PROGRAMMATIC RISK MANAGEMENT PLAN

Plains CO_2 Reduction (PCOR) Partnership Phase III
Task 13 – Value-Added Report, Update 1

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PROGRAMMATIC RISK MANAGEMENT PLAN

OVERVIEW

This document updates the previous (April 2011) Programmatic Risk Management Plan (RMP) and describes the structure and implementation of the risk management process for the Phase III activities of the Plains CO_2 Reduction (PCOR) Partnership Program. The Phase III activities of the PCOR Partnership include sixteen ongoing technical support tasks as well as two field-scale demonstration projects: 1) Fort Nelson Feasibility Project (Fort Nelson Project) and 2) Bell Creek CO_2 Sequestration and Enhanced Oil Recovery (EOR) Demonstration (Bell Creek Project). The risks associated with the PCOR Partnership, as a whole, and the individual field-scale demonstration projects are being assessed and managed separately; however, all risk assessments are being conducted using the same overall risk management framework. This RMP update reflects the fact that the risk assessment process is an iterative process, where updates are periodically conducted as new program/project information becomes available.

RISK MANAGEMENT FRAMEWORK

The risk management framework of the PCOR Partnership consists of several steps, which were largely derived from the *Project Management Body of Knowledge* (Project Management Institute, 2008, *A Guide to the Project Management Body of Knowledge* [PMBOK Guide], 4th ed.: ANSI/PMI 99-001-2008, Newtown Square, Pennsylvania). The process starts with the development of an RMP (this document) and is followed by risk identification, qualitative and quantitative analysis of the risks, and risk evaluation. Risk identification is guided by a program- or site-specific risk breakdown structure and yields a risk register that contains all of the potential risks associated with the program and/or demonstration site. Qualitative and quantitative assessments of each risk in the risk register are made by assessing the probability that a risk event will occur and the severity of the impacts that will result if it does occur. This information is then combined and depicted using risk maps to evaluate and prioritize the various risks that have been identified.[1] If warranted, the high-priority risks are further analyzed using techniques such as sensitivity analyses, modeling, and simulations. This sequence of steps collectively makes up the risk assessment.

[1] The assignment of these relative risk scores is solely for purposes of internally comparing and contrasting the different risks of the partnership and/or a specific demonstration test site. The assignment of individual relative risk scores means that a particular risk can be compared to other risks and assigned a priority for further investigation, analysis, and monitoring. As such, it is an internal, comparative assessment of the risk and does not represent an absolute assessment of its risk or impact.

Once the risks have been assessed, a response strategy is formulated and executed. Risk responses include several different strategies for negative risks, including avoidance, transfer, mitigation, and acceptance, and for positive risks, including exploitation, sharing, enhancing, and acceptance. Monitoring of the system is then conducted to ensure that the risks are successfully controlled. Communication is necessary during every step of the process to assure stakeholders that the risks are being effectively managed at all stages of the risk management process.

STATUS OF RISK MANAGEMENT ACTIVITIES

The PCOR Partnership is implementing the RMP for the program, as a whole, as well as for both the Phase III Fort Nelson and Bell Creek Projects. Specifically, to date, the risk assessment activities that have been completed are listed below and summarized in Table 1:

- PCOR Partnership Programmatic Risk Assessment

1. April 2011 – Round 1 risk assessment (Programmatic Risk Management Plan, Plains CO_2 Reduction Partnership Phase III, Task 13 – Deliverable D88, April 2011)

2. September 2013 – Interim Update of the Round 1 risk assessment for the FY2014 IEA Greenhouse Gas R&D Programme Expert Review, which was conducted as part of the U.S. Department of Energy (DOE) Regional Carbon Sequestration Partnerships Initiative on November 11–15, 2013, in Washington, D.C.

3. August 2014 – Round 2 risk assessment (this document)

- Phase III Fort Nelson Project

4. January 2010 – Round 1 risk assessment ("Fort Nelson Carbon Capture and Storage Project: Risk Management and First Round Risk Assessment Results," January 2010)

5. October 2011 – Round 2 risk assessment ("Fort Nelson Carbon Capture and Storage Project: 2010 Technical Subsurface Risk Assessment," October 2011)

Table 1. Tabular Summary of PCOR Partnership and Phase III Project Risk Assessment Activities Completed to Date

PCOR Partnership Program	Fort Nelson Project	Bell Creek Project
April 2011 – Round 1	January 2010 – Round 1	June 2012 – Rounds 1 and 2
September 2013 – Interim Update	October 2011 – Round 2	August 2014 – Round 3
August 2014 – Round 2		

- Phase III Bell Creek Project

6. June 2012 – Round 1 and Round 2 risk assessments (technical memorandum, "Updated Summary of Bell Creek Risk Assessment – Round 2 Results," dated June 18, 2012)

7. August 2014 – Round 3 risk assessment (technical memorandum, "Summary of the Bell Creek Project 2014 Risk Assessment Update," dated April 14, 2014)

This RMP update provides a summary of the results of the latest of these risk management efforts, focusing on the Round 2 risk assessment for the PCOR Partnership (August 2014) and the Fort Nelson Project (October 2011) and the Round 2 (June 2012) and Round 3 (August 2014) risk assessments for the Bell Creek Project.

SUMMARY OF PROGRAMMATIC RISK ASSESSMENT RESULTS

PCOR Partnership Round 2 Risk Results (May 2014)

This RMP update presents the latest formal update of the PCOR Partnership Program risk assessment (i.e., PCOR Partnership Round 2 risk assessment). Specifically, it presents an updated PCOR Partnership risk register, a subsequent reassessment of the probability and impact scores of the individual risks on four impact categories (i.e., cost, scope, time/schedule, and quality), and the preparation of revised risk maps.

Round 2 Risk Register

The risk register of the Interim Update risk assessment, which had been created in September 2013, was updated during the conduct of the Round 2 risk assessment. The results of this effort yielded a net increase of the risk register from 42 to 45 individual risks when two external risks were combined into a single risk and four new risks were identified (three external risks and one project management risk). With these changes, the Round 2 risk register of the PCOR Partnership consists of 45 individual risks that are distributed across the four risk categories as follows:

- External – 21 individual risks
- Technical – ten individual risks
- Organizational – ten individual risks
- Project management – four individual risks

This updated risk register provided the basis for generating the updated PCOR Partnership Round 2 risk assessment.

Round 2 Risk Maps

The individual risks of the Round 2 risk register were assigned probability and impact scores using the same rubric that was used during the Round 1 and Interim Update risk assessments (probability and impact scores were assigned to each risk by PCOR Partnership task leaders; these inputs were evaluated using Monte Carlo simulations to generate risk maps presenting the most probable [average] and the 90th percentile probability and severity scores). The risk maps were subdivided into low (green), transition (yellow), moderate (orange), and high (red) risks (Figure 1). Once again, the arbitrary threshold of 0.2 (i.e., probability × impact score = 0.2) was used to delineate the high risks. The risk maps were created for each of the four areas of potential impact: cost, time/schedule, scope, and quality using the mode and the 90th percentile scores.

Round 2 Risk Assessment Results

The results of the PCOR Partnership Round 2 risk assessment indicate that there are no risks that are persistently ranked high and, therefore, warrant the immediate attention of the PCOR Partnership. This result applies to both the mode (the most likely scenario) and the 90th percentile (which represents a conservative risk estimate by the program task leaders). Under the most likely scenario, only four external project risks were ranked as moderate, and all of the other 38 risks were ranked as low risks. Among the four moderate risks, only one individual risk, an external risk associated with the shifting of the government policy away from carbon capture, utilization, and storage (CCUS), would become a high risk with an increase in either the probability or impact score to the next highest category. All other individual risks would require increases in both the probability and impact scores to become a high-ranking risk.

