, e.g. through planting of trees or restoring peatland. Estimating the cost implications of these activities could again be done by adapting parametric models or, by using cost estimates from organisations with better access to cost data for such activities.
- Undertaking the same activities differently, to minimise the carbon, biodiversity, or other environmental impact. This is likely to be the most challenging to consider as it will be very case dependent. In many instances, the cost or resource impact may be minimal if considered sufficiently in advance. However, in some instances, there may be additional cost implications that would not necessarily be captured within cost databases.

As most cost estimating techniques rely at least partly on outturn costs of previous schemes, any environmental considerations that formed part of legislative or planning requirements of these previous schemes would be accounted for within the cost estimates. As such, as the biodiversity net gain requirement in England becomes more established, we would expect cost estimates to better reflect the associated cost implication over time. Where proposed solutions have a substantial biodiversity element, cost estimates will likely be informed by specific estimates from specialist contractors with relevant experience.

Table 6.1 below, compares the various cost estimating techniques and summarises their advantages and disadvantages. While we expect water companies will take broadly similar approaches in developing project cost estimates, there will likely be slight differences in the methodologies applied and the data sources used. We consider it more important to ensure the most appropriate methodology is applied depending on the project type and the stage of the cost estimate, rather than requiring a consistent methodology across projects.

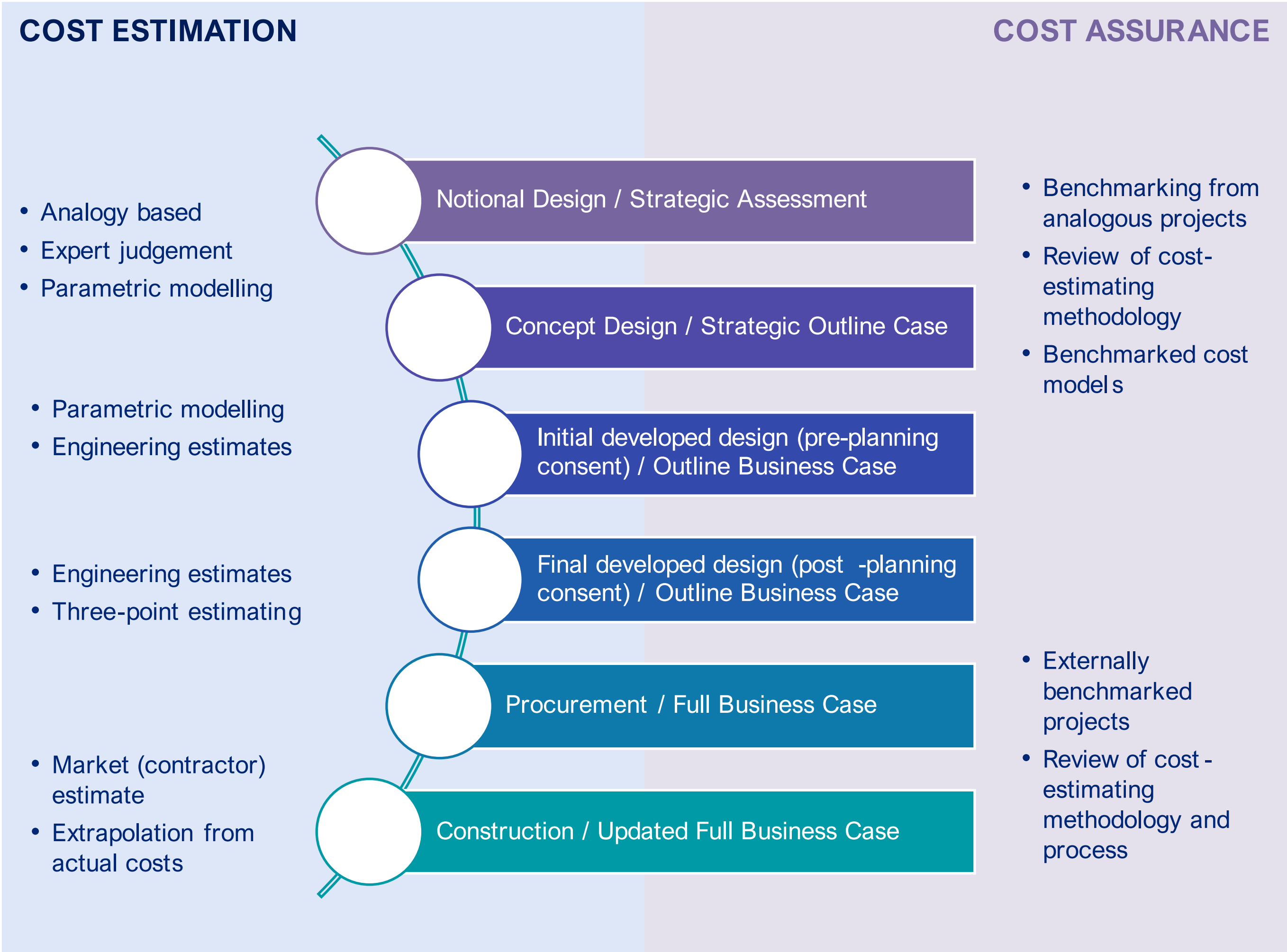
Table 6.1: Summary of cost-estimating techniques

Methodology	Suitable stages	What data, evidence and skills are required	Advantages	Disadvantages
Parametric modelling	Early feasibility stages	Historical projects with similar characteristics Requires a defined cost capture structure Appropriate cost data and modelling system	Relatively quick to complete estimates once models have been generated. Reflective of work and risk that has previously been experienced	Requires significant time to capture data and create models to be used for estimating. Accuracy levels may be wide.
Analogy-based / comparative estimating	Early stages where less design information is available. More akin to benchmarking	Similar historical projects	Relatively quick and cheap to complete less likelihood for error due to omission, since the estimates are not based on granular details	Not suitable where defined budgets and schedules are required. Wider range of accuracy May not address all the project specific items and lead to under or over measure.
Expert judgement	Early stages providing high level costs Later stages informing specific tasks within a bottom-up estimate	Knowledge and experience of works being carried out and costing.	Improvement on estimates, where experience is lacking.	Can be more expensive and time consuming to complete. Potential for missed scope if all project information is known or provided
Bottom-up engineering estimating	At detailed design stage	Solid data for task descriptions, historical cost data, current prices	Generally allows greater precision Suitable where defined budgets and schedules are required	Requires greater design information Can be more expensive and time consuming to complete.
Three-point estimating	Post conceptual to detailed design	Solid data for task descriptions, historical cost data, current prices	A balanced approach to estimating and risk	Can be more expensive and time consuming to complete.
Extrapolation from actual costs	After start of construction	Detailed outturn data from project	Allows for regular updating of cost estimates to reflect actual experience	Only suitable once project has commenced

6.3. Evolution of cost estimates at different stages of project development

In Figure 8, we illustrate the range of cost estimating techniques likely to be considered at each stage of project development , drawing on the considerations presented in Section 6.1 and the relative merits of each cost estimating technique as summarised in Section 6.2.

