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- Providing public awareness of the role of dams in the management of the nation's water resources.
- Enhancing practices to meet current and future challenges on dams.
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FOREWORD

*Risk Management for Dam Construction* was prepared by the USSD Committee on Construction and Rehabilitation. This White Paper uses and adapts accepted Project Risk Management techniques for new dams and dam rehabilitation projects. It discusses the formal Risk Management process, identifies risk categories for dam construction, reviews strategies to manage risks, and presents several case studies where risk management strategies were employed. It was written for engineers, owners, and contractors engaged in the planning, design, and construction of dam-related projects anticipated to cost anywhere from $20 million to over $500 million. Our hope is that this paper helps the industry to gain insight into the importance of Formal Risk Management for dam projects, and implement rigorous management of risk throughout the course of a project.

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This paper represents the collaborative effort of representatives from federal agencies, public utilities, private engineering companies, and construction contractors.

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1.0 Introduction and Purpose

Formal Project Risk Management is a best management and proactive practice for identifying risks, projecting their likelihood of coming to fruition, assessing potential impacts, and developing mitigation plans. Past projects have demonstrated that proper management of risk helps identify appropriate project budgets, and results in a higher quality project that meets stakeholder expectations.

The practice of dam construction and rehabilitation carries significant inherent risks that cannot be managed or mitigated by any one party. One example of a possible risk on a dam project is the potential for flooding behind a cofferdam. If this risk is proactively reviewed during design, an appropriate mitigation measure can be added to the project before construction starts. Mitigation measures might include a diversion channel, a pump system to deal with potential flooding, or an allowance item added to the construction contract to require and pay for demobilization of equipment at the engineer’s direction prior to a heavy rain event. This mitigation plan may also need to include potential costs (contingencies) in the project budget so the owner knows the full cost potential and can appropriately fund the project and risks before construction starts.

This paper uses and adapts accepted Project Risk Management techniques for design and construction of dam projects. It identifies and categorizes risk types salient to dam construction, reviews the process of risk identification and qualitative analysis, discusses guidelines for risk allocation, reviews strategies to manage risks, presents several case studies where risk management strategies were employed successfully (or unsuccessfully), and presents lessons learned. The paper concludes with a summary and recommendations for best practices for Project Risk Management that can be used by owners; design engineers; and construction managers in planning, design, pre-construction, and construction of dam related projects.

2.0 Implementation of Project Risk Management for Dam Construction

Every project has a unique set of risks that could impact its scope, budget, schedule, and quality. Risk is defined as the cumulative effect of the likelihood of certain occurrences that may positively or negatively impact project objectives. Risk is categorized by three factors: risk event, risk likelihood, and potential impact and consequences. People normally equate risk with negative consequences; however, risks can present opportunities or positive results as well.

Risk Management is needed at all phases of a dam project, but is also a key tool when considering adding the fully defined project scope, budget, and schedule to an owner’s capital improvement program. The Project Risk Management process for dams generally consists of the following steps:

- Risk Identification and Categorization
- Risk Management Strategies
- Risk Analysis and Risk Register Development
- Risk Monitoring and Updating
3.0 Risk Identification and Categorization

The first step in Project Risk Management is to identify and categorize risks during the early stages of a project, preferably during the planning phase. The planning phase is an important part of a dam project. This point of the project is when most owners rely on project teams to develop initial estimates of project scope, cost, and schedule. The owner typically uses the project cost estimates to secure appropriate funding for full cost of the design and construction of the dam project.

A typical risk identification and categorization process includes a formal project team workshop during the planning phase of a project. This workshop is used by the project team members to identify risks from several sources, including lessons learned from similar projects, project team experience, understanding of the project, technical experience, current construction trends, and impacts to the current operation of the facility. A categorized overview of some common risks identified on past dam projects is provided below.

Categorized Overview of Risks

- **Technical Risks**
  - Heavy rains during construction cause flooding of construction work zone causing delays and extra costs.
  - Design phase fails to accurately define Seismic Zone causing inadequate foundation, dam, and appurtenances.
  - Differing site conditions cause significant cost overruns and delays.
    - Geologic/geotechnical condition assessments are not done per industry standard.
    - Unknown/uncertain condition of existing facilities especially in rehabilitation projects are not fully investigated.
  - Design errors due to inadequate Quality Assurance and Quality Control cause additional cost and delays during construction.

- **Contracting and Construction Risks**
  - Unqualified bidders cause project delays and cost to all parties.
  - Unqualified construction workers and supervisors cause delays and extra cost to all parties.
  - Inadequate time for contractors to prepare bid proposal schedule cause contractor to omit proper costs in their bid resulting in cost overruns for owners due to excessive change orders and potential construction claims from the contractor.
  - Inadequate construction equipment causes delays and cost overruns for all parties.
- Using the project delivery method of awarding to the lowest responsive and responsible bidder can cause some contractors to omit certain costs in their bid to be more competitive, resulting in:
  o Poor workmanship due to short cuts and less supervision.
  o Claims due to either unclear contracts or contractor missing items in his bid.
  o Project delays due to re-work.
  o Contractor having financial issues if cost are higher than his bid.
- Lack of adequate owner’s contingency fund for cost increases during construction such as change orders and potentially higher bids cause project delays and potential work stoppages.
- Owner’s inefficient method of approving contractor Change orders or low authorization limits or these change orders cause delays to project and payments to contractor.
- Limited dam construction experience of project team members (owner, engineer, contractor) affect quality of project and/or also cause delays and cost overruns for all parties.
- Region where the dam is being built has a shortage of skilled labor, equipment, materials, and/or general services which cause project delays or increases to project costs.
- Commodities such as fuel and material increases during the construction project cause cost overruns for the contractor.
- Owner requests excessive changes to the project scope of work during construction which causes delays and cost overruns for all parties. (Scope Creep)
- Owner does not provide and/or effectively describe the Quality Assurance/Quality Control (QA/QC) program in the contract which:
  o Confuses all parties as to who is responsible for QC versus QA (i.e. Contractor responsibilities for Quality Control items versus Construction Manager/Owner responsibilities for Quality Assurance) causing delays due to re-work.
  o Causes a lack of quality construction due to insufficient trained/certified individuals for contractor’s QC program.
  o Causes contractor delays due to lack of Special Inspection hold point requirements. (For example, the construction contract documents don’t specify inspection hold requirements for State Regulators such as Division of Safety of Dams.)
- Safety issues cause unnecessary injury, poor morale, and project delays or work stoppages.
- Contractor incomplete or inaccurate contractor’s schedule does not allow all parties to pro-actively identify and track and coordinate critical path issues.
- Inclement weather such as excessive rain and/or snow extends the project duration or causes contractor to miss milestones.
- Conflicting goals of stakeholders (i.e. Regulator vs. Designer) during construction cause multiple changes to the scope of work causing delays and cost overruns.
- Lack of experienced contractor for all project components (i.e. specialized gates, valves, SCADA, etc.) cause submittal and installation delays.
- Insufficient contractor schedule and submittal information for design-build-items causes delays and cost overruns for all parties.

• Other Risks
  - Project team personnel turnover causes extra work, cost overruns, and delays. 
    (All Team Members: Designer, Construction Manager, Construction Contractor).
  - Unexpected and/or extreme environmental requirements that were not anticipated during design and/or not included in the construction contract cause changes to scope of work resulting in project delays and/or cost overruns.
  - Regulatory Agency changes requirements agreed upon during design during construction that cause project delays and/or cost overruns.
  - Regulatory permitting that is not completed prior to bidding the construction contract delays or stops construction phase work.
  - Property access issues and land acquisition that is not completed prior to bidding the construction contract delays and/or stops work during construction.
  - Public/political interruptions during construction delay and/or stop work.
  - Security breaches during construction increase cost and/or delay work (i.e. stolen equipment or materials, damaged equipment, and/or damaged work).

4.0 Risk Management Strategies

The purpose of risk management is to identify and implement a strategy to address moderate and higher risks. This is typically done by assigning a project risk owner who, in collaboration with the project team, can choose a strategy to deal with the risk. The risk owner should be the party who is in the best position to manage the risk. This could be either the owner, engineer, construction manager, or contractor depending on the specific risk. There are numerous risk strategies for dam projects. For the purpose of this paper they can be grouped in the following four strategic categories:
• **Avoid** – eliminates the probability and/or impact of the risk. For example: The owner could avoid the risk of delay due to property access issues by ensuring all temporary easements and/or property is acquired prior to advertising the project for public bid.

