Risk Management in Large and Complex Civil Infrastructure Projects: DC Clean Rivers Project

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Abstract

Risk management is essential for any organization designing and constructing complex multi-million dollar civil infrastructure projects. The DC Clean Rivers Project risk management plan uses the risk register to identify, track, and manage risks. This traditional process starts at the early planning stage and continues through construction and system startup on a divisional contract basis. This paper describes the step by step approach used in the DC Clean Rivers Project to manage risk at different stages of the project (preliminary design, procurement and contract award, and construction/startup) on multiple contracts delivered by either the Design-Build or Design-Bid-Build approach. It also describes how and when to use quantitative analysis of both cost and schedule impacts, and the frequency for updating the risk register.

Keywords: risk management, risk event, risk register, contingency, qualitative analysis, quantitative analysis.

Introduction

This paper describes the approach to risk management for a large and complex civil infrastructure program, namely the DC Clean Rivers (DCCR) Project. It describes the scope and objectives of the risk management effort, the methodologies and tools used throughout execution of the plan.

The key aspects of the project risk management plan include:

- Qualitative Risk Analysis and Risk Register Development,
- Risk Register Updating and Management, and

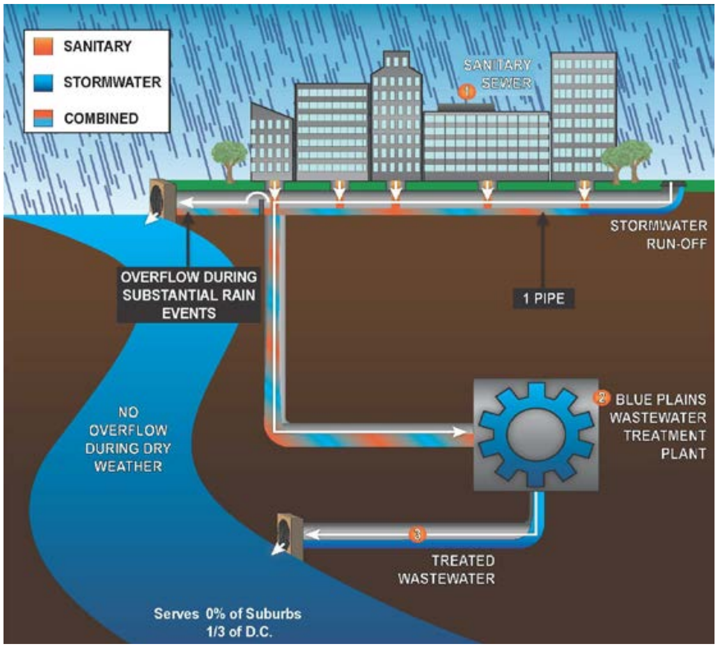
- Quantitative Analysis of Cost and Schedule Impacts of Risk Events.

For this study, the definition of risk is taken from Page 166 of Total Cost Management Framework (2012), “An uncertain event or condition that could affect a project objective or business goal.”

Background

Communities with combined sewer systems are required to prepare Long Term Control Plans (LTCP) for the control of Combined Sewer Overflows (CSO) in accordance with Section 402(q) of the Clean Water Act. DC Water’s LTCP requirements were completed in July 2002 and are currently being implemented through the DCCR Project. The DCCR Project is comprised of a system of tunnels for the Anacostia River, Rock Creek, Piney Branch and the Potomac River that will capture combined sewer flows for treatment at Blue Plains. About one-third of the district sewer system is a combined system and annual discharges into local waterway are estimated at 2 billion gallons. The Anacostia River receives 1.3 billion gallons, the Potomac River receives 640 million gallons and Rock Creek 50 million gallons of overflow each year. The schedule for completing the Project is included in a Federal Court Consent Decree between the United States, the District Government and DC Water.

Figure 1 — Overview of DC Water CSO system



The Anacostia River Projects (ARP) include 12.8 miles (20.7 km) of deep tunnels with approximately 16 shafts, several pumping stations, and several river crossings. The Anacostia River Projects are broken into four main tunneling contracts. Geographically from south to north, these are the Blue Plains Tunnel (BPT), the Anacostia River Tunnel (ART), the Northeast Boundary Tunnel (NEBT), and the First Street Tunnel (FST).

Implementation of the ARP is divided into two phases. Phase 1 of the Program includes the BPT, ART, and several diversion structures and is required to be completed by March 2018. Phase 2 of the Program, consisting of the NEBT and FST, along with the Potomac River and Rock Creek projects, must be completed by March 2025.

Project Delivery Method

Design-Bid-Build (DBB) had been DC Water's preferred project delivery method prior to the start of the DCCR Project. DC Water established new procurement regulations in July 2009 due to the nature of tunneling work and the risks imposed on all parties associated with the DCCR Project. These regulations allow DCCR contracts to be procured by either using the traditional DBB or the Design-Build (DB) with early contractor involvement (ECI). In December 2013, a hybrid delivery method that combines the traditional DBB approach and DB with ECI was added to the mix. Having these different project delivery methods available allowed flexibility and developed a culture of risk management within the project team.