Figure 8: Costing Approach and Cost Assurance potential approaches



At earlier stages of project development, top-down approaches are likely to be more appropriate:

- **Parametric estimating** has the advantage of being widely used within the water sector already, and as it is based on outturn data there is less scope for optimism bias. It is particularly well-suited to early-stage estimates where only high-level design parameters exist. However, the appropriateness of parametric estimating will depend on the suitability of the comparator data that is used to inform the parametric model.

  Issues may arise with the use of parametric estimating. The first of these is the extrapolation of parametric models to estimate the cost of schemes that are much larger or of different scope than the schemes that are inputs into the model. This should be explicitly noted as a weakness in parametrically derived cost estimates. Where it is possible to identify the relationship between scale and cost for a different asset class, this could be used to inform a scale-based adjustment.

  Similarly, parametric estimating might be applied to proposed schemes where there is an additional layer of complexity or novelty that is not explicitly captured within the parametric model. Again, the factors that make a parametrically derived cost estimate less reliable, should be explicitly noted. It may also be possible to make broad based adjustments to the cost estimate informed by previous experience. For example, if a scheme uses new technology, it may be possible to make an adjustment based on the historic relationship between the costs of first-of-a-kind and next-of-a-kind technology implementation.

Another issue arises where limited data exists for a specific scheme type. One way of mitigating this issue is to break down the scheme into smaller components where there is more data. However, there is a need to be mindful of the scope for efficiency through synergies as well as the potential for cost increases through integration challenges. Alternatively, analogy-based estimating or bottom-up engineering estimates could be used instead.

- **Analogy-based estimating**, while necessarily high-level, is useful at providing reliable order of magnitude estimates in a transparent manner. These should be considered where parametric estimating is challenging or unreliable due to insufficient data from projects of similar type, scale, complexity, and novelty. Analogy-based estimating is also a useful technique for assuring and validating estimates developed through alternative techniques.
- **Expert judgement** is a possible alternative where parametric estimating or analogy-based estimating is not possible, and where bottom-up engineering estimating is disproportionate. It draws on the knowledge of others with experience in this area, who understanding the complexity of a project of that given nature. Often the case is that expertise is limited to a section of the works and forms only part of the works, and the remaining works are required to be costed by others.

  As expert judgements are necessarily high-level, it can be difficult to understand the approach taken to account for risk and uncertainty. Consequently, it can be challenging to make appropriate adjustments to account for this.
- **Bottom-up engineering estimating** may be required at early stages of project development for schemes that are exposed to material risks due to scale, novelty or complexity, such that historic comparators are not available. One of the key challenges with engineering estimates is the increased potential for optimism bias. In Section 7.3, we discuss approaches for mitigating this.

As projects progress through to obtaining planning consents and procurement, cost estimates should be expected to transition towards use of bottom-up estimates. However, such estimates are of limited reliability unless the scope of a project is sufficiently detailed, tightly defined, and with limited potential for change. Prior to a scheme being taken through a planning consent process, the ability to tightly define a scope is limited due to the potential for substantive design changes. As a result, bottom-up estimates at this stage should be complemented by top-down estimates or should reflect a range of plausible designs.

7. BIAS AND UNCERTAINTY

At each stage of the project's development, the cost estimates developed are likely to have a varying degree of uncertainty associated with them. The key issues for internal company oversight or regulatory oversight are likely to be:

- Ensuring that companies demonstrate complete cost estimates that appropriately account for uncertainty at each stage. This will be particularly relevant once planning consent is obtained and a final investment decision is being made, as cost estimates at this stage will likely serve as the foundation for setting budgets. It is generally inappropriate to use earlier stage cost estimates as the basis of setting budgets, given the degree of uncertainty. At these earlier stages, costs should be presented as a range with a clear expectation that the budget estimate prepared later will fall within that range.
- Confirming that interactions between risk and uncertainty have been correctly identified and accounted for.

Early-stage cost estimates should be presented as a range to reflect the greater degree of uncertainty at that stage. At later stages, where point estimates are required for planning or budgeting purposes, there should be consideration of the appropriate p-value to use. This will be used to determine an appropriate contingency allowance.

In the following section, we introduce the concepts of risk, uncertainty, and bias, and outline best practice in relation to the treatment of uncertainty within cost estimates.

We begin by defining the key terms:

- **Uncertainty** is a broad term reflecting the full range of explanations for why the outturn cost of a project may differ from its estimated cost. More typically, however, uncertainty is used to refer to any element that is not considered a risk.
- **Risk** reflects discrete events that affect a project's performance in terms of cost, schedule, or benefits. Such events can typically be identified and managed. Risks usually have a probability associated with them and the impact of the risks can often be estimated. In the context of cost estimating, risks reflect events that affect the likelihood of outturn costs being higher or lower than the estimated costs.
- **Bias**, also a subset of uncertainty, refers to behavioural explanations for cost estimates differing from outturn costs. Optimism bias refers to the systematic tendency for cost estimates of large infrastructure projects to be over-optimistic relative to outturn costs.

At earlier stages in a project's development, there will inevitably be greater uncertainty as key elements affecting the scheme design will still be unknown. At these stages, there should be greater focus on broad brush uncertainty adjustments plus an allowance for optimism bias. We recommend treating these as two distinct issues as, although there is an overlap between them, the scope of uncertainty extends beyond optimism bias.

At later stages of project development, many sources of uncertainty will reduce as the design is progressively refined and locked down. At this point, many of the remaining risks will be identified and could be quantifiable, allowing for the cost estimates to include a contingency. Optimism bias is likely to reduce, however there may remain a need for an optimism bias adjustment to reflect 'unknown unknowns.'

7.1. UNCERTAINTY

The level of uncertainty present in cost estimates typically reflects the maturity of the design and corresponding choices on the data and techniques used to contrast the cost estimates. It could also reflect the use of 'first of a kind' technology or a novel engineering challenge.