• **Mitigate** – reduces the probability and/or impact of the risk. For example: The owner could mitigate or reduce a risk of differing site conditions by ensuring that geotechnical investigations and condition assessments of existing facilities meet industry standard for completeness during the design phase of the project.

• **Transfer/Share** – shares or transfers risk to the contractor. For example: The construction contract could transfer or share the risk of commodity (fuel, cement, or steel) price increases by adding escalation/de-escalation allowances.

• **Accept** – includes the risk in the project budget because it is outside the team’s influence. For example: The construction contract could include unit price items to account for variations in foundation excavation quantities. will vary by paying for excavation on a unit price basis rather than lump sum.

**Example Risk Management Strategies on Past Dam Projects**

Dam projects have different and unique scopes of work such as constructing a new dam, rehabilitating an old dam, modifying a dam to incorporate hydropower, or raising an existing dam for additional storage and/or flood control. Depending on the scope and type of project, there may be several unique risks that must be managed. Listed below are past risk management strategies used on dams. These are categorized by their use in each phase of the project.

• **Pre-Construction Phase Strategies**
  - **Technical Risk Strategies**
    o Share risk by developing baseline geologic/geotechnical conditions and include the information in the construction contract.
    o Mitigate or reduce the potential risk of differing site conditions by ensuring geotechnical investigations and condition assessments of existing facilities meet industry standard for completeness.
    o Establish criteria for hydrologic risk sharing based on probabilistic analysis.
    o Mitigate re-work issues by establishing clear QA/QC requirements in design specifications so contractor is clear about its responsibilities and is aware of owner and regulators’ inspection hold points. This will help ensure proper scheduling and reduce the potential for surprises.
    o Mitigate potential design issues by conducting third party technical reviews of contract plans and specifications.
o Mitigate change orders during the construction phase by performing a constructability review by experienced construction professionals at key points of design.
o Determine appropriate project schedule based on overview of scope, risks, and project constraints such as reservoir shutdown and time of year for construction.

- Construction Contract Strategies
  o Use alternative contracting methods to share risk between Owner and Contractor.
    ▪ Best value
    ▪ Negotiated procurement
  o Involve contractors earlier in design process to obtain their comments on contract specifications and design plans to mitigate change orders.
  o Use unit price items versus lump sum items to share risk of payment for actual material quantities.
  o Include allowance items for known uncertainties, such as allowing contractor to procure generators during a prolonged regional power outage.
  o Include a Liquidated Damages clause at certain milestones transferring risk to the contractor to be more accountable for meeting contract schedule.
  o Phase construction to mitigate impacts of differing site conditions on sequential construction activities (for example: Bid the dam foundation and complete work under a separate construction contract prior to bidding the dam building work).
  o Use pre-qualification process to pre-select contractor bid pool to mitigate the risk of not having capable bidders for specialty type work.
  o Include insurance provisions to accept risk of floods, fires, and/or other natural disasters.
  o Add special contractual provisions to transfer bidding risk to owner for escalation/de-escalation of materials such as steel, cement, and fuel.
  o Use separate contracts to complete different aspects of the project to reduce the potential for risk of change during construction (i.e. procure a professional service contract to develop and install the Supervisory Control and Data Acquisition programming after dam construction contractor has completed its work).

- Other Strategies
  o Include cost contingencies or reserves in the project budget, per industry standards such as American Association of Cost Estimators
(AACE), to anticipate future unknowns or risks outside the team’s influence.

- Perform outreach to contracting community and labor unions during design phase to reduce the risk of potential labor issues during construction.
- Perform public outreach to affected communities and businesses to reduce or mitigate potential issues prior to construction.
  - Identify all project stakeholders, meet with them often, and incorporate issues, as appropriate, into construction contract requirements (for example, use public outreach to determine: hours of work, material and equipment delivery haul routes, etc.)
- Complete environmental and permit processes before bidding the project to reduce or mitigate potential delays during construction.
  - Provide clear and specific incorporation of environmental issues into contract.
- Identify property issues to reduce the potential for project delays during construction.
- Obtain all property, easements, and rights of entry before bidding project and clearly define in contract.
- Establish site security to reduce the potential theft of equipment and materials and/or damage to the project.

**Construction Phase Strategies**

- Use formal partnering to protect against the risk of project team silos developing between owner/designer/construction manager/contractor.
- Share the Risk Register with the contractor and use as a communication tool throughout construction to monitor risks and coordinate risk management strategies.
- Use a Dispute Resolution Board (DRB) to mitigate and/or reduce the risk of untimely resolution of issues.
- Include regulatory and other outside stakeholders in partnering to mitigate the risk of them becoming outsiders to the project team.
- Plan float into the construction schedule, and clearly define in the contract who owns float, to help ensure the project schedule is accurately prepared and monitored. This will help promote good communication between the owner and contractor and help reduce or mitigate potential project delays.
- Include provisions in the contract for the contractor to use proactive procedures in planning its work, such as Job Hazzard Analysis, to reduce the potential for injuries.
- Incorporate Quality Control managers for both owner and contractor, and require they meet and discuss issues on a regular basis to mitigate or reduce the risk of re-work.
- Ensure permits are clearly included in the construction contract, and hold regular meetings to ensure compliance, to mitigate the risk of potential fines or delays to the project.

5.0 Formal Risk Analysis and Risk Register Development

Once the risks have been identified, the next step is to perform a formal risk analysis. The purpose of a formal risk analysis is to quantify and prioritize the risks and allocate resources to address those that could potentially affect the project the most. To understand the seriousness of the risk, you must know the likelihood of occurrence and the potential impact. From there, the highest priority of risks can be determined.

A Risk Register is a powerful tool that allows the project team to record and proactively manage risks identified for the project. A Risk Register records the details of all the risks identified at the beginning and during the life of the project, their grade in terms of likelihood of occurring, and potential impact to the project. The level of sophistication of the Risk Register varies depending on the magnitude and complexity of the project. In general, risks are evaluated either qualitatively or quantitatively. Quantitative risk analysis is used for larger more complex projects and includes the use of tools, such as the Monte Carlo Analysis, to obtain more accurate cost and time impacts. Quantitative analysis was not included as part of this paper because it is a topic within itself. Qualitative evaluation is easier to perform and can provide sufficient data for smaller projects and help determine the higher risks for larger more complex projects. A qualitative Risk Register that was adapted from one developed by the Tasmanian Government Agencies and Instrumentalities is presented below.

The qualitative Risk Register presented in Table 1 below includes:

- Description of Risk – describe risk and how it might be triggered.
- Impact on Project – describe how this risk could affect the schedule, cost, quality, or safety of the project.
- Assessment of Likelihood – Provide a probability or chance that the risk could occur.
- Assessment of Impact – Identify consequences to project if the risk comes to fruition.
- Grade – Grade based on likelihood of occurrence and impact.
- Change in Grade – Change of grade since last Risk Register review/update.
- Date of Review – Shows last time the Risk Register was updated.
- Management Actions – Proposed actions to either avoid, by changing scope or some component of design; mitigate by changing design; transfer to contractor; or share or accept the risk, and budget for it coming true.
- Responsible Party – Assign an “owner” to each risk with the responsibility to ensure mitigation measure(s) are developed and implemented.

- Timeline to Incorporate Mitigation Actions - Specify timeframe for mitigation action(s) to be completed.