The fourteen contract divisions representing the Anacostia River Projects applicable to the DCCR risk management approach are listed in Table 1.

Table 1 — DCCR Contract Divisions

CONTRACT DIVISIONS Anacostia River Projects		
Division	**Contract Description**	**Type**
A	Blue Plains Tunnel	DB
B	Tingey Street Diversion Sewer	DB

C	CSO 019 Overflow and Diversion Structures	DBB
D	Joint Base Anacostia-Bolling Overflow and Diversion Structures	DB
E	M Street Diversion Sewer	DBB
G	CSO 007 Diversion Structure and Sewer	DBB
H	Anacostia River Tunnel	DB
I	Main Pumping Station Diversions	DB
J	Northeast Boundary Tunnel	DB
N	LID Retrofit at DC Water Facilities	DBB
P	First Street Tunnel	DB
S	Irving Street Green Infrastructure	DBB
U	Northeast Boundary Tunnel Utility Relocation	DBB
Z	Poplar Point Pumping Station Replacement	DBB

Requests for Qualifications (RFQ) are advertised after DC Water holds an Industry Outreach. Submitted Statements of Qualifications (SOQ) and normally 3 firms are shortlisted. For DB's there will be a collaboration phase and technical proposals are evaluated. Cost proposals are opened and the total score (weighted amongst the technical and cost proposals) is evaluated for determining the DB contract awardee. In the case of DBB, there may be questions and addenda during the bidding period, and the low responsive bidder determines the contract awardee. If necessary, clarifications are issued and thereafter the contract is awarded by the DC Water Board.

The procurement process utilized for the DB and DDB contract Divisions by DC Water is shown in Figure 2 and 3, respectively.