During the initial stages of a project, various elements of the design may not have been decided yet, or could be subject to change. This being the case, it can be proportionate to use 'rules of thumb' or generic cost assumptions.

As the design is bedded down, it may be appropriate to invest in more precise cost estimates through research or investigation, reducing the uncertainty in the cost estimate.

7.1.1. Accounting for uncertainty

Uncertainty stemming from the maturity of the design can be reduced as the project progresses, e.g. as decisions are made to rule specific options in or out, potentially reducing the variance between the remaining options. Alternatively, if design options are sufficiently different, it may be appropriate to treat each option as a discrete cost estimating exercise to reduce the uncertainty associated with each option at an earlier stage.

Similarly, uncertainty stemming from data choices and techniques can be resolved through investigation and empirical research to collect data inputs which are more tailored to the specific project. These efforts would typically be targeted towards the cost items where uncertainty is most material to the viability of the project. Intuitively, materiality will be a function of the size of a cost item and the degree of residual uncertainty as a project is progressed.

Practically, uncertainty can be reflected in pessimistic and optimistic bounds around each value in the base cost estimate:

- This is an inherent feature of **parametric models**, which include confidence bounds. In theory, these bounds will reflect alternative, pessimistic or optimistic assumptions on production rates, efficiency, and material quantities and will be based on empirical data. On the basis that projects are generally more likely to run over-budget than under-budget, the probability distribution featuring the base cost, pessimistic and optimistic bounds, can be assumed to skewed to reflect the higher probability of pessimistic outcomes.

- For **analogy-based estimates**, there must be at least two data points to develop a pessimistic and optimistic bound.

- For estimates based on **expert judgement**, it may be possible to identify reasonably pessimistic and reasonably optimistic outcomes using experience and intuition. Alternatively, scenario-based judgements may allow an expert advisor to transparently present the key areas of uncertainty.

At later stages of project development much of the uncertainty will be reduced through a maturing of the scheme design and a better understanding of the requirements of the project. Nevertheless, there may remain some residual uncertainty that is inherent regardless of the maturity of the scheme design.

Three-point estimating, which we refer to earlier, is a technique for quantifying this inherent uncertainty when developing bottom-up estimates.

7.2. Risk

As mentioned, risks are generally associated with discrete events, should they transpire, which would affect a project's performance in terms of cost, schedule, or benefits. The main categories of risk are reflected in Figure below.

Figure 9: Main categories of risk when building cost estimates

Source: IPA, Cost Estimating Guidance.

Broadly, each of these categories of risk should be considered and reflected in a cost estimate. In addition to these categories of risk, the IPA identifies two further types of risk which should be reported separately to the overall cost estimate so as not to distort it. These are:

1. Opportunities for better-than-expected outcomes.
2. Critical risks/'black swan' events – risks to the continuity of the project which should be reported but which should not impact on contingency funding.

7.2.1. Accounting for risk

Broadly, the management of risk hinges on risks being identified and documented, at which point appropriate action can be taken. This could include steps to avoid risk, share risk with contractors, and/or mitigate risk through contingency funding. Through the mitigation of risk, the adjustments for optimism bias can be reduced. This is covered in the next section.

Below, we set out approaches to risk management which could apply at each stage of a project's evolution

Assessment of initial concepts

At the initial stages of the project, a ***qualitative* risk analysis** can be most appropriate given the relative immaturity of the scope and design. As a component of cost estimation, this exercise should seek to identify risks which would impact on the costs of the project. These should be documented in a risk register alongside an emerging view on the cost impact and likelihood of the risk. Each risk should be allocated to the team or individual that is best placed to manage it. The risk register should also contain the actions planned or underway for the management of the risk. It should be treated as a 'live' resource and updated with on an ongoing basis, with increasing detail as the project progresses.

At this stage, some of the risk management actions may include establishing processes to monitor risks and minimise the impact of risks should they occur, avoiding irreversible decisions (i.e., seeking to retain 'option value'), and consulting with stakeholders to reduce the potential for future conflict or misaligned expectations. The cost estimating team could also seek to commission or undertake pilot studies to better understand a specific risk and/or the efficacy of potential mitigations.

Narrowing down options and preparing for planning consents

When options are narrowed to one or two options, the design, scope, and other project variables will be sufficiently advanced that a ***quantitative* risk analysis** should be considered. There are a range of different techniques which can be applied, which vary in terms of their analytical sophistication. The choice between them depends on the data available to the cost estimating team, which itself may be a function of the materiality of the risk (i.e., a more significant risk may warrant investment in more comprehensive data and analysis).

In order of increasing sophistication, these are some of the quantitative options for risk analysis:

- **Single point analysis** – the value of a risk is simply determined as the probability of the risk multiplied by the additional cost of the risk were it to occur. This calculation produces a single 'expected value' for risk.
- **Multiple point analysis** – a similar exercise to a single point estimate, but where there are a range of potential outcomes associated with the risk (i.e., multiple costs and multiple probabilities). This analysis can produce a probability distribution of the risk value.
- **Decision trees** – an approach which can be appropriate when there are a range of options and risks over time, potentially involving sequential decisions. These can be used to evaluate risk under different scenarios, potentially highlighting the value of delaying decisions and/or retaining optionality as the project progresses.
- **Monte Carlo analysis** – a modelling technique which starts with probability distributions for the sources of uncertainty and applies these in many simulations to produce expected values for risk and confidence intervals around them. As it is often challenging to identify appropriate probability distributions for individual risks, a more common technique is to assume a triangular or PERT distribution, using the pessimistic, optimistic, and most likely outcomes as the bounds of the distribution.

Quantitative risk analysis relies on expert judgement to identify risks, quantify the probability of the risk occurring, and estimate the range of impacts. As a way of mitigating the potential for bias, this is usually done in a workshop setting involving a range of stakeholders with knowledge of the project and/or the potential risks involved – such as the project manager, designer, delivery partners, client, engineers, estimator(s). It is sometimes facilitated by an independent advisor.

Once quantified, the costs associated with the quantified risks should be included in the estimated costs as part of the project contingency.

Preparing for procurement

Once a project has received planning consent and the procurement process has commenced, the quantitative risk analysis should be refined to reflect new or improved information about the risks and mitigation actions.

The sorts of risk mitigations available at this phase may include seeking to transfer risk that they are best able to manage to contractors through the procurement process; choosing proven technologies over the less well-established; reinstating options or developing new ones to increase the resilience of the project to external factors; and/or, abandoning components of the proposal if they entail excessive risk with insufficient mitigation.