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Probability Score						
Range	Midpoint					
0.75–0.99	0.87	0.044	0.087	0.20	0.30	0.70
0.50–0.74	0.62	0.031	0.062	0.124	0.20	0.50
0.25–0.49	0.37	0.019	0.037	0.074	0.148	0.30
0.16–0.24	0.20	0.010	0.020	0.040	0.080	0.20
0.11–0.15	0.13	0.007	0.013	0.026	0.052	0.104
0.06–0.10	0.08	0.004	0.008	0.016	0.032	0.064
0.01–0.05	0.03	0.002	0.003	0.006	0.012	0.024
<0.01	0.01	0.001	0.001	0.002	0.004	0.008
Impact Score		0.05	0.10	0.20	0.40	0.80

Figure 1. Risk map showing low (green)-, transition (yellow)-, moderate (orange)-, and high (red)-risk categories based on the product of assigned probability and impact score.

Phase III Project-Specific Risk Assessments

The PCOR Partnership has developed an integrated approach for implementing large-scale commercial CCUS projects. This integrated strategy involves feedback loops among the program elements of site characterization; modeling and simulation; risk assessment; and monitoring, verification, and accounting (MVA) (Figure 2). Knowledge gained in each program element is shared across the other program elements. For example, as new knowledge is gained during site characterization, it can reduce the degree of uncertainty in the geologic assumptions. This reduced uncertainty will then propagate through modeling and simulation, risk assessment, and MVA efforts. The results of the Fort Nelson Project and Bell Creek Project risk assessments, which are part of the site-specific integrated strategy being conducted at each site, are provided in the remainder of this section.

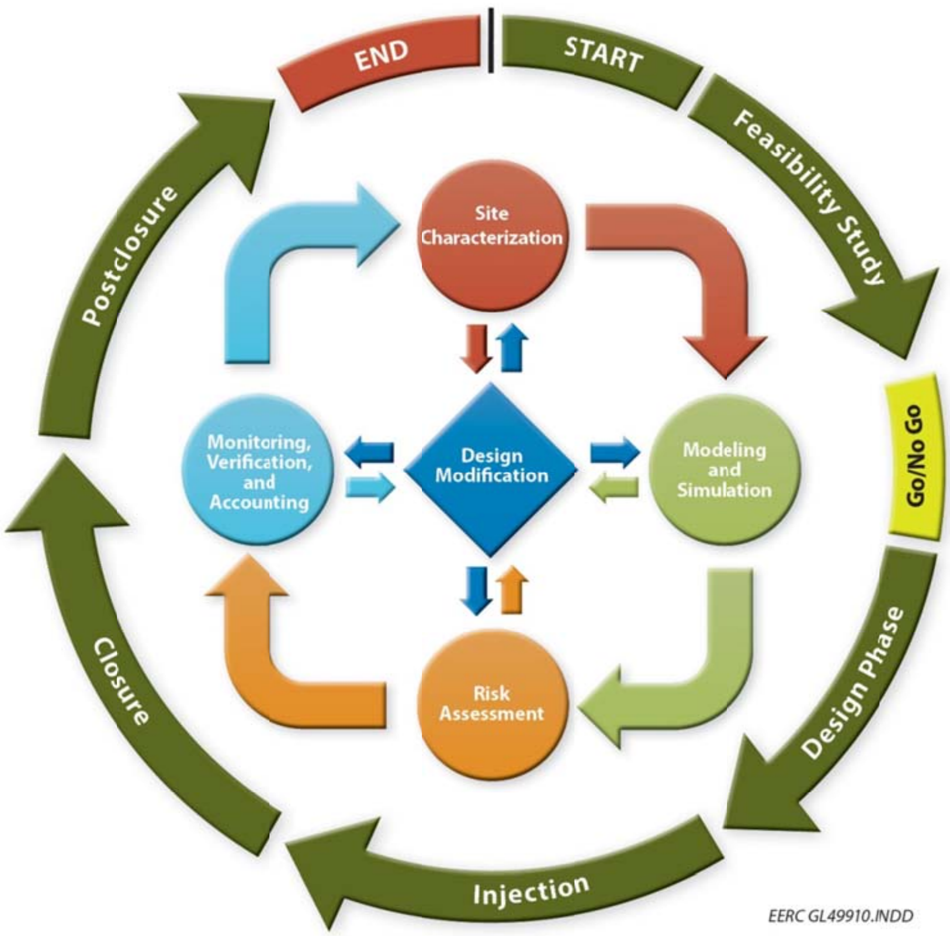

Figure 2. PCOR Partnership integrated strategy for CCUS project implementation: site characterization, modeling and simulation, risk assessment, and MVA.

Fort Nelson Saline Formation Demonstration Test

To date, two iterations of a site risk assessment (Round 1 and Round 2) have been completed for the Fort Nelson Project. The Fort Nelson Round 1 risk assessment results were summarized in the PCOR Partnership Risk Management Plan (Programmatic Risk Management Plan, Plains CO_2 Reduction Partnership Phase III, Task 13 – Deliverable D88, April 2011). The Fort Nelson Round 2 risk assessment, which updated the previous risk assessment using the additional characterization, modeling, and simulation results and data that had been collected through December 31, 2010, was published in October 2011 ("Fort Nelson Carbon Capture and Storage Project: 2010 Technical Subsurface Risk Assessment," October, 2011). The results of this Round 2 risk assessment are summarized in this RMP update.

The Fort Nelson Round 2 risk assessment expanded the previous risk assessment by evaluating the project risks associated with two different sour CO_2 (CO_2–H_2S mixture) injection locations:

1. Proposed alternate drilling location (c-47-E) ("Risk Track 1")
2. Original test well location (c-61-E) ("Risk Track 2")

The results of the Fort Nelson Round 1 risk assessment suggested that sour CO_2 injection at location c-61-E could impact adjacent commercial gas pools before the end of their productive life. As part of the integrated strategy for project implementation (Figure 2), an alternate injection location was evaluated in the Fort Nelson Round 2 risk assessment. The alternate injection location is located approximately 5 kilometers west of the original test well location and was chosen to reduce the likelihood that the sour CO_2 injection would impact the commercial gas pools before the end of their productive life. In addition to the dual-track injection locations, the Fort Nelson Round 2 risk assessment incorporated Monte Carlo simulation into the risk profile assessment to develop a probability distribution for individual risks rather than a discrete (i.e., single) value.

Fort Nelson Round 2 Risk Register

A total of 32 risks were identified and included in the Round 2 risk register of the Fort Nelson Project. These risks were grouped into five general classifications:

1. Capacity
2. Containment
3. Injectivity
4. Seismic
5. Strategic

Fort Nelson Round 2 Risk Maps

These risks were assigned a frequency[2] score (i.e., the probability of its occurrence) and severity[3] score (i.e., the consequence of the risk on cost, time/schedule, quality, and scope). Each risk was then mapped using a color-coded grid designating low-, transition-, moderate-, or high-ranking risks. In addition, Monte Carlo simulation was conducted to generate a probability distribution of the project risk ranking scores.

Fort Nelson Round 2 Risk Assessment Results

The Monte Carlo simulations provide a more complete characterization of the risk profiles of the dual-risk tracks for the Fort Nelson Project. Specifically, histograms of the project risk profile scores that were generated by the Monte Carlo simulation for the alternate drilling location at Well c-47-E (Risk Track 1) and the original test well location at Well c-61-E (Risk Track 2) were generated along with a cumulative probability plot of the Monte Carlo results. A review of these risk maps and Monte Carlo simulations for each of the 32 project-specific risks of the Fort Nelson Round 2 risk assessment yielded the following conclusions:

- Overall project risk is lower for the new proposed drilling location than the original Round 1 risk assessment test well location, largely because of the decreased likelihood of impacting the commercial gas pools.

- Leakage of CO_2, H_2S, or formation brine to usable groundwater and leakage of CO_2 or H_2S to the atmosphere at either injection location are considered unlikely.

- Seismic risks at either injection location are considered unlikely, as the Fort Nelson Project study area is located in a region of extremely low natural seismicity.

- Capacity and injectivity concerns remain higher at the new proposed alternate drilling location (c-47-E) than the original test well location (c-61-E) because of the lack of site-specific subsurface data at this alternate location.