- Rough Order of Magnitude (ROM) Cost - Specify the rough order of magnitude cost should the risk occur.
<table>
<thead>
<tr>
<th>Id</th>
<th>Description of Risk (including any identified 'triggers')</th>
<th>Impact on Project (Identify consequences)</th>
<th>Assessment of Likelihood</th>
<th>Assessment of Impact</th>
<th>Change</th>
<th>Date of Review</th>
<th>Management Actions</th>
<th>Responsible Party</th>
<th>Timeline to Incorporate Mitigation Actions</th>
<th>Rough Order of Magnitude (ROM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#</td>
<td>A &quot;newspaper headline&quot; style statement. Also identify relevant triggers that may cause the risk to be realized.</td>
<td>Describe the nature of the risk and the impact on the project if the risk is not mitigated or managed.</td>
<td>See table below</td>
<td>See table below</td>
<td>Change in Grade since last review – See table below.</td>
<td>Date of last review.</td>
<td>Specify planned mitigation strategies to avoid, mitigate, transfer or accept risk.</td>
<td>Specify who is responsible for undertaking each mitigation action.</td>
<td>Specify timeframe for mitigation action(s) to be completed.</td>
<td>Specify the rough order of magnitude cost of the risk should it occur.</td>
</tr>
</tbody>
</table>
The tables below provide suggested ratings for likelihood and impact of each risk, grades for the combined effect of likelihood and impact, and recommended actions for grades of associated risk.

| Table 2. Qualitative Rating for Likelihood and Impact of each risk |
|-----------------------|-------------------------|----------------|
| L | Low | E | Extreme (Used for Impact only) |
| M | Medium | NA | Not Assessed |
| H | High | | |

| Table 3. Grade: Combined effect of Likelihood/Impact |
|---------------------------------|------------------|------------------|-----------------|-----------------|
| Likelihood | Impact  |
| | Low | Medium | High | Extreme |
| Low | D | D | C | A |
| Medium | D | C | B | A |
| High | C | B | A | A |

<table>
<thead>
<tr>
<th>Recommended actions for grades of risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade</td>
</tr>
<tr>
<td></td>
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<td></td>
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</tbody>
</table>

6.0 Risk Monitoring and Updating

To be effective, the project team must consider the Risk Register a “living document” that is reviewed and updated regularly throughout the entire life of project. Risk monitoring and updating maintains a current understanding of all project risks and helps the project team develop or implement mitigation strategies as needed. A Risk Register can also be used as a tool for the owner’s management to update policy makers (Boards and Councils) on the progress and potential cost overruns or schedule risks during all phases of the project. This allows policy makers to be more comfortable that a project is being managed effectively.

The Risk Register should be updated using a formal process at key project milestones, during planning, design, construction, and post construction.
**Planning**

The project team should create the Risk Register as part of the planning process. It is not expected that all the risks will be identified or developed during planning. However, starting this process early will help the owner identify project risks that could affect the project scope, schedule, and budget. Also as part of the project approval process, owners typically need to determine proper financing and timing for this debt. Identifying schedule risks will help the owner with determining a more realistic schedule for issuing debt. Tasks that occur in the planning phase, such as the environmental permit process, technical and geotechnical studies, and the appropriate level of cost estimates with escalation factors will help identify risks.

**Design**

Once a dam project’s full budget is approved and the project moves through the more detailed design phase, some risks will decrease; some will remain potential problems to be managed and monitored; and others will materialize and potentially affect the project scope, budget, or schedule. The Risk Register is used during the design phase to make appropriate design changes; enhance construction contract specification language; and set appropriate milestones, project incentives, and liquidated damages for the construction contract. Risks mitigated during design should be removed from the Risk Register before the project enters construction.

**Construction**

The Risk Register is used during construction to identify how project scope or schedule delays affect hard and soft construction costs, such as additional staff labor, consultant contract extensions, permit extensions, etc. One way to engage the contractor in this process after a project is bid, is to hold a separate risk management workshop to proactively review these risks as they relate to the current construction contract moving forward. This can be done as part of partnering or a separate agreed upon workshop. During construction, risks should be reviewed monthly. New risks may need to be added and others removed from the Risk Register as construction advances through the testing, start-up, and commissioning of the project.

**Post Construction**

The Risk Register is used during post construction to assure all stakeholder commitments have been met. These may include verifying fulfillment of all environmental permit requirements, property used for construction access was returned to pre-construction condition, and confirmation of the design intent of the dam through post construction testing. It can also be used as a lessons learned tool for similar projects in the future. The lessons learned data from the post construction Risk Register should include detailed reasons for all scope, schedule, or budget changes that occurred during the life of the project.
7.0 Risk Management Case Studies

This section provides examples where Risk Management has been used either informally or formally on past dam projects. Examples of real project risks and risk mitigation strategies that were employed successfully (or unsuccessfully) are described under each project section. Some key risk management lessons learned are also provided. Table 4 provides background information for each of the case studies.

### Table 4. Case Study Background Information

<table>
<thead>
<tr>
<th>Project Name</th>
<th>Owner</th>
<th>Approximate Construction Cost ($ Million)</th>
<th>Risk Management Process</th>
<th>Major Risks Discussed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Big Tujunga Dam</td>
<td>Los Angeles County Department of Public Works</td>
<td>$100</td>
<td>Informal</td>
<td>Dam Material Selection, PMF and Spillway Design, and Flood and Fire Risk During Construction</td>
</tr>
<tr>
<td>Olivenhain Dam</td>
<td>San Diego County Water Authority</td>
<td>$140</td>
<td>Informal</td>
<td>Sequencing Construction, Use of Onsite quarry, Construction Cost Estimates, Dam Material Selection, Power Considerations for Construction, and Factory Inspection Overruns</td>
</tr>
<tr>
<td>Cleveland Dam</td>
<td>Metro Vancouver Canada</td>
<td>$26</td>
<td>Informal</td>
<td>Reduce the potential for inundating the contractor’s equipment creating construction claims, and for contamination of the reservoir</td>
</tr>
<tr>
<td>Calaveras Dam</td>
<td>San Francisco Public Utilities Commission</td>
<td>$550</td>
<td>Formal</td>
<td>Abutment Slope Stability. Landslides, Faulting, Sequencing Construction, and Environmental Compliance</td>
</tr>
</tbody>
</table>
7.1 Big Tujunga Dam – Los Angeles, California

Project Description

Big Tujunga Dam, shown in Figure 1, is a concrete variable radius thin arch dam at the base of the San Gabriel Mountains that was built in 1930-31 for flood control and water conservation. The dam’s crest is 244-feet high (74.4-meters), crest is 400-feet long (122-meters), and thickness varies from 8-feet (2.4-meters) at the crest to 73-feet (22.3-meters) at the base of the maximum section. In 1975, it was determined that the dam was unable to resist a maximum credible earthquake (MCE) or pass the probable maximum flood (PMF). Therefore, in 2010, the Los Angeles County Department of Public Works (LACDPW) completed a $100 million seismic and hydraulic upgrade of the Big Tujunga Dam. The upgrade converted the dam into a thick arch structure, enabling LACDPW to fill the reservoir to its full 5,750 acre-feet (ac-ft) (4396 cubic meter) storage capacity for the first time since 1975.

Figure 1. Big Tujunga Dam, Los Angeles County, California

Risk Management Process

A formal Project Risk Management process, as described earlier, was not used for Big Tujunga Dam. However, risks were evaluated during planning for the retrofit design, including evaluation of rehabilitation alternatives and how to properly share, between the owner and the contractor, the risk of flooding during construction. In addition, an informal risk evaluation
process was performed continually during the rehabilitation design. Project components were
designed utilizing conservative assumptions, especially where retrofit of features required using
minimal available as-built information. Risks and costs of project rehabilitation alternatives
were discussed during initial project concept development. Design issues and associated risks
were discussed during project milestones (i.e. 30, 60, and 90 percent design phases). Finally,
formal partnering meetings were used to identify construction risks and develop risk mitigation.

**Risk Management Strategies Used**

The risks encountered for the Big Tujunga Dam rehabilitation were similar to those encountered
in new dam construction, but also included project specific challenges due to the unique nature
of the rehabilitation construction scheme. The risks encountered and results are listed below,
sorted by risk management strategies defined in this paper.

**Avoiding Risks**

- Use conventional mass concrete for dam rehabilitation

During alternatives evaluation and early design phases of the dam rehabilitation, options for the
type of concrete to be used in the dam thickening were investigated. Conventional mass concrete
(CMC) was compared and contrasted against a relatively new technology in dam construction,
roller compacted concrete (RCC). The lower cost for RCC was considered a notable advantage
over the more labor intensive CMC. However, given the tight and difficult spacing in the narrow
canyon, number of penetrations through the new concrete, complex geometry of the variable
radius arch and ogee overtopping spillway, and regulator concerns regarding the strength of the
bond between RCC lifts (which was critical for a highly seismic area); the LACDPW made the
decision to go with the “tried and true” CMC construction method for thickening the dam.