7.3. Bias

Bias refers to behavioural explanations for cost estimates differing from outturn costs. These can be conscious or unconscious. Examples include bias in the choice of data or data techniques to inform cost estimates (i.e., sampling bias, survival bias), and optimism bias – the systematic tendency for large infrastructure cost estimates to be overly-optimistic relative to outturn costs.

The scope for optimism bias can differ depending on the cost estimating technique. For example, there is potentially more scope for optimism in the case of a bottom-up estimate with many individual decisions, where the 'best case' cost scenario could be assumed for each, compared to other, top-down techniques applying historical project data in aggregate.

7.3.1. Accounting for Bias

Steps can be taken throughout the project development process to reduce the impact of bias on project cost estimates. For example:

- The use of a cost model based on contract award and/or outturn data for projects of similar scale, complexity and/or type will implicitly capture a degree of optimism bias.

- Assumptions could be chosen based on expert opinion and/or cross-referenced against other, relevant data points.
- In the review and assurance stage, an independent assurer can sense check assumptions and cost estimates to combat bias which may be present in the choice of methodology or stemming from workplace practices or culture.

Optimism bias specifically can be dealt with in a regimented way, following the framework set out in the Green Book.[6] The Green Book notes that ideally optimism bias assumptions would be based on an organisation's own historical evidence, but it also offers generic assumptions for other situations. For strategic water resources solutions, where a water company's own evidence base may not be directly applicable, it may be more appropriate to mandate generic assumptions for consistency and comparability between projects.

The Green Book framework involves starting with an upper bound assumption for optimism bias and scaling it back once it can be demonstrated that factors contributing to optimism have been managed. The five steps of making an optimism bias adjustment are as follows:

1. Decide which project types to use.
2. Start with the upper bound assumption for the chosen project type (i.e., the worst-case scenario).
3. Consider whether the optimism bias assumptions can be reduced relative to the upper bound. This assessment covers each of the contributory factors and the extent to which each has been mitigated.
4. Apply the optimism bias factor to the cost estimate.
5. Review optimism bias adjustment as project progresses.

The All Company Working Group Cost Consistency Methodology[7] developed with Mott MacDonald proposes a modified version of the Green Book framework. The main modification relative to the process set out in the Green Book relates to the method of weighting the contributory factors before calculating the optimism bias adjustment. The weightings are needed because the contributory factors have been assessed as having varying levels of impact. The proposal involves grouping the 26 contributory factors into five categories, as well as combining the contributory factors across the standard and non-standard civil engineering project types. This has the effect of producing weightings which are more generic and less influenced by factors which may be specific to the projects in the dataset used to create the granular assumptions.

Further, the Cost Consistency Methodology provides guidance on the application of mitigation factors to reduce the optimism bias assumption. It sets out practical descriptions of high, medium, and low confidence for each contributory factor and proposes that high confidence would allow for full mitigation, medium confidence for partial mitigation (i.e., mitigation factor of 0.5) and no mitigation for low confidence risks. Mitigation factors determined in this way are still applied to the individual contributory factors, even though the factors are grouped, and standard and non-standard civil engineering works categories are combined to determine the weightings.

A template for accounting for optimism bias in this way was provided alongside the All Company Working Group Cost Consistency Methodology.

7.4. Presenting risk and uncertainty

A final cost estimate for each stage of the project development process is, as noted previously, typically conceptualised as: Final Cost = Base Cost (i.e. the deterministic cost estimate) + Uncertainty + Risk. Practically, uncertainty is captured by establishing pessimistic and optimistic bounds around the base cost point estimate

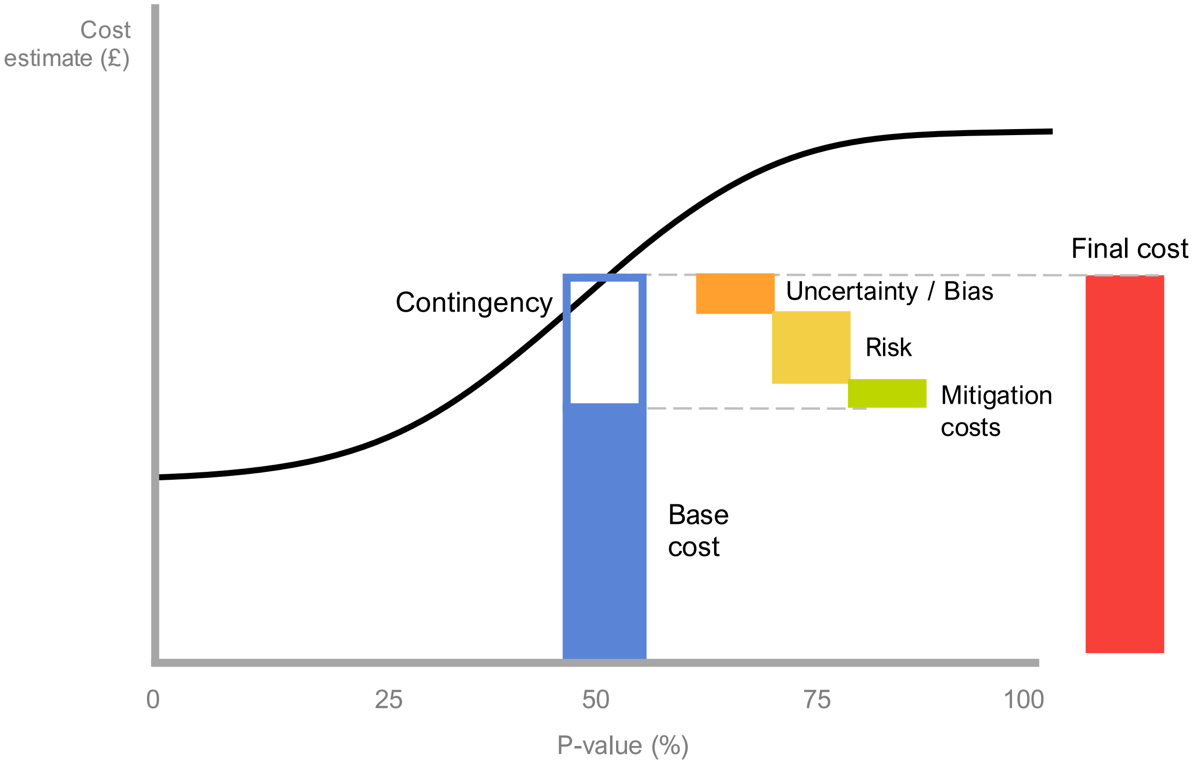
[6] HM Treasury (2013) Green Book supplementary guidance: optimism bias. Available at gov.uk

[7] Mott MacDonald (2020) Cost Consistency Methodology, Technical Note and Methodology

(described in section 7.1.1) and by making an explicit adjustment for optimism bias (section 7.3.1). Risk is reflected in the final cost in two ways: the mitigation costs of high probability risks, and a probability-weighted average of event driven risks, reflecting the value of those risks (section 7.2.1).