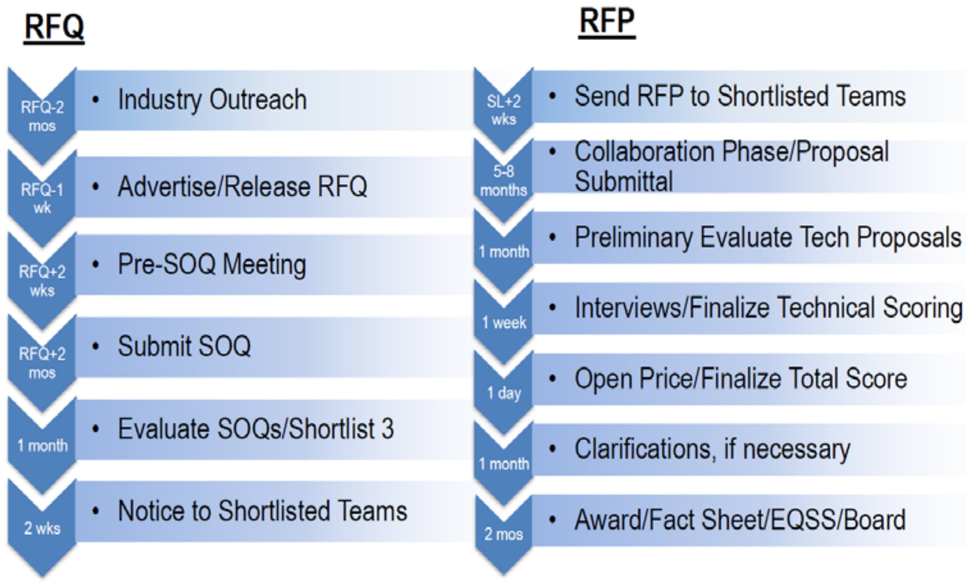


Figure 2 — DC Water Procurement Process for DB Contract Divisions

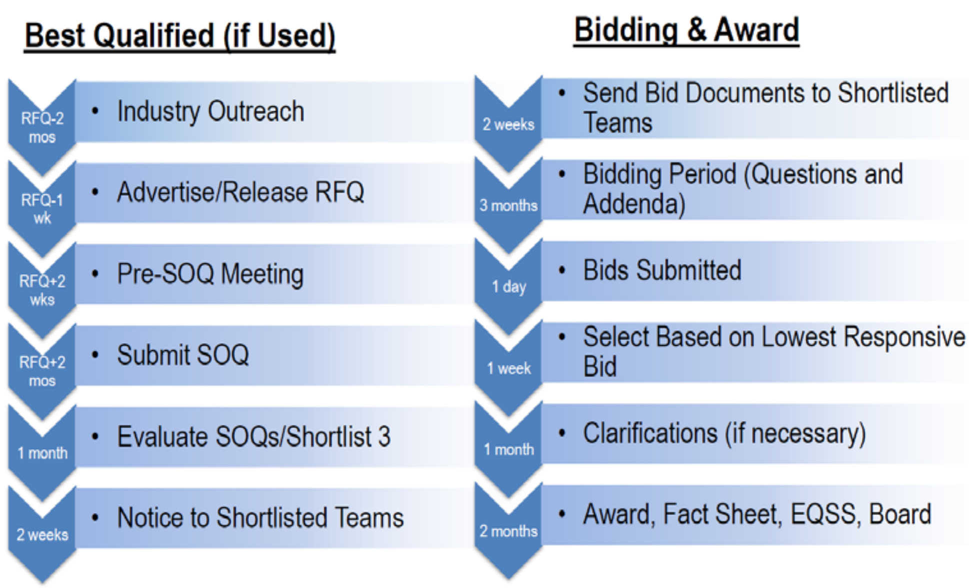


Figure 3 — DC Water Procurement Process for DB Contract Divisions

Earlier, Wone et al. (2015) had presented an overview of the DCCR procurement process and the risk management approach is further developed in the following sections of this study.

Risk Management Methodology

DC Water (2014) promulgated the DCCR Project Risk Management Plan which is the guideline for effectively decreasing the probability and impact of adverse risk events for the DCCR Project. Figure 4 shows the structure and format used in preparation of DCCR Project Risk Registers.

Risk ID	New	Originator	Status	Risk Description	Areas Impacted	Pre-Mitigation			Previous (July 2014)			Mitigation Actions /Comments	Current (March 2015)		
						Likelihood of Occurrence (L)	Severity (S)	Risk Rating (L x S)	Likelihood of Occurrence (L)	Severity (S)	Risk Rating (L x S)		Likelihood of Occurrence (L)	Severity (S)	Risk Rating (L x S)
					S - Schedule C - Cost H - Safety/Health O - Other	1. Very Unlikely 2. Unlikely 3. Possible 4. Likely 5. Very Likely	1. Insignificant 2. Minor 3. Moderate 4. Significant 5. Severe	Intolerable Very Significant Substantial Tolerable Negligible	1. Very Unlikely 2. Unlikely 3. Possible 4. Likely 5. Very Likely	1. Insignificant 2. Minor 3. Moderate 4. Significant 5. Severe	Intolerable Very Significant Substantial Tolerable Negligible		1. Very Unlikely 2. Unlikely 3. Possible 4. Likely 5. Very Likely	1. Insignificant 2. Minor 3. Moderate 4. Significant 5. Severe	Intolerable Very Significant Substantial Tolerable Negligible
103a		PCO	Active	NTP construction for Division Y (Dewatering Pump Station) contract moved earlier resulting in impact to BPT Design-Builder. [RESIDUAL RISK: Design of Div Y affects Div A construction.]	S - Schedule C - Cost	3	3	9	5	5	25	1. Optimize schedules for interfacing contracts.	4	2	8
103b		PCO	Active	NTP construction for Division Y (Dewatering Pump Station) contract moved earlier resulting in impact to BPT Design-Builder. [RESIDUAL RISK: Div Y Construction affects Div A construction.]	S - Schedule C - Cost	3	3	9	4	2	8	1. Optimize schedules for interfacing contracts. 2. Informal collaboration meetings.	4	2	8

Figure 4 — Structure of DCCR Project Risk Registers

Standardized Risk Categories

The risk breakdown structure is standardized using the below format. Risk events are categorized either as Planning, Design, Procurement, Construction or Operations risks. In addition, the following fourteen risk event subcategories were developed to further organize project risks.

- Project Planning and Development
    - 100 General Planning
    - 200 ROW & Easements
    - 300 Permits
    - 400 Public Relations/Acceptance
    - 500 Legal/Funding
- Design
    - 600 Engineering
- Procurement
    - 700 Contracting Issues

- Construction
    - 800 Material, Equipment & Labor Supply
    - 900 Environment/Public Impacts (permit non-compliance)
    - 1000 General Site Conditions
    - 1100 Subsurface Excavations
    - 1200 Material Installation
    - 1300 Safety & Security
- Operations
    - 1400 System Operations

Qualitative Risk Analysis

Qualitative risk analysis is performed and risk registers are developed for all contract Divisions including both DB and DBB Divisions, as required. The order of development will be based on the overall project schedule, with priority given to early development of risk registers for Division contracts being awarded earlier in the schedule.

The qualitative risk analysis uses assessments of relative Likelihood and Severity to provide Risk Ratings for prioritization and relative ranking against other risks. The following is used, as necessary, to assist workshop attendees in the qualitative analysis process.

The relative Likelihood (L) of occurrence is evaluated as a 1-5 rating as shown in below Table 2.

Table 2 — Risk Event Likelihood of Occurrence

Level	Description	Likelihood of Occurrence
1	Very unlikely	L < 5%
2	Unlikely	L = 5% - 20%
3	Possible	L = 21% - 50%
4	Likely	L = 51% - 75%
5	Very likely	L = 76% - 100%

The relative Severity (S) of the event is evaluated as a 1-5 rating in Table 3.