**Mitigating Risks**

- Change from a “stepped” spillway to a traditional ogee with flip bucket

The rehabilitation design required passage of an increased PMF, which required utilization of a
dam overtopping scheme to save costs on expensive abutment modifications for adding spillway
capacity. The overtopping spillway concept selection included evaluation of several spillway
design types: a stepped spillway that spanned the full height of the dam from the crest to the
base, a spillway chute on the downstream face of the dam, and an ogee with flip bucket. The
spillway chute was dismissed during early concept development as too expensive to construct on
the 244-foot (74.4-meters) high dam downstream face. The stepped spillway was considered
during early concept development when the original seismic rehabilitation scheme considered
converting the arch dam into a gravity structure through construction of a significant mass of
concrete behind the dam. Steps were added on the overtopping gravity structure to dissipate the
energy of the PMF overtopping flows; however, it was determined that the magnitude of the
revised PMF flows would overwhelm the stepped structure, skipping over the energy dissipating
steps and adding risk of foundation erosion and undercutting of the dam structure. Later,
structural optimization was performed using finite element analysis, which reduced the dam
thickening cross section, creating a thick-arch dam rehabilitation scheme. The thick arch
concept steepened the downstream face of the dam, which eliminated the possibility of using a stepped spillway concept. Thus, a spillway overtopping concept was developed that utilized an ogee crest with flip bucket to discharge overtopping flows away from the dam, which was compatible with the optimized dam cross section.

- Add a splash pad to avoid erosion at the dam toe

Upon development of an overtopping spillway concept for passage of the increased PMF, concerns were raised regarding the possibility of erosion and undermining of the dam toe from a “back roller” and turbulence caused by the impacting jet of water from the overtopping spillway. Although the jet impact area was targeted well beyond the base of the dam, the risk of extreme erosion and dam failure still existed due to the possibility of rock being trapped in the back roller turbulent flows, resulting in a “washing machine” effect. To reduce the potential risk of dam failure or damage from severe erosion at the toe of the dam and base of the abutments during large flood events, a large concrete splash pad, roughly 30-feet (9.2-meters) high and extending 70-feet (21.3-meters) from the dam toe, was added to fill the base of the canyon immediately downstream of the dam.

**Sharing Risk**

- Define flood risk and potential for spill events during construction

The dam rehabilitation involved thickening the dam with over 70,000 cubic yards (53,434 cubic meters) of concrete. The construction work required dewatering of the plunge pool downstream and diverting releases approximately 1,000-feet (304.9-meters) downstream to keep the foundation excavation and concrete placement area dry during construction. The risk of maintaining a dry construction area utilizing valve bypass and conventional dewatering methods was contractor risk and responsibility; however, given the multi-year construction of the rehabilitation, there was also risk of damage to the dry construction area from discharges over the existing spillway on the right abutment of the dam during a large storm event. This risk was separated into a distinct event that would require emergency demobilization from the plunge pool area, based on a contractor developed demobilization plan. The contractor was provided historical hydrologic and operations information at the dam, to utilize as the basis for bidding a separate “emergency demobilization” bid item to be paid when the contractor was directed to demobilize prior to an emergency spill event. In this way, the contractor did not need to incorporate extra “risk” money into their base bid. Rather, they could be assured that they would be paid to demobilize and re-mobilize if the event occurred, and the owner would not need to pay unnecessarily if the event did not occur. This example illustrates appropriate risk sharing between the owner and contractor because the risk was out of the contractor’s direct control. It was appropriate for the owner to share in this risk and pay only if the event occurred, rather than have a large sum of risk money “buried” in the contractor’s base bid for the work.

**Lessons Learned**

Following the completion of each project, assessing lessons learned is necessary to determine what worked and what could have been done better, smarter, faster, and with less cost. Given the unique challenges of the rehabilitation design and construction of Big Tujunga Dam, there
were lessons to be learned that could be used on future dam rehabilitation projects. The list below captures several of the most notable lessons learned.

- Separate excavation and foundation treatment contract from main construction contract

Before construction of the thickened arch for the seismic rehabilitation of Big Tujunga Dam could take place, excavation and foundation preparation in the area immediately downstream of the dam was required. In addition, the highly fractured left abutment required a number of deep rock anchors and tendons for stabilization of a postulated out of slope planar feature. Although a thorough geotechnical investigation program was implemented to characterize the foundation conditions for the thick-arch design, the investigation could not identify all rock jointing features or depth to competent bedrock at all locations along the foundation contact. Moreover, the rock above the anticipated foundation surface was covered by gunite on the abutments and water in the plunge pool. During excavation operations, several rock joint features were uncovered that required additional and unexpected foundation treatment or over-excavation to reach a competent surface. The exposed foundation also revealed that the postulated out of slope planar feature was not as distinct or pervasive as originally estimated, which meant that the anchoring and tendon scheme could have been reduced. These additional foundation treatments added to the construction schedule, which in turn required faster completion of other construction items to meet the fixed contract completion date. Limited time was available to re-evaluate and optimize the rock anchoring scheme because of the construction schedule pressures. This experience shows that, where foundation excavation, treatment, and stabilization are significant components of a rehabilitation project, awarding a separate excavation contract prior to the main construction contract would allow time for adjustments to the foundation and treatment design, and limit risk of costly project changes.

- Provide allowance for rehabilitation design development

The seismic and flood rehabilitation design of Big Tujunga Dam required project-specific considerations and a tailored design effort to meet the project’s unique needs and tight regulatory standards. Examples include a new overtopping spillway adapted to the existing dam crest geometry, a new fixed radius thick-arch concrete section placed against the existing variable radius arch dam, routing of variable invert elevation penstocks through the new thick-arch concrete section to a common downstream elevation, integration of new controls and instrumentation into the existing dam systems, consolidation grouting design layouts placed onto generalized excavation contours developed using information from 80-year old as-built information, and so on. Integration of new project features required making assumptions based on sparse as-built information that was not always verified or developed further due to budget limitations. The original rehabilitation design effort was restricted to a budget set and benchmarked to an industry standard percentage of estimated construction cost for new projects. As such, the design did not reflect the detail required to fully define the highly complex retrofit project. While the overall project was successfully completed with relatively minor adjustments during construction, the fees for engineering services during construction exceeded those of the original design fees; reflecting the additional detailing effort spent by the engineer during construction. Several change orders during construction resulted from the lack of detail, and could have been avoided with additional investment during the design phase. It is recognized that the typical design-bid-build practice in dam construction usually requires detailing and
clarifying information by the engineer during construction; however, it was apparent that, when
design details are left for clarification during construction, risk is also transferred to the
construction contract, resulting in increased costs. Because dam rehabilitation projects may
contain more unknowns than a new dam project, it is recommended that owners include
contingencies in their budgets for rehabilitation projects and invest in a complete design to save
costly risk transfer to the construction phase.

- Provide adequate definition and refinement to bid items

Rehabilitation projects often require development of design detail with limited as-built
information, which results in estimates of construction quantities and level of effort that may not
fully reflect the actual construction. While the bid items were well defined for the Big Tujunga
Dam rehabilitation, there were instances where bid items and quantities were exceeded by over
25 percent due to unanticipated conditions that required additional work to complete
construction. Examples include grouting for deep rock anchors, which exceeded anticipated
quantities two to threefold; and consolidation grouting, where several holes required excessive
quantities due to intersection with major rock discontinuities not previously identified. For these
items, some level of uncertainty should be expected and it is appropriate to include specific
quantities in the bid documents so the contractor does not take on unnecessary risk that they
cannot control.

However, there were other items that required changes due to unanticipated conditions, such as
the drainage curtain, which encountered a stilling well conduit in the dam that was not clearly
indicated on the as-built drawings. A number of other construction scope clarifications and
change orders occurred during the project that, as a whole, could have been avoided with
thorough verification of as-built information and fewer items attached to specific quantities. In
these cases, using lump sum for some types of construction scope items can be an effective and
appropriate way to transfer a reasonable level of risk to the contractor for certain bid items that
can be reasonably well defined. While lump sum bid items increase a contractor’s risk by
requiring an estimate of the bid item level of effort, the owner and designer must provide
thorough background information and description to be used as the basis for these items, to limit
the transfer of excessive risk and cost.

- Consider wide range of risks from multi-year contracts

Dam rehabilitation projects are often complex due to the need to work within and around an
operating facility, which typically results in long construction periods that span over many
months and years. The Big Tujunga Dam rehabilitation lasted over three and a half years,
experiencing three summer and winter seasons in Southern California. This exposed the project
to increased probability of flooding damage, environmental compliance violations, and fire
damage. As described above, the contract documents considered flooding risk and provided a
risk transfer mechanism. However, the contract documents did not consider risk of fire damage
or delay, which ended up being the only major external risk event experienced at the project
(although likely equal in probability to certain flooding risk). Towards the end of the second
summer of construction, in early August, a large fire event swept through the Angeles National
Forest and much of the San Gabriel Mountain range, including the Big Tujunga Dam site. The
fire damaged construction raw materials stored onsite and some existing structures, but largely
missed a major portion of the equipment and in-progress construction onsite. The larger impact from the fire was a denuded forest that was highly erodible, producing slope failures blocking access to the construction site. The restricted access to the site and general recovery from the fire resulted in a delay of more than one month. This delay required a negotiated change order to the contractor for lost and standby time. The project would have benefitted from a fire demobilization and remobilization plan developed by the contractor and owner with risk shared appropriately. Prior planning and risk identification for the fire would have minimized damage, cost, and lost time. Long-term projects would benefit from an early risk brainstorming session that focuses on and accounts for increased exposure to risk from multi-season construction.