The Fort Nelson Round 2 risk assessment was subject to several limitations, mostly attributable to the lack of site-specific characterization data in and around the proposed alternate drilling location (c-47-E). The Fort Nelson Round 2 risk assessment recommended the following high-priority data collection/data analysis efforts for the next iteration of the project risk assessment:

- Drilling an exploratory well and collecting additional data near the proposed alternative sour CO_2 injection location (c-47-E).

[2] The term "frequency" was retained in the Fort Nelson risk assessment for consistency with the original Round 1 risk assessment from January 2010. The term is synonymous with "probability."
[3] The term "severity" was retained in the Fort Nelson risk assessment for consistency with the original Round 1 risk assessment from January 2010. Subsequent risk assessments for the PCOR Program and Bell Creek Project risk assessments replaced this terminology with "impact." The terms are synonymous.

- Collecting and analyzing three-dimensional seismic data in the area over/around the alternative injection location.

- Conducting geomechanical and geochemical laboratory tests of the reservoir rock collected from the new injection location.

- Conducting predictive simulations using an updated site geologic model.

Presently, the site owner/operator is unable to complete the above-mentioned data collection and analysis efforts as the company has currently put the project on hold. As a result, the initiation of sour CO_2 injection will be delayed, precluding the completion of the project within the Phase III program time frame of DOE (i.e., by 2017).

Bell Creek CO_2 Sequestration and EOR Demonstration

Two preliminary screening-level risk assessments were completed for the Bell Creek Project in April (Round 1) and June (Round 2)[4] 2012. A third-round risk assessment was completed in April 2014 to update these prior risk assessments by incorporating additional project knowledge that had been gained since their completion. All of these risk assessments were performed in accordance with the risk management framework that was utilized for the PCOR Partnership Program and the Fort Nelson Project. The outputs of these risk assessments were reviewed by an EERC work group prior to the implementation of the baseline MVA program. The results of the Round 2 and Round 3 risk assessments, as well as some initial observations from a recently initiated MVA program, are presented in the remainder of this programmatic risk update.

Bell Creek Round 2 Risk Assessment

Bell Creek Round 2 Risk Register

A total of 120 potential technical risks and 24 potential strategic risks were identified and included in the project risk register. It is important to note that many of these risks were permutations of the same failure mode, but with impact to different elements of the project. For example, lateral migration of CO_2 beyond the Phase 1 pool boundary was one potential failure mode, but this was separated into seven different risks in the project risk register based on impacts to 1) updip plugged and abandoned wells, 2) updip gas wells, 3) downdip water aquifer, 4) downdip plugged and abandoned wells, 5) Phase 2 pool, 6) Phase 3 pool, and 7) Phase 7 pool. Therefore, the total number of potential technical risk failure modes was significantly less than 120.

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[4] The preliminary Bell Creek Round 2 risk assessment updated the Bell Creek Round 1 risk assessment in two ways: 1) The scoring of the individual risks in the risk register engaged more of the senior PCOR Partnership staff, who were intimately involved in the Bell Creek Phase III Demonstration project and 2) the lower end of the probability classification, which ranged from 1% to 24%, was parsed into additional categories (i.e., <1%, 1% to 5%, 6% to 10%, 11% to 15%, and 16% to 24%) to increase the resolution of the scoring. The results of the Bell Creek Round 2 risk assessment are discussed in this document.

The technical risks for the Bell Creek Project were grouped into seven general classifications:

1. Group 1 – Capacity, Injectivity, and Retention

2. Groups 2 through 7 – Containment (vertical and/or lateral leakage to the atmosphere, usable groundwater, or gas pools and lack of CO_2 retention)

The strategic risks represented potential strategic risks to the site owner/operator.

Bell Creek Round 2 Risk Maps

Probability and impact scores were assigned to each risk by the PCOR Partnership task leaders. Rather than providing a single discrete value for each risk probability, respondents were asked to provide their minimum and maximum estimates. Using these frequency scores, and assuming a normal distribution, the 10th (P_{10}) and 90th (P_{90}) percentiles were determined for each risk probability, and these values were plotted for each risk impact to "map" the potential risks. As previously discussed, each risk was mapped using a color-coded grid designating low-, transition-, moderate-, or high-ranking risks.

Bell Creek Round 2 Risk Assessment Results

A review of the risk maps showed that all of the P_{10} values for all 120 technical risks and the 24 strategic risks were ranked "low," indicating that no immediate action was required and that these risks should continue to be monitored moving forward. When the P_{90} values were considered, some of the risks maintained this low ranking, while most of them moved to a higher-ranking category, i.e., either "transition" or "moderate"; however, none of the risks moved to a "high" category, which would require immediate action. With regard to the risks ranked as transition and moderate risks, it is uncertain whether a reduction in the former will result in any improvements in the resulting impacts, which relegates risks in this category to treatment only if risk reduction is possible or affordable. In other words, these risks represent a "second tier" of risks, only to be managed after the moderate or high risks have been addressed and if it is possible to do so.

Only three technical risks and two strategic risks were ranked as moderate risks and lay in a position on the risk maps where an increase in either the risk probability or impact score to the next highest level would result in their movement into the "high" risk category (all other "moderate" risks would require an increase in both risk probability and impact scores to the next highest level to yield a similar shift to the "high" risk category). The three technical risks that were ranked as moderate were associated with the following:

- CO_2 retention, as it relates to successful recovery for EOR operations.

- Short-circuiting of CO_2 resulting in insufficient contact of CO_2 with the oil.

- Lateral migration of the CO_2 beyond the Phase 1 pool boundary into updip plugged and abandoned wells.

The two strategic risks that were ranked as moderate were related to the following:

- Reductions in project funding or elongation of the project schedule because of financial and programmatic changes at DOE.

- Personnel or ownership changes by the operator.

Bell Creek MVA Activities

The EERC has completed 1 year of baseline monitoring as part of the Bell Creek Project MVA plan. A review of the MVA data collection program concluded that the risks identified during the Bell Creek Round 2 screening-level risk assessment are adequately addressed by the current MVA program. Most risks are being monitored using more than one measurement, providing redundant lines of evidence for inferring leakage of CO_2 or other fluids beyond the expected plan. The Bell Creek Project has begun injecting CO_2, and the operational monitoring phase of the MVA has been initiated. These operational data, in conjunction with the baseline MVA results and project simulation/modeling results, will be used in an iterative approach to evaluate potential risks over the project life cycle, consistent with the integrated approach to project implementation (Figure 2).

Bell Creek Round 3 Risk Assessment

A third-round risk assessment was completed in April 2014 to update the previous risk assessments by incorporating additional project knowledge that was gained between April/June 2012 and February 2014 (approximately 20 to 22 months). Additional project knowledge was acquired during this period as a result of the following project activities:

- Installation of two groundwater-monitoring wells (0504 FH and 3312 FH)
- Conduct of two vertical seismic profiles (VSPs)
- Conduct of MVA baseline and operational sampling
- Three-dimensional (3-D) seismic data collection and processing
- Installation of one dedicated geophone/passive seismic
- Characterization of collected core
- Reservoir fluids testing, including minimum miscibility pressure (MMP)
- 33 baseline pulsed-neutron logs (PNLs)
- Pressure monitoring and bottomhole pressure (BHP) measurements
- Additional reservoir static geocellular modeling and dynamic simulations
- CO_2 injection initiated at the site in May 2013
- Monitoring of production and injection rates

Bell Creek Round 3 Risk Register

Based on these site activities, several modifications were made to the previous risk register. The primary change was the addition of a new risk category, "Executing Field Work," which contains ten additional individual risks related to field activities. In spite of this addition of ten risks, the net result of the Round 3 risk assessment update was a net reduction of the total number of individual technical risks in the risk register from 120 to 95.