Table 3 — Risk Rating

Level	Description	Cost	Time
1	Insignificant	C < $ 250 thousand	< 1 week
2	Minor	C = $ 250 thousand to $ 500 thousand	1 week to 2 weeks
3	Moderate	C = $ 500 thousand to $ 1 million	2 weeks to 1 month
4	Significant	C = $ 1million to $ 3 million	1 to 3 months
5	Severe	C > $ 3 million	> 3 months

It also should be noted that the relative severity, in terms of either cost or time, can be scaled up or down depending on the cost/size of the Division being analyzed.

The qualitative risk rating (L x S) is expressed as a single numerical value between 1 and 25 which allows it to be evaluated/prioritized against other risks. This is shown in below Table 4.

Table 4 — Likelihood times Severity

Rating	Likelihood X Severity (L X S)	Risk Response
Intolerable	>16.5	Unacceptable; mitigate
Very Significant	>=12.5 & <=16.5	Unacceptable; mitigate
Substantial	>=8.5 & <12.5	Early attention
Tolerable	>=4.5 & <8.5	Attention
Negligible	<4.5	Monitor/accept

These matrices are then summarized using the following chart (for visual representation only) as shown in Figure 5 where L, M, H mean Low, Medium and High, respectively.

SEVERITY							
	Severe	5	L	M	H	H	H
	Significant	4	L	L	M	H	H
	Moderate	3	L	L	M	M	H
	Minor	2	L	L	L	L	M
	Insignificant	1	L	L	L	L	L
			1 Very unlikely	2 Unlikely	3 Possible	4 Likely	5 Very likely
			LIKELIHOOD				

Figure 5 — Risk Matrices Visual Representation

The typical process for developing Division specific risk registers is as follows.

- The draft Division risk register is structured as presented in Figure 4, with the defined risk categories and subcategories outlined above. The draft risk register is developed using available conceptual design documentation and project knowledge; and using information from previously developed risk registers for Divisions faced with similar risks.
- A qualitative risk analysis workshop will be facilitated with the initial design team using this draft risk register. A risk matrix guideline document will be produced for each workshop, as necessary to assist workshop attendees in the qualitative analysis process. The purpose of the workshop is to revise and build upon the draft risk register, to brainstorm additional risks, perform pre-mitigation qualitative analyses of risks, develop risk mitigation strategies, and assess mitigation task responsibilities and status. If necessary, the above tasks can be addressed in multiple workshops.

Risk Register Updating and Management

Division risk registers are formally updated throughout the initial design phase of the work. The formal updates will be timed to correspond with formal internal Division milestone submittals (i.e., at 60%, 90% submittals, etc.). Figure 6 provides an outline of the risk register process during this phase of the project. The goal of the updates is to reflect project progress relative to addressing risks, and will include the following.

- Updates to mitigation tasks and responsibilities,
- Mitigation status updates,
- Assignment of deliverable and completion date targets for mitigation measures,
- Documentation of mitigation measures taken,
- A separate independent cross-check of RFP/Contract Documents to verify that mitigation measures have been incorporated, and
- Assessment of current qualitative risk ratings.