7.2 Olivenhain Dam – San Diego, California

Project Description

The Olivenhain Dam, shown in Figure 2, is located in the northern portion of San Diego County, was constructed in the early 2000’s, cost almost $200 million, and was the first Roller Compacted Concrete (RCC) gravity dam permitted by the state of California. It is 318-feet (97-meters) high with an RCC volume of 1.44 million cubic yards (1.1 million cubic meters). The Olivenhain Dam has the typical geometry for concrete gravity dams with a vertical upstream face and a 0.8 Horizontal to 1 Vertical sloping downstream face. The crest is 20-feet (6.1 meters) wide and approximately 2,570-feet (783.5-meters) long. The dam is at the end of a boxed canyon and impounds over 24,000 acre-feet (29,603,564 cubic meters) of water. The dam is designed and constructed to survive and remain fully operational after a large 7.25 magnitude seismic event.
Risk Management Process

A formal Project Risk Management process, as described earlier, was not used for Olivenhain Dam. However, risk analysis was performed during the planning and environmental process to help select the reservoir and dam site, project delivery method, and other project alternatives. Informal risk management also occurred during design. Design issues were discussed and cost and risks for alternative designs were brainstormed in formal team workshops at each project deliverable milestone (i.e. 30 percent, 50 percent and 100 percent design). Finally, formal partnering was used during construction, and many of the partnering meetings were used to identify construction risks and develop action plans to deal with them.

Risk Management Strategies Used

Olivenhain Dam project risks were unique to dams, as well as to the project itself. Below is a list of those risks and results, sorted by the risk management strategies defined in this paper.

Avoiding Risks

- Separate foundation excavation from dam construction to avoid indirect construction costs due to delays
The Olivenhain Dam was on a tight schedule and budget. During design, the project team assessed the risk of additional cost due to delays caused by differing site conditions in the foundation excavation work. To avoid this risk, the project was built in separate construction contracts. The first contract required the contractor to prepare the foundation by excavating approximately 600,000 cubic yards (458,015 cubic meters) of varying geologic conditions.

A construction contract to build the dam was executed separately, after completion of the foundation work. This approach allowed multiple stakeholders to benefit from reducing the potential risk of delays and additional cost as follows:

- The foundation contractor addressed differing site conditions during foundation excavation without impacting the construction of the dam.
- The regulator was given time to view the completed foundation excavation, and discuss potential design revisions with the designer, prior to awarding the construction contract to build the new dam.
- The designer made adjustments to the foundation surface and dam following completion of the foundation excavation and prior to execution of a construction contract for the main dam.
- The designer was also able to adjust estimated RCC quantities and better define the cost estimate following completion of the foundation excavation and prior to advertising the construction contract for the dam.
- The owner communicated more accurate project costs to its Board of Directors prior to advertising the construction contract for the dam.

This risk management strategy proved to be effective, as there were a number of differing site conditions during the foundation excavation contract that resulted in additional excavation and dental concrete placement that extended the contract. Since the foundation work was completed before awarding a new construction contract for the main dam, costly overhead delays were eliminated for work related to the main dam. Another side benefit of this risk management strategy was the estimated RCC quantity was more accurate because the foundation excavation was complete.

- Use onsite quarry for concrete aggregate to avoid truck traffic through community

RCC requires a significant amount of aggregate. During the planning process for this project, the community raised concerns over the truck traffic this project would cause on local roads. Alternatives were analyzed and discussed, which resulted in including a provision in the construction contract for all aggregate be produced from an onsite quarry. The use of an onsite quarry proved a good risk management strategy for Olivenhain Dam. Because of the rural location of the project, it proved to be less costly than importing aggregate. It also eliminated over 100,000 truck trips through local roads and aided in community support for the project.

**Mitigating Risks**

- Use Roller Compacted Concrete for dam construction
The Olivenhain Dam was built in an active seismic area and was required to remain operational after the maximum probable earthquake for that area (7.25 magnitude). The design team performed a risk analysis on the type of material to be used for the project, which indicated a concrete dam was needed. However, since RCC has similar structural properties as conventional concrete and had a history of being placed in shorter time periods, the team chose RCC to save cost and schedule. This proved to be true, since the RCC portion of the dam was constructed in about half the estimated time it would have taken for conventional concrete.

Sharing Risk

• Use trucks to convey RCC versus conveyors (proposed by the contractor)

The construction contract required that the RCC be placed on the main dam via a conveyor system. Large trucks were not allowed to drive on top of the fresh RCC due to the dry consistency of the mix. The reduction of cement and fly-ash in the contract mix was originally implemented during the design phase as a cost savings measure for the project. However, during partnering meetings, the contractor requested to modify the mix to allow truck travel on the fresh RCC. Although the testing program for the new mix was extensive and time consuming, the contractor was able to work on other aspects of the project during this process, such as quarry development, inlet/outlet tower construction, and offsite mechanical fabrication. Adjusting the mix resulted in allowing the contractor to use trucks to convey RCC on the main dam, which reduced the overall RCC placement schedule to seven months, down from the estimated nine to ten months. This resulted in significant cost savings to the owner for construction management, field inspection, and overhead costs.

• Include milestones on RCC placement

RCC placement is typically a 24 hour 7 day per week operation that requires multiple shifts of the owner’s consultant inspectors and resident engineers to provide quality assurance for the work. The risk of consultant cost overruns due to the RCC placement schedule going longer than expected was a concern to the owner. The owner shared this risk with the contractor by including milestones for starting and completing the RCC placement, and assigning liquidated damages to these milestones. The intent of this strategy was to incentivize the contractor to meet the schedule for RCC placement. This strategy appeared to be effective, as it reduced the number of increases to the professional service contract for construction management, field inspection, and lab inspection overruns. It is unknown, however, if this increased the cost of the construction bid.

Lessons Learned

Following the completion of each project, the Water Authority used the best management practice of assessing the lessons learned to determine what worked and what could have been done better, smarter, faster, and less costly. Since the Olivenhain Dam was the first RCC Dam permitted and built in the state of California, there were a number of lessons learned. A few of the more significant ones are discussed below.

• Reduce risk of delay for Programming Supervisory Control and Data Acquisition system
The delivery method for the Programming Supervisory Control and Data Acquisition (SCADA) system was included, in its entirety, in the construction contract for the main dam. The construction contract required the contractor to procure, install, program, and test the entire SCADA system. This resulted in a second tier subcontractor being the driving force to complete the project. Following award of the construction contract, several changes were made to the equipment, which also required changes to the scope of work for the contractor’s subcontracted programmer. Some of these equipment changes caused issues with the programming and delayed startup and operation of the SCADA system. Based on the cost and delays experienced, a new risk mitigation strategy was put in place for future Water Authority projects. The new strategy shares the risk by requiring the contractor to provide and install the necessary equipment as specified by the designer. However, instead of requiring the contractor to program the system, the Water Authority will procure a separate professional services contract for programming. The contractor is required to coordinate with the programmer throughout procurement and testing of the system.

- Reduce risk of higher than expected bid cost

During the design phase of the project, many changes occurred that affected the construction cost estimate. These included: changes to scope or work that affected constructability, economic changes to bidding climate, electricity availability to site, and escalation of costs for materials. Due to schedule constraints, these changes were completed without a full risk analysis of the cost impacts. Since these changes were not fully accounted for in the construction cost estimates prepared prior to advertising the project for bid, higher than anticipated bid prices occurred. This resulted in a delay to awarding the project. To help mitigate this risk in the future, the Water Authority adopted a new approach to cost estimating including:

- Requiring consultants to prepare cost estimates using a bottom up approach (i.e. estimate it like a contractor)
- Using economic indicators related to the basket of goods being built, (i.e. for dams, factor in potential escalation of cement, fuel, and other dam related costs)
- Factoring the current projected bidding climate into the 100 percent construction cost estimate, (i.e. how many bids expected will affect how competitive costs will be)
- Preparing three construction estimates for larger complex dam projects; one from the designer, one from the construction management consultant, and one independent construction estimate
- Requiring each entity to submit the 100 percent construction cost estimate as a range in probable costs rather than a singular value, based on variables such as cost escalation and competitive bidding environment

- Include factory inspection as a cost to be reimbursed by the contractor to the owner

Construction of the Olivenhain Dam required many large valves and hydraulic structures to be fabricated offsite. As per industry standard, the owner hired professional service consultants to provide offsite inspection of this equipment to reduce the risk of it not working as intended once it reached the site. One of the lessons learned on this project was that large equipment such as butterfly valves can be manufactured in multiple locations around the world and manufacturing
schedules vary. This resulted in significant increases to the owner’s inspection costs. To better estimate and manage these costs for larger complex projects, the Water Authority has implemented a process requiring the contractor to include all factory inspection costs the owner will incur in the construction bid. This has resulted in better scheduling and monitoring of equipment procurement by the prime contractor, resulting in tighter management of factory inspection costs.