This is depicted in the figure below. The range of possible costs can be expressed as a probability distribution reflecting a range of possible uncertainty and risk outcomes. Depending on the methodology employed, optimism bias and risk may be captured within the probability distribution (as illustrated in the figure), or may need to be captured as a separate adjustment.

Figure 10: Stylised 'build-up' of final cost including risk and uncertainty



The median or 'P50' value within the probability distribution, is commonly used to set the contingency allowance for public sector infrastructure projects. However, RAPID and Ofwat should consider asking water companies to report against other probable outcomes at Gate 4 and during the business planning process, such as P80, to provide flexibility in the project evaluation and approval. The basis for using P50 is that it makes sense when projects form part of a wider portfolio, as is the case for the public sector. Across the portfolio, the aggregate outturn costs should correspond with the sum of all the P50 estimates for the individual projects. For individual schemes or smaller portfolios, it may be appropriate to vary this assumption and potentially use a higher p-value. The choice will depend on factors including risk appetite, procurement model, regulatory model and the extent to which water customer will be exposed to cost overruns.

As an example, Defra's 2011 impact assessment of the costs and benefits of Thames Tideway presented costs on a P80 basis.[8] For the 2015 update of the costs and benefits, P50 costs were presented as more definitive modelling of project risks gave Defra the confidence to use a less conservative estimate.[9]

The Oil and Gas Authority's (OGA) United Kingdom Continental Shelf Decommissioning cost estimate provides a helpful illustration of how this is applied in practice.[10] We summarise the approach in the box below:

[8] Defra (2011) Thames Tunnel: strategic and economic case, costs and benefits. Available at gov.uk

[9] Defra (2015) Thames Tideway Tunnel: strategic and economic case, costs and benefits, 2015 update. Available at gov.uk

[10] Oil and Gas Authority (2017) UKCS Decommissioning: 2017 Cost Estimate Report. Available at ogauthority.co.uk

United Kingdom Continental Shelf Decommissioning cost estimate

The OGA undertook a cost estimating exercise to understand the costs of decommissioning oil and gas fields on the UK Continental Shelf.

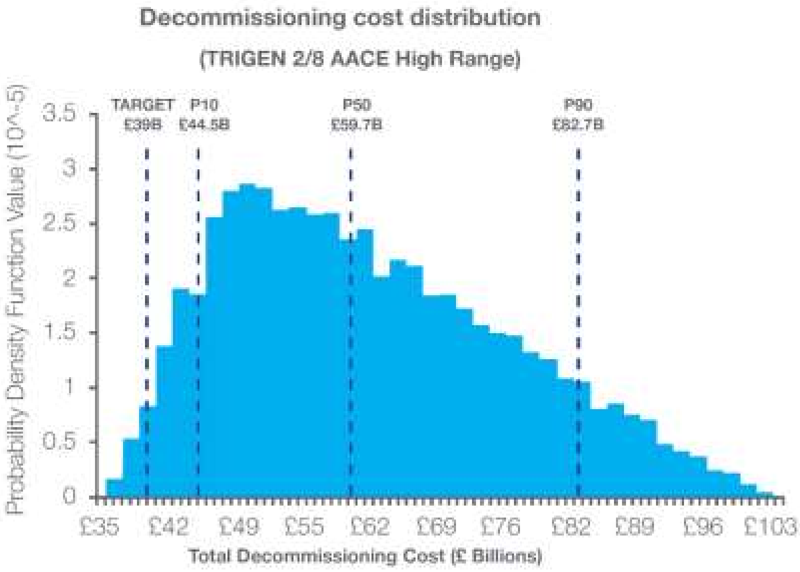
We understand the OGA developed a parametric model with probabilistic uncertainty ranges using a variant of the triangular distribution, the tri-gen distribution. This probabilistic estimate was then assured by being compared against a deterministic cost estimate.

The OGA's analysis did not account for any discrete risk events and, therefore, do not capture risk or the costs of mitigating such risks. Bias is partly accounted for in the uncertainty range through the OGA's choice of probability distribution.

The figure below shows the cost estimates produced by the OGA:

Figure 5: Probabilistic cost outcomes

P-Factor	GBP Billion
P-10	£44.5
P-50	£59.7
P-90	£82.7
P-Mean	£61.7



8. COST ASSURANCE

Cost assurance provides confidence that cost estimates are accurate. It should be undertaken by both water companies when developing their cost estimates and by regulators when deciding whether to progress projects through the Gated Process. Cost assurance can be undertaken through independent review of the assumptions and methodology underpinning cost estimates. It can also involve benchmarking the cost estimates against a set of comparable projects. More project-specific costs may be harder to benchmark.

Cost assurance refers to processes to provide Project Leadership teams and regulators with confidence in project's cost estimate. Broadly, these activities are split between checking the cost estimating methodology is suitable and has been undertaken appropriately, and using quantitative techniques to benchmark or sense-check the main estimate. These categories of cost assurance are discussed below. This section concludes by presenting options for cost assurance for aspects of cost which are difficult to benchmark.

Although this section provides guidance around best practice in relation to cost assurance, we must note that the most appropriate method for cost assurance and cost benchmarking will depend on the scheme. As the economic regulator for water companies, Ofwat can choose how to assess costs based on what it considers is appropriate at the time taking into account the type of investment being requested and data availability.

8.1. WATER COMPANY COST ASSURANCE

As noted in Section 2, we expect water companies to initiate their own reviews to assure the cost estimates. The precise tasks and level of effort will vary depending on the stage of project development. We identified several different approaches for each stage in Figure 8.

There are several ways in which water companies, or their advisers, may undertake cost assurance; these are described below for the various steps of the cost estimating process.