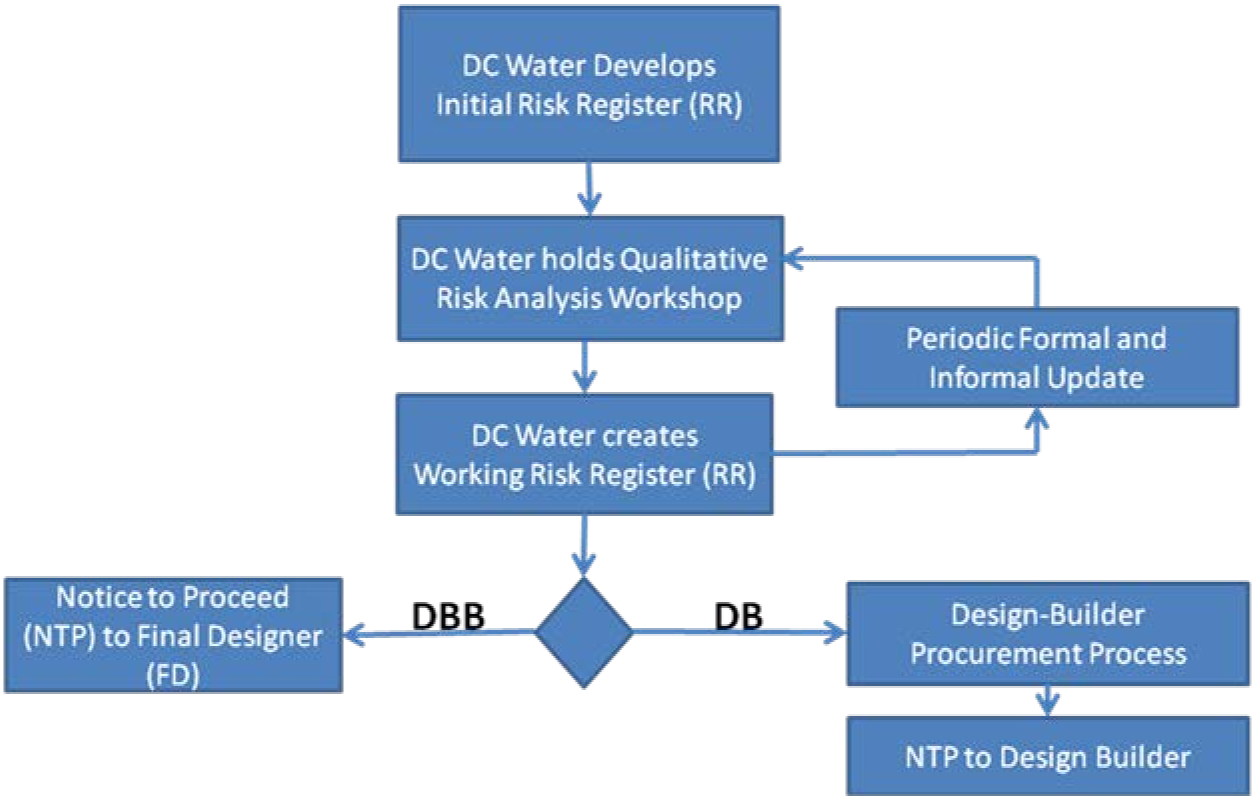


Figure 6 — Initial Design Risk Register Process Flowchart

At the completion of each formal update, a revised working risk register is provided to the Division Program Manager. For DB Divisions, the revised risk register is provided to the Project Review Board (PRB) for review and comment, and this also serves as a means of keeping them aware of significant ongoing risk issues. For DBB Divisions, the revised risk register is attached as an Appendix to each specific Division Design Report and then reviewed internally as part of the internal submittal review process.

Risk management efforts continue during final design and construction (i.e., for Design Builders, in the case of DB projects; and for final designers, in the case of DBB projects). For DB projects, these requirements will start with RFP submittal requirements for Proposers, and extend through the construction of the work with technical specification requirements. Proposers are required to prepare a risk management plan as a part of their proposals. The risk management plan will be used by DC Water to evaluate the Proposer's understanding of the risks and challenges on the project, and how it intends to mitigate such risks. Typical information required includes how risks will be identified, prioritized and tracked throughout the project, and how contingency and/or mitigation plans will be developed and implemented.

DB Risk Register Process

Following contract award, the DB will be required to utilize and expand upon the risk management plan and risk register requirements submitted in his/her proposal to meet the technical requirements of the Contract Documents, which include, at a minimum.

- Submittal of a detailed risk management plan,
- Requirements to develop, maintain and update a project risk register, and
- Requirements to submit an updated risk register at regular intervals throughout design and construction.

An outline of the DB risk register process is shown in Figure 7.