- Analyze the effect of material and equipment delivery restrictions on project costs and schedule

Due to community concerns, the owner was requested to limit delivery hours to between 7 a.m. and 4 p.m. Monday thru Friday only. Since RCC dams are typically a 24 hour/7 day per week operation, this limited the contractor’s window to deliver materials, which added costs for storing materials onsite for longer periods. A risk analysis could have helped factor the increased project cost and time, versus the community impacts or benefits for limited deliveries. This analysis could have been used to help policy makers with decisions regarding limitation of delivery hours.

- Analyze the availability of dependable electric power

During the late 1990’s and early 2000’s there was a perceived risk of temporary electrical power outages within the San Diego region. The San Diego County Water Authority worked with the local power company to build a new 69 KV power line and electric transmission station at the project site. However, due to the perception of unreliability and cost of electric power from the local utility, the contractor chose to power his equipment with onsite generators. It is unknown how much this added to the bid price. Therefore, as part of the risk management strategy, an electric power study should be completed during design. This will determine if local utilities are able to provide dependable power during construction, or if onsite or standby generators will be required to ensure construction can be completed in a continuous manner. This will help the owner determine how best to include sharing the risk of electrical power outages with the contractor.

7.3 Cleveland Dam – North Vancouver, Canada

Project Description

The Cleveland Dam, shown in Figure 3, is one of two reservoirs that provide most of the water for Metro Vancouver (MV), the water utility for Greater Vancouver, British Columbia. The dam and reservoir, constructed in the early 1950’s, are located on the Capilano River, north of North Vancouver. The reservoir is formed by Cleveland Dam, a 300 foot (91 meter) high concrete gravity dam founded on bedrock in a steep sided canyon. Adjacent to the bedrock canyon, the geology has been highly glacially modified, creating an abutment (left abutment) with historically high seepage. The reservoir is a vital supply for the utility and must be operational at all times.

The project described in this case study is the construction of a left abutment seepage reduction blanket that was completed in 2002. The design consisted of three components:
• A soil-cement slurry wall (lower component)
• An RCC blanket (middle component)
• A geosynthetic clay liner (GCL) (upper component)

Figure 3. Cleveland Dam, North Vancouver, Canada

The three-component design was based on the ability to lower the reservoir during the construction period to permit access for construction. The reservoir can only be lowered 60 feet (18.3 meters) during the winter months, when water usage is low and spring flows can refill the reservoir for summer and fall supply. Lowering the reservoir to the maximum depth of 60 feet (18.3 meters) left the lower portion of seepage zone underwater; therefore, the slurry wall design was selected as the barrier needed to meet seepage criterion for the lower component of the wall.

The construction plan involved lowering the reservoir a nominal distance below the slurry wall construction bench. This water level was selected to ensure adequate water supply through the planned winter construction. Complicating construction was the very wet winter weather in northern Vancouver and the limited outlet works capacity at the lowered reservoir level. In addition, common multi-day winter storms coming off the Pacific, gave little warning and fell mostly as rain at the reservoir elevation (480 feet or 146.3 meters).

The risk of the reservoir rising uncontrollably during slurry wall construction and inundating the construction bench and installation equipment, as shown in Figure 4, was understood during design and as the project specifications were prepared. It was also understood that the water supply is made potable with minimal treatment and that contamination by slurry spills was not acceptable. A risk assessment was performed to reduce the potential for inundating the contractor’s equipment creating construction claims, and for contamination of the reservoir. This
resulted in a risk sharing approach for the owner and contractor that worked well during construction.

**Risk Management Process**

MV and the design engineer performed a relatively informal risk assessment. It was based on the development of failure modes (what would happen in the reservoir inundated the construction bench) and options to reduce the risk, as well as roadblocks that would prevent implementation of risk mitigating actions. The major components of the plan were risk sharing and enhanced weather forecasting.

**Risk Management Strategies Used**

MV enlisted Environment Canada (the weather forecasting agency in BC) to provide the enhanced forecasting. Weather updates were obtained hourly, focusing on the direction of typical incoming storms. These forecasts were modeled to evaluate the rates of rainfall (in the watershed and at the reservoir) and their relation to reservoir rise with the outlet operating at maximum capacity. A model was developed to provide an early warning (up to one day) of a reservoir rise above the construction bench.
To minimize impacts from construction bench inundation, an assessment was performed on activities required to prevent damage to construction equipment and works, and reservoir contamination. The assessment indicated the contractor would need to move the equipment and slurry containment structures and cap the exposed slurry wall. To ensure that the contractor would take the warnings of construction bench inundation seriously, it was described in the construction documents and a line item was added to the bid schedule for contractor pricing. This permitted MV to require the contractor to take this action and allowed the contractor to get paid for mitigation work and loss in project schedule. The process permitted cost and risk understanding, resulting in a fair sharing for MV’s protection and the contractor’s potential equipment loss.

**Lessons Learned**

Since the construction bids were price competitive, contractors needed to consider the opportunity for the interruption, the cost of such required activities, and the approach of competitors. Review of the bids indicated that each bidder approached this item in a relatively similar manner, permitting the bid analysts to accept the pricing of this item.

The in-reservoir construction was performed over 16 months, starting in the winter of 2001, when weather was slightly wetter than normal. Several storms occurred during the scheduled construction, most of which were not sufficient to initiate this risk reduction measure. However, there were two times when the weather and reservoir rise did require activation of the measure. In one case, the construction bench was inundated; and in the other, the reservoir rose to within a couple feet of the bench. In both cases, MV was satisfied that appropriate measures were implemented to meet its needs, and that the contractor took timely action.

The cost of each mitigation was relatively high, but the opportunity for an unexpected inundation of the construction bench, equipment, and slurry was considered significantly higher.

**7.4 Calaveras Dam – Alameda County, California**

**Project Description**

San Francisco Public Utilities Commission (SFPUC), serving 2.6 million customers in the San Francisco Bay Area, owns and operates 10 dams and 3 hydropower plants within the Hetch Hetchy Regional Water system. Calaveras Dam, shown in Figure 5, is an existing 90-year old 220-foot (67 meter) tall hydraulic fill dam, and one of the most important facilities within the system as it impounds water to form the largest local Bay Area reservoir.

In 2001, the SFPUC, in cooperation with the California Department of Water Resources Division of Safety of Dams (DSOD), lowered the reservoir to about 40 percent capacity due to seismic safety concerns with the existing dam. The Calaveras Fault, located 1,500 feet (457.3 meters) from the dam site, is considered to be capable of a magnitude 7.25 maximum credible earthquake (MCE), resulting in peak ground accelerations of about 1.1g at the dam site.

In 2002, planning began for a project to replace the existing dam with a new zoned earth and rockfill dam immediately downstream of the existing structure. Construction began for the
Calaveras Dam Replacement Project (CDRP) in 2011 and the project is expected to be complete in 2019. The CDRP includes the following major elements:

- A new 220-foot (67 meter) tall earth and rockfill dam to replace the existing dam
- A new spillway and stilling basin
- A new intake tower and shaft, where the drain line and three adits from the existing facility will be connected to the new shaft and fitted with new valves and SCADA controls
- A new 78-inch (198 centimeter) outlet conduit to connect to the existing downstream portal of the 72-inch (183 centimeter) outlet tunnel, and extend the outlet works downstream beneath the new dam
- New fish screens added to the existing adits of the intake tower
- New access roads, electrical buildings, and other appurtenant facilities
Risk Management Process

The SFPUC implemented a comprehensive risk management program and formal partnering for the CDRP, which are essential and invaluable components to the anticipated successful completion of a very challenging project.