In summary, the 95 individual risks were categorized into seven groupings as follows:

1. Group 1 – Capacity, Injectivity, and Retention

2. Group 2 – Containment (Lateral Migration – CO_2/Formation Water)

3. Group 3 – Containment (Vertical Migration via P&A Wells – CO_2/Formation Water/Oil)

4. Group 4 – Containment (Vertical Migration via Injection Wells – CO_2/Formation Water/Oil)

5. Group 5 – Containment (Vertical Migration via Producing Wells – CO_2/Formation Water/Oil)

6. Group 6 – Containment (Other)/Seismic

7. Group 7 – Executing Field Work/Other

Bell Creek Round 3 Risk Maps

Probability and impact scores were assigned to each risk by the PCOR Partnership task leaders. Four risk maps were created for each of the 95 risks, one each for the impacts of cost, time/schedule, scope, and quality. The probability score was unchanged across all four risk maps (i.e., the probability that the risk could occur was unaffected by the impact of interest); however, the impacts of these events on the cost, time/schedule, scope, and quality varied based upon the impact of interest. Two types of risk maps were created: 1) most likely and 2) 90th percentile estimate:

- *Most likely values*. The most likely values were the mode (the most frequently reported score) of the group assessment. These risk maps represent the most likely assessment of each individual risk probability and impact or the best estimate given the Project Team's current technical knowledge of the Bell Creek Project.

- *90th percentile estimate*. Rather than use the maximum score value, which commonly reflects the input of only a single individual and is the worst-case estimate, the high-end estimate on the risk maps displays the 90th percentile value of a triangular distribution. The triangular distribution is a continuous probability distribution with a lower limit, *a* (best-case estimate); an upper limit b (worst-case estimate); and a mode c (most likely estimate), where $a < b$ and $a \leq c \leq b$. The triangular distribution is commonly used in risk assessment when not much is known about the distribution of an outcome besides its smallest and largest values and the most likely outcome (Fenton and Neil, 2013).

Bell Creek Round 3 Risk Assessment Results

The Bell Creek Round 3 risk assessment process involved a thorough, integrated approach to obtain input from the PCOR Partnership technical staff and to quantify risk scores such that each of the 95 risks on the final technical risk register could be mapped and evaluated for their relative ranking.

Under the most likely scenario, which represents the best estimate given the PCOR Partnership's current technical knowledge of the Bell Creek Project, all 95 risks mapped within either the low or transition risk map fields. None of the 95 risks was determined to be either a moderate or high risk.

Under the 90th percentile assessment, into which a significant conservative level was used to capture the maximum scores of the group responses, most of the risks still mapped within the low or transition categories. However, the increased probability and/or impact scores for this upper estimate placed several risks into the moderate category. None of the risks mapped into the high category, indicating that even under the conservative assumptions embedded in the 90th percentile estimate, there were no immediate risks requiring further analysis and/or short-term risk treatment.

ANALYSIS OF RISK TRENDS AND IMPLICATIONS REGARDING RISK MANAGEMENT STRATEGIES

Risk Trend Analysis Technical Approach

The risk trend analysis evaluates changes in the PCOR Partnership Programmatic Risk Assessment (RA) risk scores across RA1 (April 2011), RA2 (September 2013), and RA3 (August 2014). In order to allow for valid comparisons across RAs, the technical approach controls the three primary sources of uncertainty and variability in the three different RAs:

1. Uncertain risk scoring by different PCOR Partnership personnel.
2. Variable numbers of respondents who participated in each RA.
3. Variable numbers of risks in each of the four risk breakdown groups (external, technical, organizational, and project management).

Uncertainty in the risk scoring and variability in the different numbers of respondents who participated in each RA were addressed by modeling risk scores using Monte Carlo simulation and deriving a statistical distribution for each risk score, as opposed to a point estimate such as the mean, mode, or P_{90}. Variability in the number of risks in each risk breakdown group was addressed by normalizing the sum of risk probability × risk impact to the total number of risks in a particular risk breakdown group. A summary of this risk trend analysis technical approach is provided below.

Monte Carlo Simulation and Normalization

Risk-scoring uncertainty was modeled using a Monte Carlo simulation approach to capture the interpersonnel scoring for risk probability and risk impact. Separate simulations were done for RA1, RA2, and RA3, and the outputs from these simulations were then compared using different graphical summaries.

The minimum, average, standard deviation, and maximum risk probability and risk impact scores for each risk from RA1, RA2, and RA3 were compiled into Microsoft Excel® (Excel). Standard scores were then calculated for each of the five metrics (the probability score and the four impact scores – cost, time/schedule, scope, and quality, for a total of five metrics per risk). These standard scores were used to define the parameters of a truncated normal distribution. Probability, cost, time/schedule, scope, and quality for each risk were simulated for 1000 realizations in Excel using a uniform random number to simulate a random draw from each truncated normal distribution. These values were then combined into four "risk criticality numbers" as probability × cost, probability × time/schedule, probability × scope, and probability × quality to generate four rows of 1000 risk criticality numbers, one row for each type of risk impact.

Next, using the rows of risk criticality numbers generated above, the average risk criticality number was calculated for a particular risk breakdown group. The minimum, average, standard deviation, and maximum of each risk within a particular risk breakdown group were calculated to define a new truncated normal distribution for that group. For example, in RA3, there were ten technical risks. The minimum, maximum, average, and standard deviation were calculated across all 10,000 simulations (1000 realizations across ten different risks) to generate the parameters of a new truncated normal distribution for RA3 technical risks. Therefore, each RA and each risk breakdown group were defined by a truncated normal distribution of risk criticality numbers, i.e., probability × cost, probability × time/schedule, probability × scope, and probability × quality.

It is important to note that the calculation of these risk criticality numbers is solely for purposes of internally comparing and contrasting the individual risks that were identified as part of RA1, RA2, and RA3. These risk criticality numbers are an internal assessment of that risk, relative to all of the other identified risks, and do not represent an absolute assessment of its potential impact on the PCOR Partnership Program.

These risk criticality numbers are "normalized" in the sense that valid comparison across RAs can now be conducted, because the primary sources of uncertainty and variability (risk scoring, number of respondents, and number of risks) have been accounted for in the approach.

Graphical Summaries

Probability Density Function and Cumulative Distribution Function Curves

The probability density function (pdf) and cumulative distribution function (cdf) were calculated for each risk breakdown group for RA1, RA2, and RA3. These pdf and cdf curves were then overlaid onto a single graph to compare the distribution of the average risk score within a group across the three RAs. Overlays for pdf and cdf curves for external, technical, organizational, and project management risks are shown in Figures 3 (a and b) through 6 (a and b), respectively.

The pdf curves show the "center-of-mass" of the truncated normal distribution, and the "peak" of the curve represents the most likely risk scoring response. In Figure 3a, the shift in the peak for RA3 to the left (in comparison to RA1 and RA2), in addition to the narrow "peakedness," shows that the average assessment of external risks has decreased from RA1 to RA3 and that the respondent scores had less uncertainty in RA3.

The cdf curves show the probability ($X \leq x$) of the truncated normal distribution. A shift to the left for a cdf curve (in relation to other RAs) shows an overall decrease in the risk score. A steeper slope (more vertical) means that there is less uncertainty. For example, in Figure 3b, the shift to the left for RA3 (in comparison to RA1 and RA2), in addition to the steeper slope, shows that the average assessment of external risks has decreased from RA1 to RA3 and that the respondent scores had greater certainty (steeper slope) in RA3.

The pdf and cdf curves were used to assess broad changes in each of the four risk breakdown groups: external, technical, organizational, and project management risks, across RA1, RA2, and RA3.

Boxplots

The pdf and cdf overlays show the average risk score distribution among multiple risks within a given risk breakdown group. These plots are helpful for showing broad trends and for inferring whether, on average, the risk scoring has changed across RAs. However, averaging across multiple risks can "smooth" the response, muting the signal for risks that are scored low with risks that are scored high, which complicates interpretations for why the pdf and/or cdf curves show a shift in one direction or the other. Therefore, in addition to the pdf and cdf plots of average risk scores for an entire risk breakdown group, boxplots of risk criticality numbers for each risk were generated to help in the interpretation.

Boxplot comparisons could only be made for risks that were retained from RA1 through RA2 and RA3. Risks unique to a particular RA were not compared using boxplots, because as noted above, these risk criticality numbers are solely for purposes of internally comparing and contrasting the individual risks, and their absolute value has no meaning beyond comparing among risks.