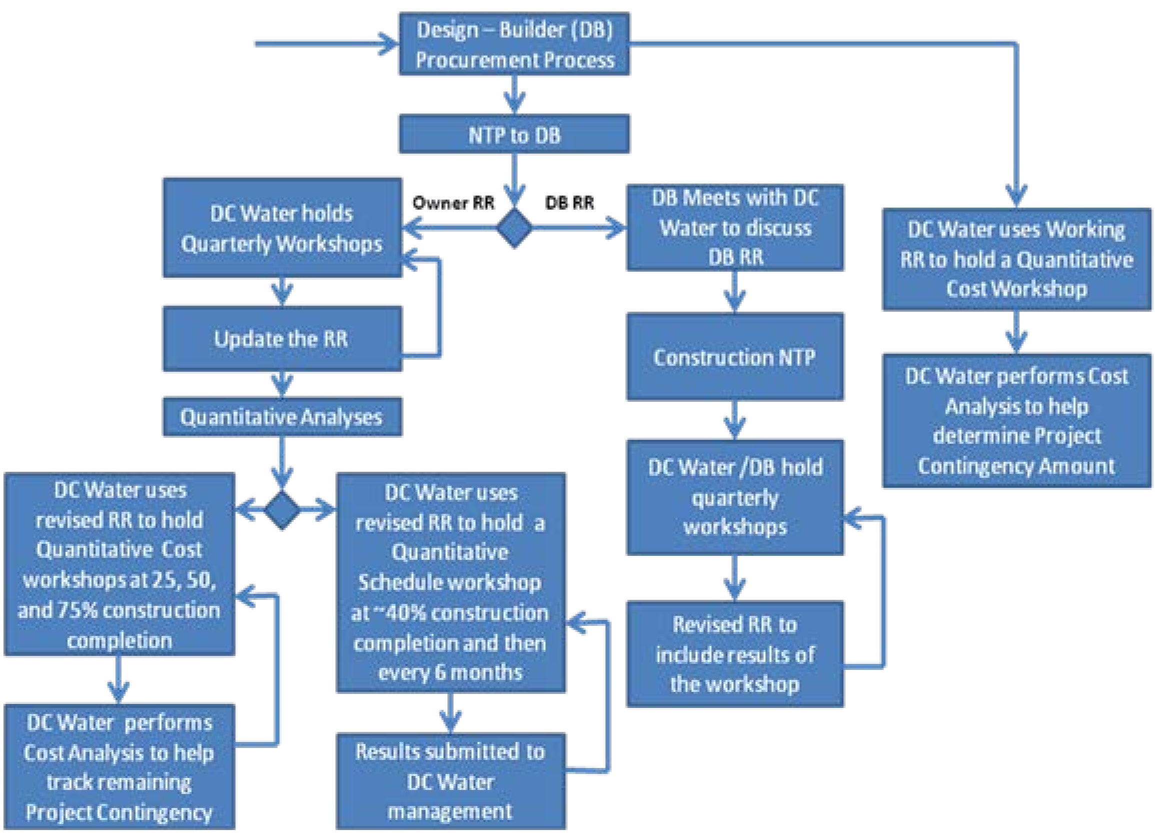


Figure 7 — DB Risk Register Process Flowchart

As indicated above, Quantitative Cost Workshops are held at 25, 50 and 75% construction completion and a Quantitative Schedule Workshop will held at 40% construction completion and every 6 months thereafter. The benefit of conducting these analyses is that results can be used as a sanity check against the contingency dollars being utilized.

DBB Risk Register Process

The risk management process through final design for DBB projects is summarized below and shown in Figure. 8, where CCM means DC Water's Consultant Construction Manager.

- The final designer participates in a risk management workshop to identify project risks and risk mitigation measures, and qualitatively assess the risk rating of the identified risks based on the risk's likelihood of occurrence and severity. The risk ratings serve as a guide for the final designer in assigning a priority for preparing mitigation plans.
- At the completion of the workshop, a risk register with all identified risks, mitigation measures, and entities responsible for carrying out planned mitigation measures is prepared by the final designer.
- The final designer will review and track progress of all risk mitigation plans measures and update the risk register as needed.
- The updated risk register is submitted along with the Interim, Prefinal and Final Submittals.

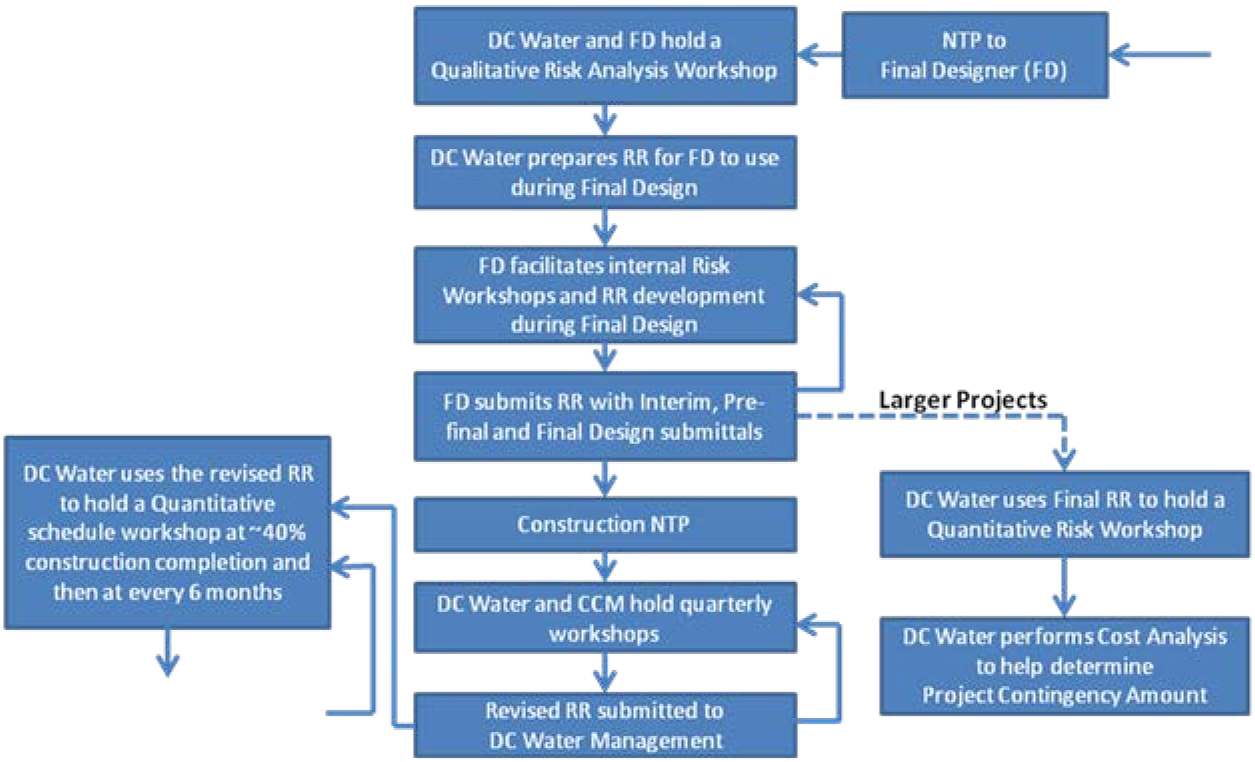


Figure 8 — DBB Risk Register Process Flowchart

As indicated above, there will be a Quantitative Schedule Workshop held at 40% construction completion and every 6 months thereafter similar to the DB process.