A formal risk register was developed and used during the planning, design, and environmental review stages of the project and was very effective at identification and mitigation of major risks. Many of the identified risks were associated with the seismically active and complex geologic setting, the highly sensitive environmental setting with numerous threatened and endangered species, and hydrologic risks typically associated with dam projects. An additional unusual challenge for the CDRP is that the Franciscan Mélange Complex geologic unit at the site contains Naturally Occurring Asbestos (NOA), which affects many aspects of the planning, design, and construction of the project.

A more comprehensive risk management program was implemented during the construction phase. A number of risks that were recognized during the pre-construction phases of the project were not fully characterized and quantified until the construction phase. New risks were introduced and risks that were thought to be relatively minor during the pre-construction phases ended up being larger than anticipated.

A Risk Management Team was formed at the beginning of construction, including representatives from each of the major functions, consisting of the Project Manager, Construction Manager, Designer, Scheduler, Cost Estimator, Quality Assurance Inspector, Environmental Compliance Manager, Safety Personnel and the Construction Contractor. The
first task for this team of experts was to identify project risks within the different risk categories and include them in the risk register. Risk categories typically include a broad spectrum of risks, including contractual compliance issues such as timely and accurate documentation of field changes, technical challenges such as differing site conditions, environmental compliance challenges such as nesting birds, quality issues such as concrete curing temperature control, schedule challenges such as weather delays, and safety challenges such as inspector vehicles mixed with construction vehicles on haul roads.

To understand the total project’s risk exposure, a Monte Carlo simulation was performed. The results provided total project risk exposure at different confidence levels, which allowed the organization to allocate appropriate contingency for the project given an acceptable confidence level established for the program. The SFPUC’s goal was to assign enough contingency to cover risk exposure at the 80 percent confidence level. However, the risk register is a living document, and the CDRP Project team has been continuously managing the project by reviewing, reassessing, and updating the risk register monthly. When risks are added or probabilities of occurrence are adjusted, the level of contingency needs to be re-assessed. This has proven to be a powerful communication tool to help the project secure additional contingency funding, as several large risks have been realized over the course of the project.

Risk Management Strategies Used

The CDRP Project team has found that the risk register is a powerful tool for managing the project’s budget and schedule. However, even with a formal and fully developed risk management process, some of the project risks could not be fully avoided or mitigated.

For those risks that were fully characterized, mitigation measures were implemented by including design elements to address them. Although a considerable amount of money was spent for the changes in design elements, the benefits to avoid and mitigate the risks far outweighed the cost of dealing with the consequences of the impacts if they were not mitigated. Other risks identified and thought to be relatively minor during the design phase, but not fully characterized, were often found to be much more substantial when the risk was realized during the construction phase.

Avoiding Risks

One area of concern early in planning and design of the project was related to pairs of nesting bald eagles observed at Calaveras Reservoir over the past 10 to 12 years. One historic nest was located approximately 30-feet (9.1-meter) from the projected location of a major haul road that would be used to transport clay from the borrow pit at the southern end of the reservoir to the dam site at the north end of the reservoir. With a requirement to provide a 660-foot (201.2-meter) diameter construction buffer around the nest once an eagle pair is observed displaying reproductive behavior, this haul route could be rendered unusable between January 1 and August 31 of each construction season. The impact could either force the project to use the more costly barge option or as a worst case, cause a delay to the project schedule of approximately one year. To avoid this risk, several actions were taken:
• Provide an alternate haul route (barge route across the reservoir) in the environmental impact report (EIR) that would avoid the bald eagles if they were to nest near the preferred route during construction.

• Obtain an eagle nest “take” permit from the US Fish and Wildlife Service (USFWS). This permit allowed for the placement of cones to exclude habitation on two eagle nests previously occupied.

• Actively monitor the nesting eagles in the vicinity to determine if there are potential behaviors that would impact the project. Evaluation of this risk continues during the construction phase.

During construction, the eagle pair has been returning to a nest located more than 660-feet (201.2- meters) from the preferred haul route. Monitoring continues during the nesting season as required by the USFWS permit.

This is an example of the importance of an early and proactive approach to risk avoidance during not only planning and design, but also during construction. Careful planning in the pre-construction phases of the project allowed for plans and options to be provided in the design. However, during construction, risks are not static and it is essential that risks and their associated avoidance and/or mitigation measures are continually assessed and modified as needed.

**Mitigation Risks**

The planned shutdown window for the outlet works was known to be very tight. Activities include installation of several sections of 78-inch (198-centimeter) diameter pipeline, installation of temporary 48-inch (122-centimeter) diameter pipeline, dam foundation treatment, installation of a grout curtain, grouting below the existing outlet works, test fills for dam embankment, installation of filter blanket and toe drain system, downstream filters, upstream rock shell, core filter, refurbishment and re-installation of a 72-inch (183- centimeter) fixed cone valve at the new stilling basin location, and electrical work at various buildings and vaults. All work must be complete on time so the outlet works can go back into service prior to the 2016-17 winter season.

Of these activities, the project team identified the connection of the new 78-inch (198-centimeter) outlet to the existing pipeline, and refurbishment of the fixed cone valve as having the most uncertainty and risk. Should there be problems with either activity; the resulting delay may push past the end date of the shutdown.

To mitigate risk, the SFPUC secured an additional short shutdown window in advance of the planned shutdown to perform investigative work related to these two activities. Issues discovered, if any, could be acted upon prior to the start of the 2016 shutdown.

For the outlet works tie-in connection of the new outlet pipe to the existing pipe, the tie-in point was excavated and surveyed to verify the tie-in point coordinates. The survey showed that there was a one-foot (30-centimeter) horizontal offset between the tie-in point shown on the contract drawings and the existing pipe in the field. To accommodate this unforeseen offset, the project team directed the contractor/pipe manufacturer to lengthen a short cut-to-fit section of 78-inch (198-centimeter) diameter steel pipe.
The fixed cone valve (FCV) refurbishing subcontractor was invited to inspect the existing FCV prior to taking possession of it during the planned shutdown. The FCV was operated in the dry and the subcontractor was able to take various measurements of the valve seat from inside the FCV. The inspection also revealed a pair of bent screw jacks. The subcontractor felt confident that the screw jacks could be repaired, but as a backup plan, they intend to purchase a new pair.

This proactive approach was not expensive, and it helped to avoid risks that could have had a huge impact and delay to the project if not discovered until the contractor was in the middle of the critical 2016 shutdown.

**Sharing Risks**

In addition to the environmental challenges caused by the special status species present on the project site, the presence of natural occurring asbestos (NOA) in the Franciscan Mélange Complex geologic formation within portions of the site creates another major challenge with respect to health and safety risk.

The CDRP site contains two primary geologic formations, namely highly fractured sandstones (Temblor Sandstone) and hard intact blue schists, graywackes, and greenstones embedded within a matrix of siltstone, shale, and serpentinite (Franciscan Mélange Complex). To build the new dam, the Franciscan Mélange Complex must be excavated and removed in preparation for the dam and spillway foundation, and the excavated material, such as blue schist and greenstones, will be processed for building the upstream shell of the dam embankment.

NOA, specifically chrysotile and amphiboles, has been documented in serpentinite, blue schists, and greenstone within the Franciscan Mélange Complex rocks. When disturbed, these NOA-containing materials may become airborne with dust generated during construction operations. In general, NOA is a long thin fiber that, when inhaled for a prolonged duration, can lead to a range of adverse health-effects including asbestosis, which is a chronic, degenerative lung disease; lung cancer; and mesothelioma, which is a rare form of cancer that develops in the lining of the lung. Since asbestosis does not typically result from environmental asbestos exposure (e.g., Nicholson 1986, HEI-AR 1991), the potential for asbestos-related cancer is the primary concern for protection of workers and the public at the CDRP.

Protecting public health is SFPUC’s top priority, including workers at the project site, residents in the general vicinity, and visitors and park workers in the regional park near the site. During the design phase, considerable investigative work was performed to delineate the presence of NOA on the project site and ensure a good understanding was acquired prior to construction. Top industry experts were hired to guide the development of strategies for both the environmental review process and incorporation of NOA-related requirements into the plans and specifications for construction.