- **Collection of data** – Ensure that the cost data is collected in a structured and consistent manner, with a clear understanding of inclusions and exclusions within the captured data.
- **Storage of data** – Review of the systems in place for data storage, ensuring that the data is secure, well maintained and contains the key relevant information.
- **Use of data** – Verify that only the correct data is used and carried forward into modelling, reviewing any inclusions or exclusions. The review should check that the cost estimate is transparent about the potential weaknesses of the costs estimate, and that any uncertainty adjustments appropriately account for this. Such weaknesses may arise from imperfections in how comparison data is adjusted for factors such as the nature of the cost (i.e., estimate versus outturn), project scale, risk, uncertainty, and site-specific factors. These adjustments are discussed in section 8.2.

Where parametric models are used for estimating purposes, we would expect these to be assured. This should be achieved by the assurer addressing the following key points:

- **Model creation** – Review the systems used to assess appropriateness of the key variable(s) known to influence costs, the choice of model specification, and that costs have been adjusted consistent with prevailing guidance (e.g., Ofwat-accepted construction indices).
- **Outcome of models** – Testing to ensure the parametric cost models provide realistic construction costs, demonstrate efficiency within the industry and are suitable for estimating costs. Ensure that the models' limitations are identified in a benchmarking report and that a confidence grade is attributed to the outputs.

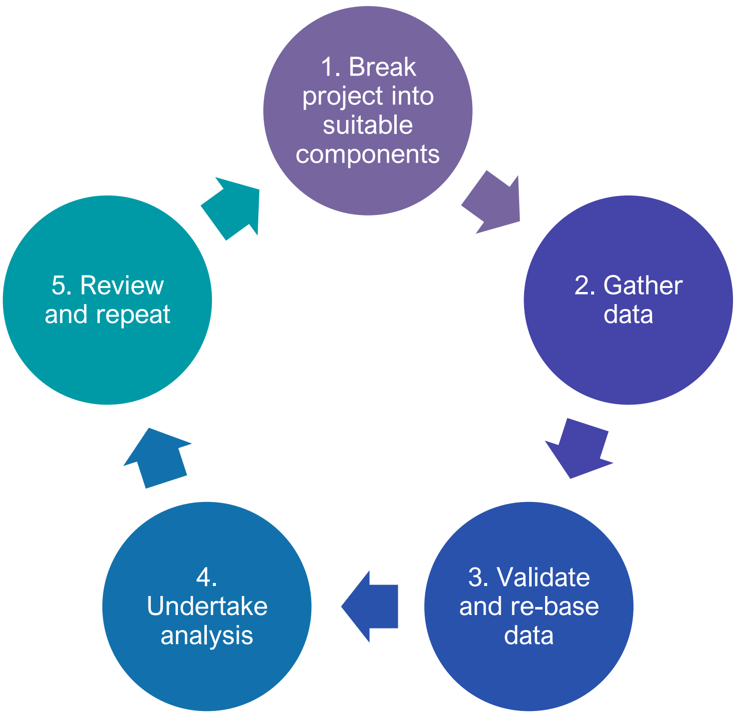
Regulators can also undertake these activities. A proportionate approach could be to commission a 'peer review' of the cost assurance undertaken by project proponents.

8.2. Cost benchmarking

In the context of cost assurance, benchmarking involves comparing projected project costs against data collected from completed projects. Utility regulators regularly undertake benchmarking to scrutinise company proposals and evaluate the efficiency of utility companies relative to each other and companies in other industries.

The tools and process of cost benchmarking are similar to components of the cost estimating process covered earlier in this report. To describe this process, we adapt the steps from the IPA's Best Practice in Benchmarking in Figure 11. Each of these is explained below. The similarities with the cost estimating process will also be highlighted.

Figure 11: Steps for top-down benchmarking



Step 1: Breaking project into components

Cost benchmarking is typically undertaken on a top-down basis, though this can encompass a range of different approaches. Top-down benchmarking exercises can be undertaken at a very high-level, where overall scheme costs are compared against the total costs of similar schemes, or the scheme can be broken down into individual components that are separately benchmarked against similar components. At its simplest, this may be breaking down costs into asset costs and project on-costs, though often costs are broken down further into different asset types. Such costs can be broken down even further to a very granular level, where individual activities (e.g. laying pipes) are benchmarked against one another.

The first step of any cost benchmarking exercise, therefore, is to decide the level of granularity at which costs will be benchmarked. The reasons for undertaking a more granular approach include:

- To allow the project to be broken down into generic components which will be more comparable across other infrastructure projects, and thereby easier to benchmark, with other projects.
- To carve out elements of the cost estimate for which there may not be sufficient comparison data to construct a benchmark. This could apply to particularly innovative or unique components of a project.

However, there are some downsides to taking a more granular approach:

- The more granular the data, the more resource intensive the benchmarking exercise becomes, both in terms of developing and maintaining the benchmark dataset and in terms of constructing a benchmark estimate.
- Disaggregating outturn cost data of historic projects requires a detailed understanding of the technical scope of the project as well as a robust method for allocation costs to the various components. Care will also need to be taken to ensure that cost elements are not 'lost' during the process of disaggregation. A simple check at this stage could be to confirm that the sum of the disaggregated components, including those carved out from the benchmarking, remains equal to the total project cost submitted by water companies.

The cost benchmarking database we are developing as part of this commission, broadly matches the level of granularity water companies will use to develop their cost estimates. We have also proposed a structure in line with international standards for breaking down costs to specific components.

Step 2: Gathering comparison data

Next, the comparison data corresponding with the components identified in Step 1 should be identified. Broadly, this involves taking outturn cost data from completed projects and disaggregating the cost into the individual components that match the structure developed within Step 1. Costs may be straightforward to disaggregate where outturn cost data is recorded at a granular level, or it may require judgment-driven assumptions. Such assumptions should be applied consistently and transparently recorded.

Since the components will have been chosen explicitly for benchmarking, they should correspond with data available to Ofwat/RAPID. For any components which fall outside the Aqua database, but still require assurance via benchmarking, a suitable source for comparison data should be identified. This could include historical data from water sector projects which Ofwat/RAPID may possess, or empirical studies to collect original data (e.g., market testing).

A key challenge in the context of the RAPID solutions is benchmarking projects that include substantially novel components or at a substantially larger scale than historic projects. The main approach used to tackle these issues is to break down a project into components that are more granular and, therefore, more easily benchmarkable. However, the benchmark exercise should recognise that bespoke projects and larger scale projects may include more significant levels of project risk than more routine or smaller scale projects.

Step 3: Validate and re-base comparison data

Steps must be taken to ensure that the data to be used for benchmarking is adequately comparable with the project under assessment. Part of this exercise involves comparing the technical scope of the comparator data with the project cost components, to identify which activities are included within an observation and which are not. This analysis may lead to some comparator data being excluded if it is not sufficiently similar in scope. Deviations from the technical scope of the project cost components should be documented for reference when interpreting the results.