Quantitative Risk Analysis

Quantitative risk analyses is performed to further define the risks to a specific Division in terms of the cost and schedule impacts of identified risk events, and to assist DC Water in establishing appropriate budget contingencies. Due to the complexity and time associated with performing these analyses, they are typically performed only on the larger underground projects with substantial risk profiles. Each analysis is performed during initial design, following the 60% design document review. Updates to quantitative analyses are completed, as necessary, and/or as respective to formal project re-estimation.

The quantitative analysis approach used to evaluate cost and schedule impacts are similar. The steps that are followed in performing quantitative analyses for respective Divisions of the DCCR Project are summarized below.

- The existing qualitative risk register is reviewed to identify risks forming the basis of the quantitative analysis. All risks with a “negligible” risk rating will be eliminated, and all non-negligible risks that accrue to DC Water will be incorporated into the analysis.
- The range of possible cost impact outcomes should a given risk event occur is quantified. These are represented in the model by continuous distributions of the resulting costs should a particular risk event be triggered. For the DCCR Project, this is typically accomplished by identifying a “most likely” value for the risk, its maximum and minimum values as well as the 10% and 90% values, thus creating a 5-point probabilistic distribution curve of cost impacts for that risk. For example, the “90% value” represents the estimated dollar amount that will be greater than the cost impact of the risk event 90% of the time.
- The Owner’s % of Risk is identified and evaluated because not all risks accrue 100% to the Owner. This parameter is established as an “if/then” threshold, which sets a minimum amount where all risks below that figure accrue to the Contractor (i.e., = $0 to the Owner) and where any amounts above the threshold would go through to a mathematical “randomizer” that will let certain risks through to the Owner based on proportions.
- A quantitative risk analysis workshop is held and specialists from relevant disciplines review and better establish the probabilities and cost impact probabilistic distribution curves described above. They will also assist in identifying correlations between different risk events (e.g. the risk of ending up with a Contractor with a poor safety record should be positively correlated to the risk of experiencing a greater number of accidents during construction).
- The quantitative analysis is run using numerous Monte Carlo simulations (typically 100,000 "what-if" scenarios) to provide cumulative distribution curves of the total cost resulting from simulated risk events
- The simulation results will be summarized by a cumulative distribution curve of the estimated total risk costs for the project, which also identifies relevant confidence intervals (typically 80%, 85%, 90%, and 95%) that allows DC Water to establish budget contingencies based on their risk tolerance level. Budget contingency amounts can be adjusted following the quantitative analysis workshop based on the use of allowances in the contract and/or on the updated status of risk mitigation measures. Figure 9 shows a quantitative analysis of schedule risk events.

- A sensitivity analysis (regression) is performed, as necessary, to identify the main sources of cost to the project. These sensitivity analyses are useful tools for revealing the key constituent sources of risk and helping DC Water to focus efforts on those areas which would have the most beneficial effect.