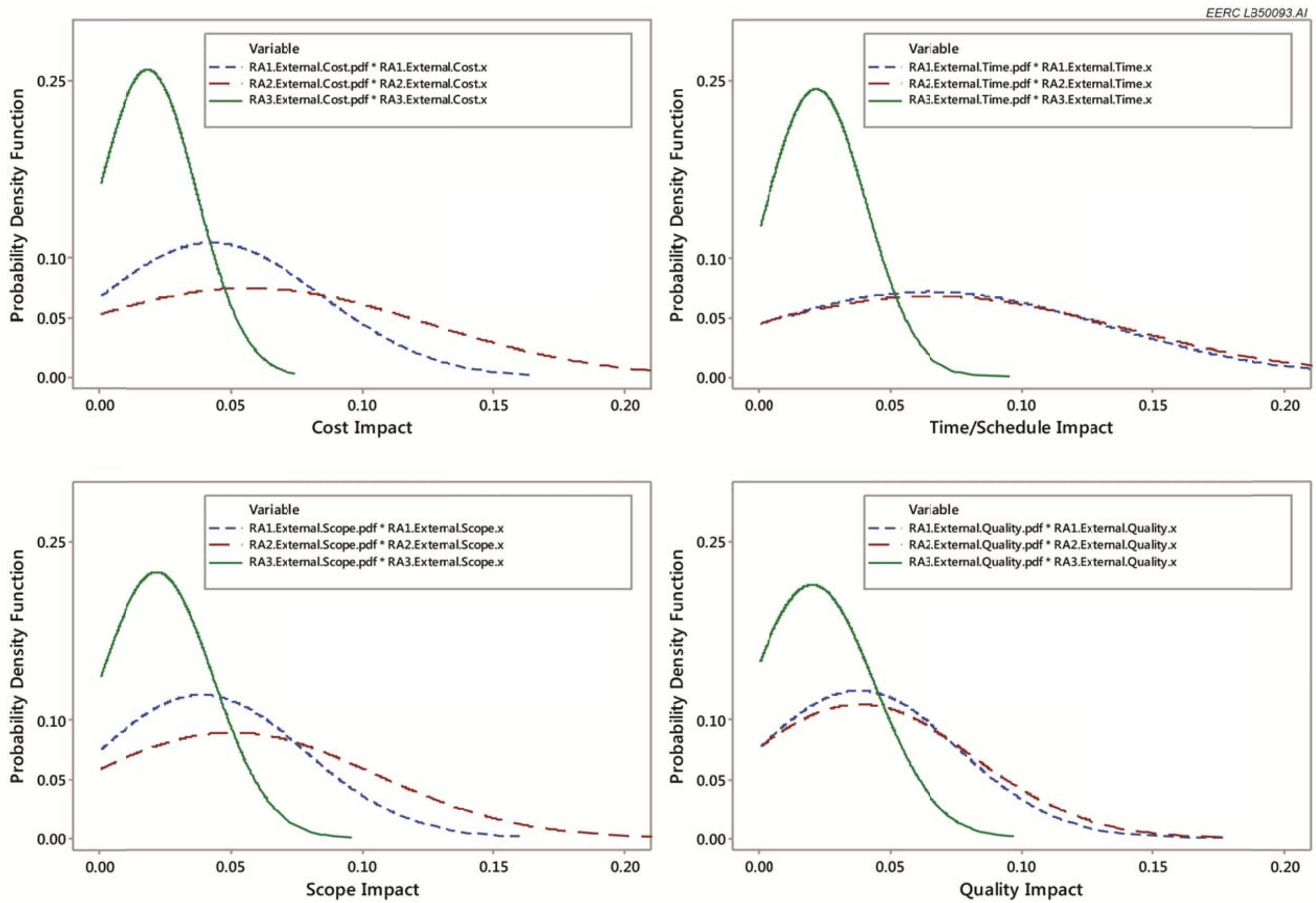

Figure 3a. pdf curves for the average external risk for RA1 (April 2011 – dashed blue line), RA2 (September 2013 – red dashed line), and RA3 (August 2014 – solid green line).

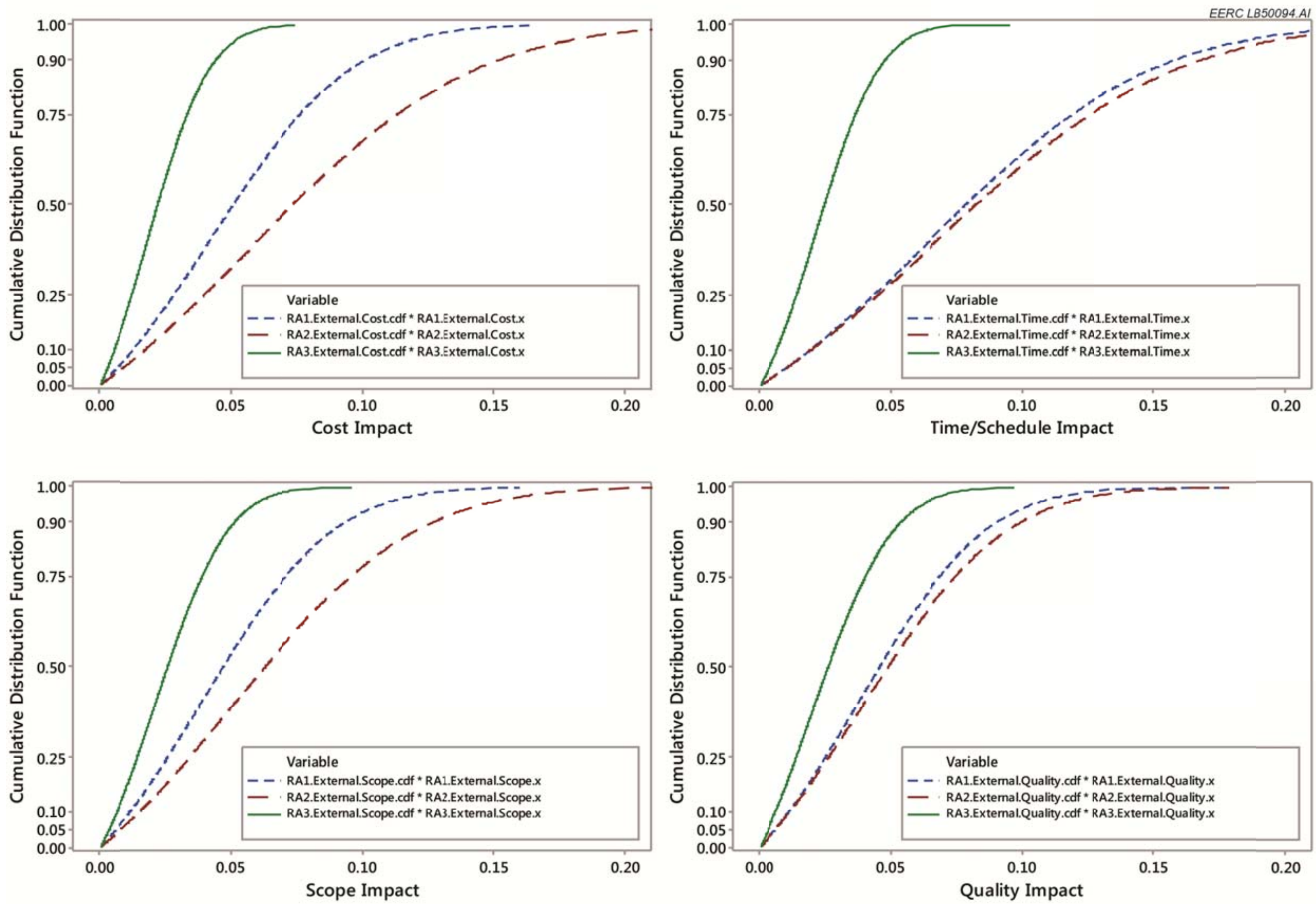

Figure 3b. cdf curves for the average external risk for RA1 (April 2011 – dashed blue line), RA2 (September 2013 – red dashed line), and RA3 (August 2014 – solid green line).