Re-basing adjustments may be necessary to account for:

- Risk, uncertainty, and project contingency.
- International projects in the comparator set.
- Inflation.
- Procurement strategy and contract type.
- Changes in legislation (e.g., safety, environmental), technical codes or government policies, which might lead to cost variation between the comparator set and project under assessment.

Adjustments for risk, uncertainty and/or project contingency may be necessary when the basis for the comparison data differs from the project being assessed. This is because comparison data could reflect a cost estimate, contract award, or outturn cost, and risk may be captured and reported in different ways. For example, for a completed project, some risks are likely to have transpired and the associated contingency moved to outturn costs. Ideally there will be sufficient data from these projects to reconstruct a P50 or P90 forecast from the outturn costs. If using a cost estimate or a contract award without an explicitly priced risk, an industry average risk allowance could be used to make this adjustment.

Additionally, a risk allowance may be necessary to account for the fact that the benchmarked project includes several bespoke elements or is at a materially larger scale than the projects being used to develop the benchmark. The size of such risk adjustments may be informed by standard industry adjustments, or through an analysis of the relationship between scale and outturn cost.

The international factors which should be considered for adjustments include exchange rates, labour productivity, and differences in regulation affecting comparability (e.g., environmental, design standards). Typically, location factors are applied to international projects; these could be propriety factors compiled by consultants, or publicly available indices, such as Purchasing Power Parity.

Adjustments for inflation are used to normalise project costs provided in different price time bases. This is typically done by applying an inflation index, of which there are multiple options (Table 3 refers). The choice of index will depend on the nature of a particular cost component (e.g., a civil engineering cost index will be relevant to some cost components). If comparator projects are multi-year, the index should be applied to the mid-point of the project or to the point of maximum expenditure.

Table 2: Indices for inflation adjustments

Index	Description	Comment on usage
CPIH	The lead measure of inflation for the UK economy, reflecting UK consumer price inflation, including housing costs and Council Tax.	• As a measure of consumer price inflation, CPIH is broader than the costs faced by water companies and infrastructure projects. More targeted indices may be more appropriate. • Available from the Office of National Statistics (ONS).[11]
Tender price	Indices which track the price of work priced by contractors for their clients, usually from when the tender is accepted.	• Used to normalise estimates and budgets between projects and sub-contractor works occurring at different dates. • Available from BEIS,[12] RICS (e.g., BCIS All-in Tender Price Index) and cost consultancies.
Cost price	Indices measuring movements in the costs of labour (e.g., statutory employment costs), material and plant to a contractor, exclusive of overheads and margins.	• Used to reimburse contractors for inflation during a project, when inflation risks are allocated to the client. • Available from BEIS, RICS (e.g., General Civil Engineering Cost Index) and cost consultancies.
Output price	Indices measuring the price level of work being undertaken in a given period. Normally reflect accepted tender prices in previous periods.	• Originally used to deflate output from current to constant price levels, but now also used in statutory and contractual applications. • Available from BEIS, RICS (e.g., BCIS All-in OPI) and cost consultancies.

[11] ONS, Consumer Price Inflation (includes all 3 indices – CPIH, CPI and RPI) QMI

[12] BEIS, BIS prices and cost indices

Changes in legislation, technical codes or government policies can cause cost variation between the comparator set and project under assessment. This could include changes which have occurred since the historical projects were undertaken, or future changes that water companies have reflected in their cost estimate. An example is the Biodiversity Net Gain regulations expected to come into effect in November 2023. Since the associated costs will not be reflected in historic projects, they would ideally be carved out from the cost estimate before it is benchmarked. To facilitate this, Ofwat/RAPID could issue guidance to companies to separately identify new policy-related costs if a particular threshold is exceeded (e.g., 1% of project value), so that they can be dealt with separately.

Making appropriate re-basing adjustments is inevitably driven by judgement and will require assumptions to be made. A set of principles should be defined at the outset around how these re-basing adjustments will be made, which should then be documented and applied consistently,

Step 4: Undertake analysis

Following validation and re-basing, the comparison dataset should contain historic observations which are sufficiently similar to the project under assessment that any differences between the project and the set are meaningful for cost assurance. The differences (or similarity) will be meaningful when external factors have been accounted for in Step 3, such that the comparator set represents a reasonable benchmark for the cost estimate.

Benchmarking can be undertaken with reference to the mean, median or mode of the comparison set, or through more sophisticated techniques such as regression modelling or non-parametric modelling (e.g., data envelopment analysis). In the case of regression modelling, an important analytical choice will be the selection of independent variables, or 'cost drivers', referenced in section 6.2 in the context of parametric modelling. In the water sector, typically only a single independent variable is used, but sometimes this is increased to two.

Step 5: Review and repeat

The results of benchmarking can provide information on the reasonableness of cost estimates. A project which deviates from historic trends may require scrutiny and challenge to ensure that cost estimates are not unrealistically high or low.

When analysing results, attention should be paid the outliers in the comparator set and a decision made on whether outliers should be removed or retained. Outliers could be caused by imperfections in the re-basing assumptions, in which case these could be refined. Ultimately, it is important to be able to provide a contextual explanation for outliers and any deviation between the benchmarked project and comparator set.

Benchmarking can be undertaken at multiple stages of the Gated Process, with refinements to the methodology to reflect the maturity of the project and granularity of the cost estimate.

8.3. Non-benchmarked costs

It may not be possible to benchmark some components of projects where there is a lack of comparison data. This could occur in the case of a component which is unique, innovative, and/or not typically undertaken by a water company (e.g., social or environmental components).

Such components are only likely to be relevant from a cost benchmarking perspective if they form a material proportion of the overall project cost estimate. Where they are material, the methods for dealing with these components are likely to be bespoke to the specifics of the project and the component. Generally, two potential approaches are:

- Seeking relevant examples from outside of the water industry. For example, a wetland linked to a reservoir may be comparable to conservation efforts undertaken by Local Authorities or The Crown Estate.
- Greater reliance on assurance techniques (as covered in Section 8.1).