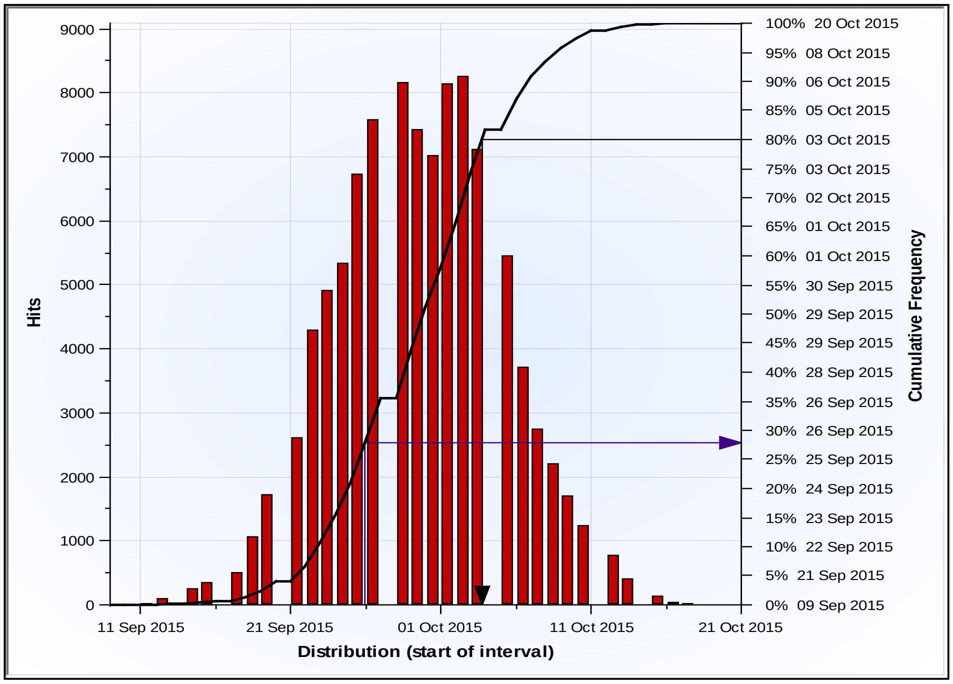


Figure 9 — Quantitative Analysis of Schedule Risk Events

Using the above described methodology, DC Water has developed a risk management process to readily monitor the Division contingency status through construction as an outcome is shown in Figure 10. This figure tracks the actual project contingency utilized during the construction period and readily visualizes the remaining contingency. A recommended minimum reserve amount of project contingency based upon Quantitative Cost Analysis at that construction phase is also shown. If trending indicates the remaining contingency will be less than the minimum reserve amount, then augmentation of the project contingency may be initiated via the DCCR change order process.

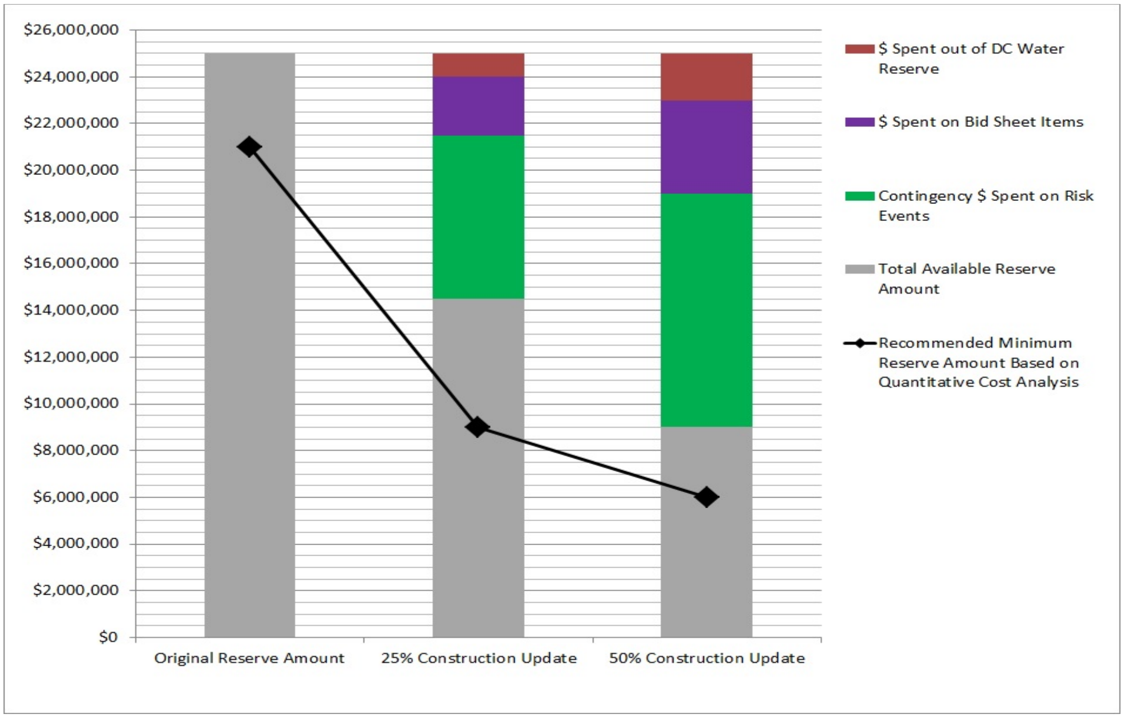


Figure 10 — DCCR Contract Division Contingency Monitoring

Conclusion

The methodology described in this study results in an effective risk management plan for large civil infrastructure projects that is:

- Built upon ongoing qualitative risk analysis,
- Requires continuous risk workshops involving project stakeholders,
- Uses probabilistic modeling simulation to provide numerical ranges of the potential current cost and schedule impacts, and
- Establishes appropriate project contingencies and subsequently as a comparison to the current available project contingency.

Further, the DCCR Risk Management Plan has demonstrated its utility as a Project Management tool that:

- Helps develop realistic schedule milestones to better manage contract interfaces and meet consent decree deadlines,
- Enables understanding of current risk position,

- Tracks contingency spending given occurring risk events, and
- Updates program schedule analysis (identifies impacts to other Divisions).

Acknowledgement

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