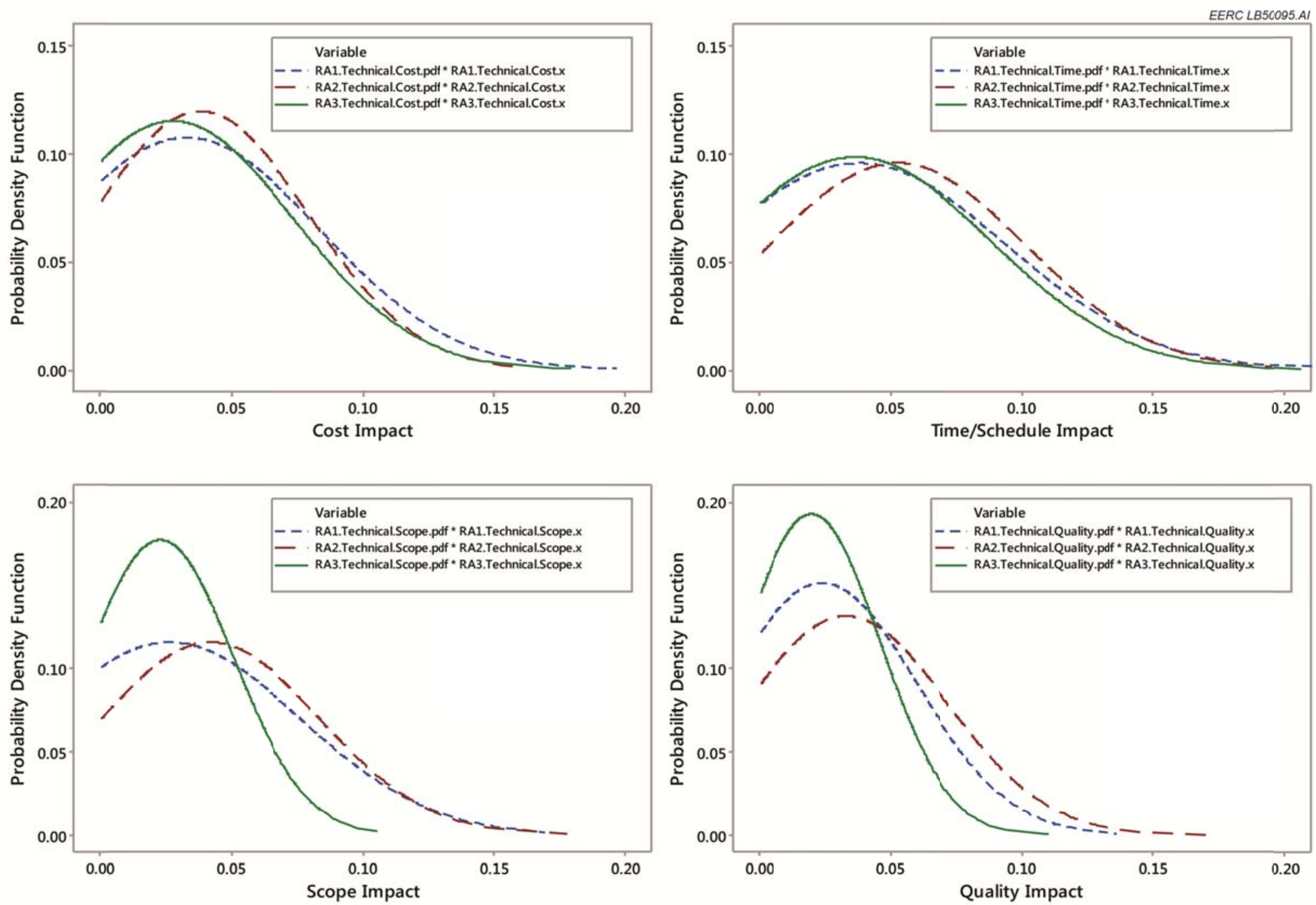

Figure 4a. pdf curves for the average technical risk for RA1 (April 2011 – dashed blue line), RA2 (September 2013 – red dashed line), and RA3 (August 2014 – solid green line).

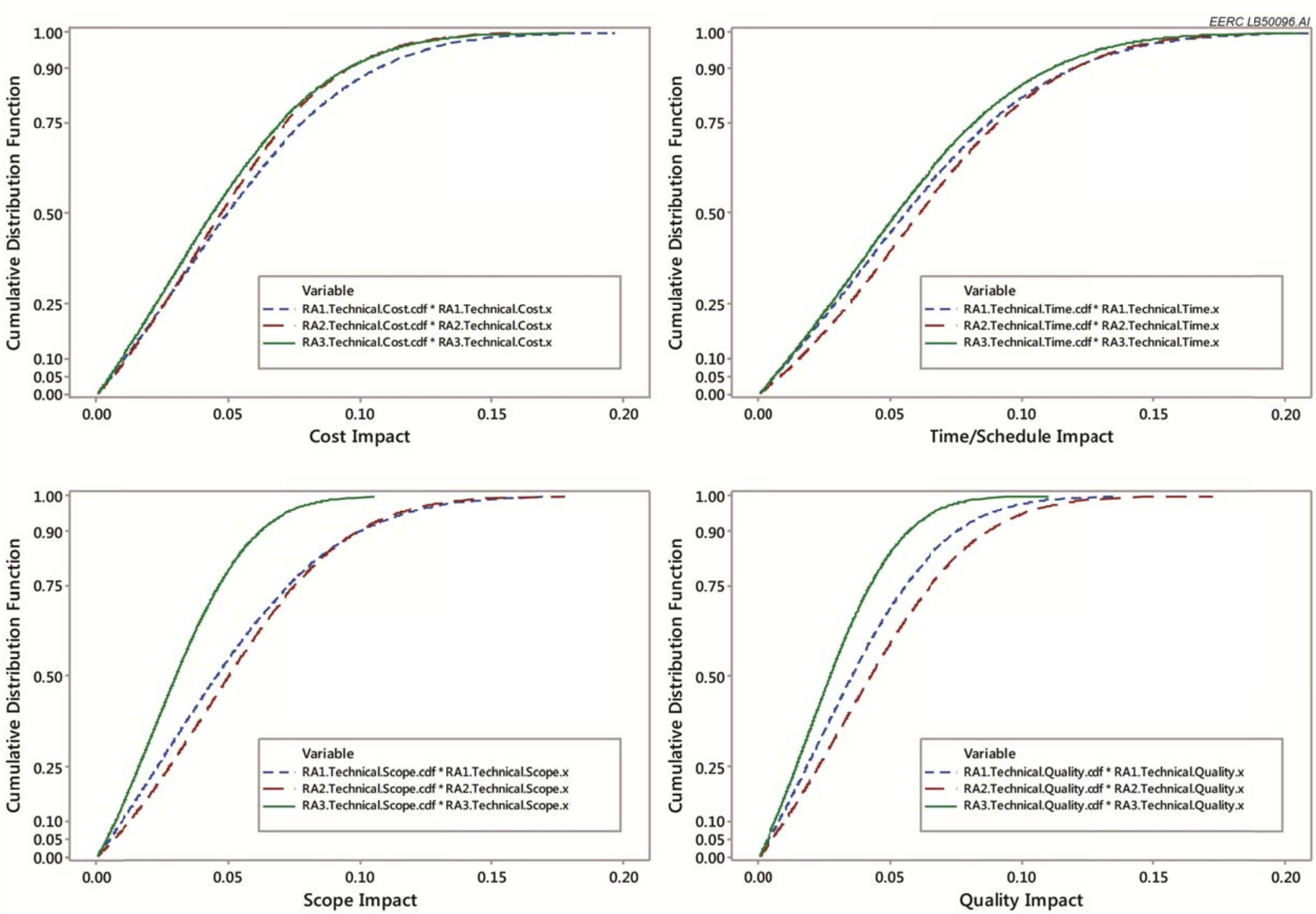

Figure 4b. cdf curves for the average technical risk for RA1 (April 2011 – dashed blue line), RA2 (September 2013 – red dashed line), and RA3 (August 2014 – solid green line).