GLOSSARY

Analogy-based estimating	A cost estimating technique that looks at comparator projects to infer the cost of future projects.
Base estimate	An estimate of project cost without any adjustment for risk or uncertainty.
Bottom-up cost estimating	A cost estimating technique where cost estimates are built up based on the individual tasks that make up a work element, assigning resource requirements (e.g. labour, materials) and costs to each individual task, and aggregating up.
Capex	Capital expenditure
CESMM	Civil Engineering Standard Method of Measurement
Comparative estimating	See analogy-based estimating.
Cost assurance	The process of revieing and providing confidence in a project's cost estimate.
Cost benchmarking	The process of either estimating a project cost, or assuring a project cost, with reference to outturn costs from other projects.
Cost estimating	The process of forecasting the costs of a proposed capital project. This can cover just capital costs (i.e. the costs involved with constructing the asset), or they can cover whole life costs (i.e. inclusive of opex and decommissioning costs).
Cost model	A mathematical representation of the relationship between the cost of a project (or a component of a project) and its cost driver(s). For example, the mathematical relationship between the diameter of a pipeline, the length of the pipeline, and its cost.
CPIH	Consumer Prices Index including owner occupiers' housing costs. A measure of consumer inflation.
Engineering estimates	See bottom-up estimating
Expert judgement	A cost estimating technique that relies on the experience and 'gut feel' of experts to estimate the costs of a project.
Opex	Operational expenditure
Optimism Bias	The tendency for project appraisers to be over optimistic around project costs, timeline, and benefits. Optimism bias adjustments refer to explicit adjustments made to the estimates of a project's costs, benefits, and duration, to reflect this tendency. Such adjustments are typically based on data from past or similar projects and adjusted for the unique characteristics of the project in hand.
Parametric modelling	A top-down cost-estimating technique that uses outturn costs from previous projects to inform the costs of future projects.
RAPID	Regulators' Alliance for Progressing Infrastructure Development
Risk	Discrete events that, should they transpire, would affect a project's performance in terms of cost, schedule, or benefits.
Standard Method of Measurement (SMM)	Standard Method of Measurement is a reference document used to standardise the measurement of civil engineering works, to aid cost estimating, tender pricing, and valuing completed works.
Three-point estimating (3PE)	An alternative approach to developing bottom-up cost estimates that accounts for uncertainty.
Top-down cost estimating	Cost estimating techniques where the cost of a project as a whole is estimated, or where cost of large components of a project are estimated and then aggregated. Contrasts with bottom-up cost estimating.

TR61	A collection of capital and operational cost estimation models for the water industry.
Uncertainty	A broad term reflecting the full range of explanations for why the outturn cost of a project may differ from its estimated cost. More typically, however, uncertainty is used to refer to any element that is not considered a risk.
Work Breakdown Structure (WBS)	A breakdown of a scheme into constituent components, either at a high level, e.g. broken down into broad asset groups, or much more granular.

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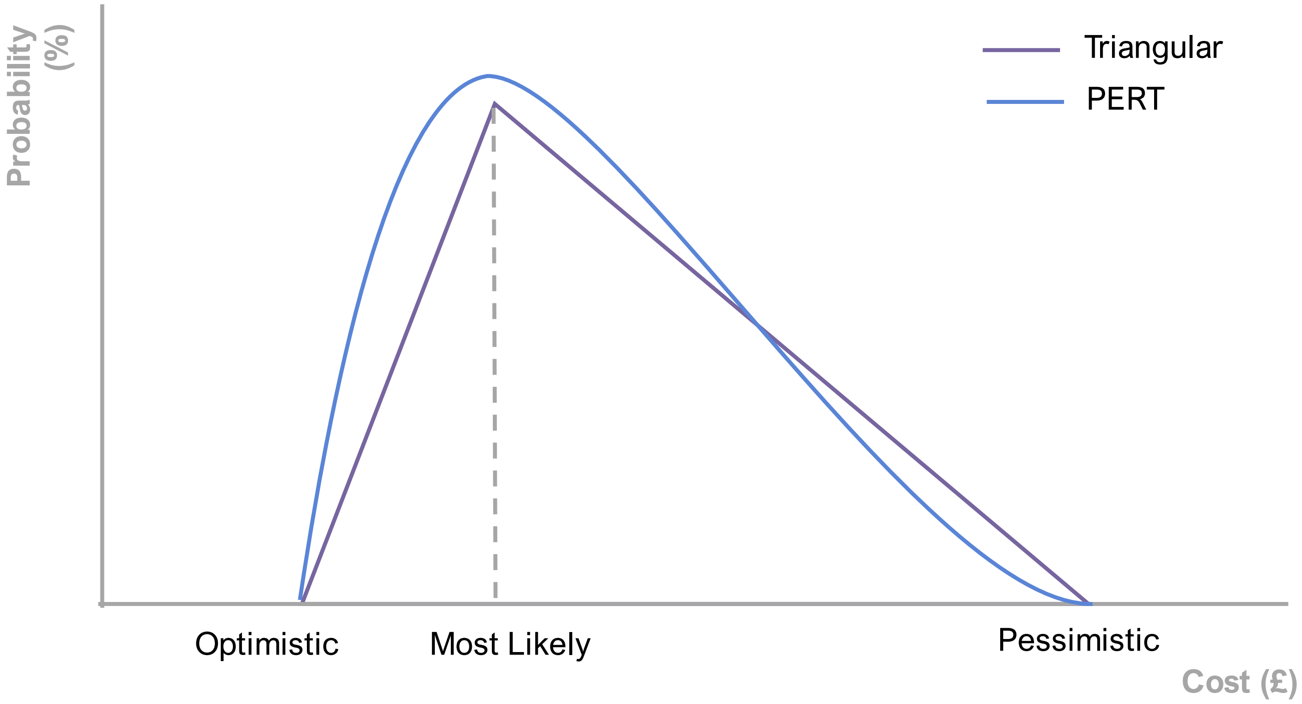
Appendix A TRIANGULAR AND PERT DISTRIBUTIONS

A **triangular distribution** is a triangular-shaped probability distribution where the upper bound is set as the cost under the pessimistic outcome, the lower bound is set as the cost under the optimistic outcome, and the modal bound is set as the cost under the most likely outcome.

A **PERT distribution** is an alternative distribution that relies on the same three points – an upper bound, a lower bound and most likely (modal) – but with a smoother shape.

These two distributions are illustrated in Figure 12.

Figure 12: Illustration comparing triangular distribution with PERT distribution



There are also other variants of these distributions, such as the **tri-gen distribution** where the most optimistic and pessimistic outcomes at the nth percentile (e.g. the 5th and 95th percentiles). This is valuable where the estimated optimistic and pessimistic may be subject to bias (e.g. optimism bias).

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