In addition, a comprehensive baseline air quality monitoring program was implemented to document the existing concentrations, types, sizes, and dimensions of the asbestos fibers in the atmosphere in the vicinity of the site before construction started. Together with the geologic unit information and anticipated construction activities, an extensive dust monitoring program called a Comprehensive Air Monitoring Program (CAMP) and dust control requirements were
developed during the design phase. The CAMP was developed based on regulations and procedures established for assessing risk from exposure to toxic substances by the federal, state, and regional governmental entities, including United States Environmental Protection Agency (USEPA), California Air Resources Board (CARB), and Bay Area Air Quality Management District (BAAQMD). The CAMP was designed to assure that no airborne asbestos would leave the site at concentrations sufficient to cause unacceptable exposure for people who may visit, recreate, work, or live in the areas surrounding the CDRP site. As a commitment to the public, CDRP has defined an acceptable level of risk above and beyond the guidelines provided by the regulatory agencies. Protocol requires that if airborne NOA is detected at a level above the acceptable level of risk, immediate corrective actions must take place to bring the levels within the acceptable level of risk.

The project team and contractor have been following the CAMP and dust control plan to closely monitor and manage the levels of asbestos generated from the site. Given the level of uncertainty and anticipated level of effort required to avoid the risk of exceeding the established threshold, a substantial amount of budget was set aside in the bid documents to provide resources for out-of-scope mitigation measures that may be necessary to address the risk.

While the project team has been able to control the NOA emissions on the site to date, the experience gained from the project over the past four years has prompted the team to continuously evaluate and test new mitigation measures in anticipation of the upcoming activities of mining hard rock from the Franciscan Complex in Borrow Area B for the upstream shell of the dam. This example highlights that risk mitigation plans are living documents that need to be continuously evaluated, monitored, and improved over the life of the project.

**Unavoidable Risks**

During the design phase of the CDRP, difficult and complex site geology was identified as a risk to the project. The design team implemented more than 11,000-linear feet (3,353-meters) of geotechnical soil and rock borings, 80 test pits, bucket auger borings, fault trenches, downhole televiwer and seismic logging, piezometer installation, borehole pressure meter and dilatometer testing, seismic refraction surveys, and a comprehensive laboratory testing program. Preliminary evaluations of the left abutment revealed existing, undisturbed slopes that were steeper than 1 horizontal to 1 vertical (1H:1V), including near vertical cliffs approaching 20 feet (6.1 meters). These evaluations provided confidence that the design slope (1.3H:1V) would be stable and supported the detailed stability assessment completed by the design team.

During construction, the excavation of the left abutment slope above the future spillway revealed geologic features that brought excavation slope stability into question. Supplemental geotechnical investigations in previously inaccessible areas of the left abutment identified large ancient landslide complexes (Slides A and B) that could affect the stability of the left abutment. Ultimately, the final slope needed to be redesigned and flattened to approximately 2H:1V to ensure long-term stability of this slope above the future dam and spillway.

This final slope change triggered other changes – specifically, additional excavation volume, double handling of material because of constrained site conditions, re-sequencing of construction
activities, and construction of a strand tieback reinforced wall to provide the contractor a staging area for the construction of the upper spillway structure.

The 2H:1V revised final slope resulted in 1.6 million cubic yard (cy) (1.2 million cubic meters) of additional excavation that needed to be hauled and permanently disposed. In addition, approximately 1.4 million cy (1.1 million cubic meters) of left abutment material that was intended to be placed directly into the downstream shell of the new dam now had to be hauled to a temporary storage site, then double-handled for later placement into the new dam. The time needed for additional excavation, hauling, and double-handling of material required the project team to re-sequence construction activities to not impact planned shutdown windows.

Construction of a “strand tieback reinforced wall” in the upstream shell was required to provide the contractor a staging area for the construction of the upper spillway structure and foundation grouting activities on the left abutment upon removal of Slide B in the upstream shell. During construction of the strand tieback reinforced wall, it was subsequently discovered that (a) the existing rock mass in the southern end of the strand tieback reinforced wall was more fractured than anticipated and (b) the contact of Slide B was deeper than originally shown and anticipated. These conditions resulted in additional work not included in the original change order.

Even though the risk of slope instability due to differing site conditions in the left abutment was identified in a general sense during the design phase of the project, the ancient landslides discovered during construction were not anticipated, and had considerably more extreme consequences than any differing site condition mitigation scenario previously considered. This example demonstrates that even well intended risk mitigation planning is not always a “silver bullet” and some risks that are unknown or not well understood prior to construction do sometimes occur. In this case, although the project team demonstrated tremendous teamwork to develop a solution within a short timeframe during construction, this issue nevertheless resulted in significant delay and added cost to the project.

**Lessons Learned**

Dam construction projects are complex and don’t always move forward as originally anticipated. In the case of the CDRP, the complex geology created differing site conditions including several bedrock faults and an ancient landslide complex discovered during construction. These unexpected and significant challenges caused the project construction schedule to be extended from four to eight years, with a commensurate construction cost increase from the original bid of $260 million to approximately $550 million. Nevertheless, under extremely challenging conditions, a proactive risk management program coupled with outstanding teamwork through formal partnering has allowed the project to move forward and is on track for successful completion in 2019.

During the design phase, a number of risks were identified, however not all were fully characterized, due in large part to the construction manager and contractor not being available to participate in the risk assessment process. New risks were introduced, and risks originally thought to be relatively minor during the pre-construction phases ended up being larger than anticipated. Although independent constructability reviews were performed, one of the “lessons learned” was that there is no substitute for early construction manager and contractor
involvement in the risk assessment process. Although this can prove to be challenging for public contracting, where traditional design-bid-build methodology is often employed, the SFPUC has embraced alternate delivery methods on many recent projects to better utilize the contracting community in the early project development to gain their input on mitigating risks.

The implementation of formal partnering on the project meant that, at an early stage, the owner, designer, and contractor learned to communicate at all levels. This type of cross-communication helped everyone involved know where to turn for answers, and provided a firm understanding of what each partner could be trusted to deliver.

The pre-qualification process and attention to potential staff candidates ensured that the contractor’s team was capable of quickly supplying efficient solutions to the re-sequencing problems. Thus, when construction challenges surfaced necessitating partial re-design, the re-design and construction re-sequencing plan was developed and implemented relatively quickly. The cost and schedule impacts to the project were large, but were undoubtedly mitigated to a great degree through outstanding teamwork.

As the CDRP progressed, the project team continued to implement the key elements of the risk management strategy. Many risks were avoided, while those that could not were handled with progressively greater efficiency. Ultimately, this proactive and collaborative approach to risk management has been seen to foster a truly valuable mindset amongst the entire project team. When risks are realized, the typical conversation has been effectively changed from “whose fault is this?” to “how can we solve this?”

8.0 Risk Management for Dams — Summary and Conclusions

Formal Risk Management is a benefit to complex dam projects because it helps identify more accurate project schedules and costs for all stakeholders. This is not only good policy for successful budget and schedule controls, but also a tremendous communication tool to help stakeholders better understand the project and related risks, and obtain early buy-in and ownership of those risks. Whether a risk is identified during an early phase of the project or in construction, it is very important to provide transparency to all stakeholders so realistic expectations can be established. Use of formal Risk Management also helps ensure that project owners have fully funded the project through construction completion. The more proactive designers, construction managers, and contractors can be in identifying and managing risks, the better and more successful a project will be for all stakeholders.

The project team can have a huge influence on the success of a project by using this formal risk management process throughout the life of a project (from planning through post-construction). This includes bringing the entire team of experts together during the early planning and design phases to proactively identify risks. Once the project risks are identified during the early stages of planning, the team can analyze the risks through a qualitative or quantitative analysis. The team can then decide which risks require owners and/or champions to be assigned during the design phase to manage that risk. Strategies to manage risk include avoiding, mitigating, transferring/sharing, or accepting a risk.
Formal Risk Management should continue during the construction phase. The project team should share their risk register with the contractor and engage him in the management of project risks that are under his control. The contractor may also identify new risks that need to be managed. This process can be done thru a formal partnering process or as part of regular construction progress meetings. This will ensure that all parties are working in a pro-active manner to identify and manage risks.

Based on the case studies presented in this paper, it is evident that there are many risks that will occur during execution of dam construction projects. The case studies presented demonstrate that a proactive project team can effectively manage risks. As shown, proactive management of risks helped: reduce some risks from occurring and significantly reduced the impact of other risks that occurred. The case studies also showed that due to formal risk management, owners were able to include additional budget or contingencies for risks that cannot be controlled because they are outside the influence of project stakeholders. These case studies also highlight the importance of continuously and rigorously managing the risks throughout the course of the project, so they can be mitigated to the extent possible, or until they expire and are no longer threats to the project.