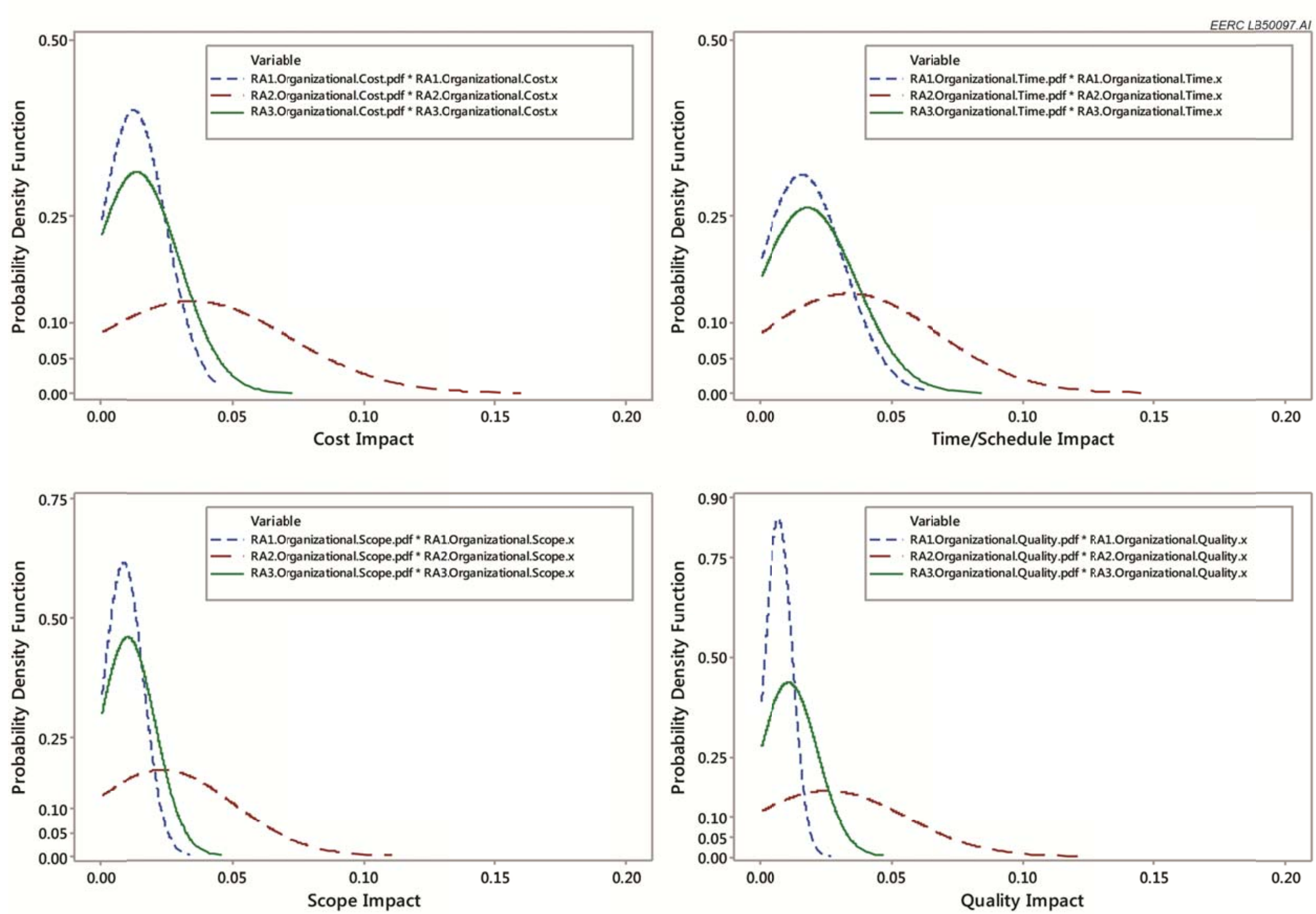

Figure 5a. pdf curves for the average organizational risk for RA1 (April 2011 – dashed blue line), RA2 (September 2013 – red dashed line), and RA3 (August 2014 – solid green line).

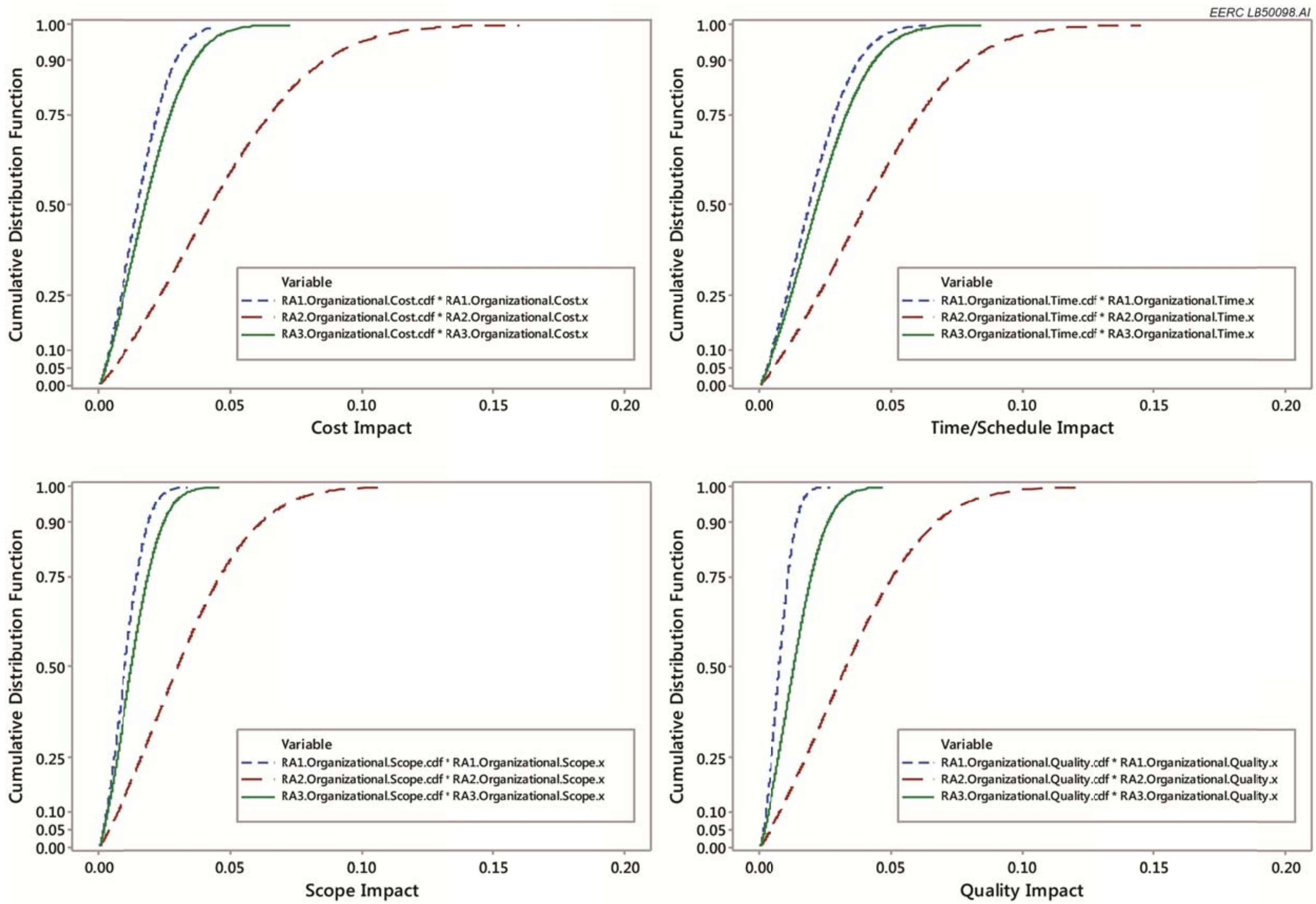

Figure 5b. cdf curves for the average organizational risk for RA1 (April 2011 – dashed blue line), RA2 (September 2013 – red dashed line), and RA3 (August 2014 – solid green line).

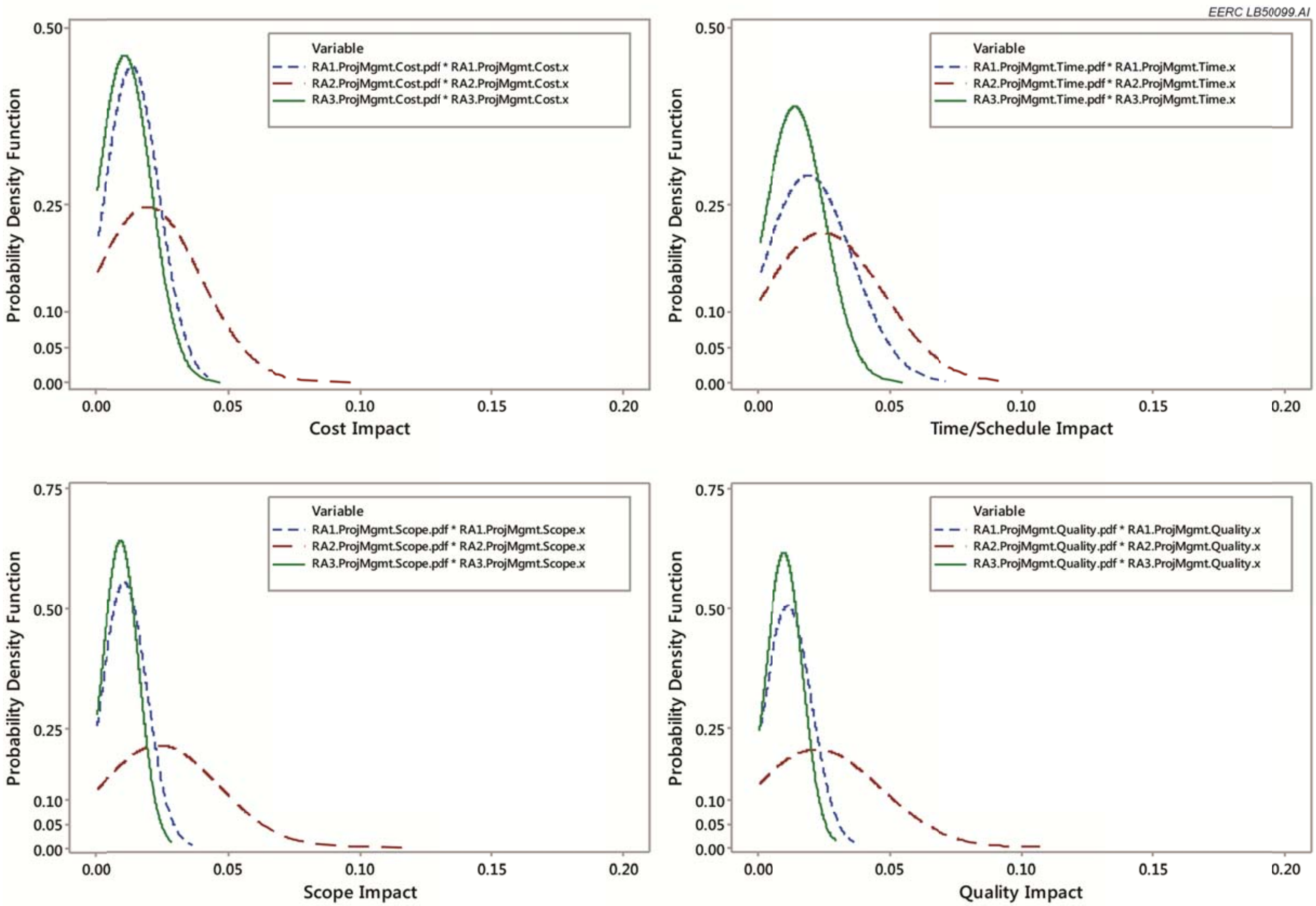

Figure 6a. pdf curves for the average project management risk for RA1 (April 2011 – dashed blue line), RA2 (September 2013 – red dashed line), and RA3 (August 2014 – solid green line).

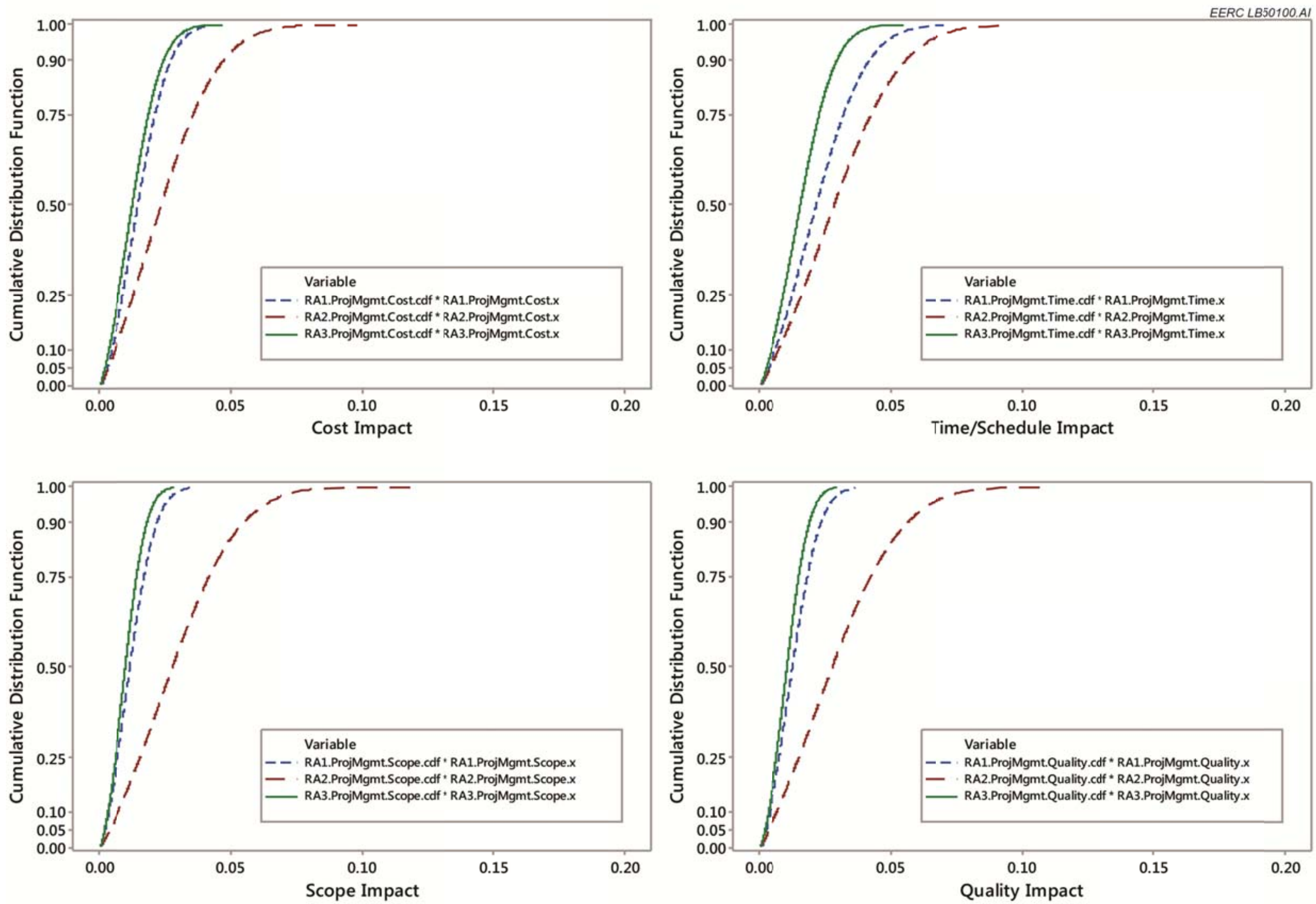

Figure 6b. cdf curves for the average project management risk for RA1 (April 2011 – dashed blue line), RA2 (September 2013 – red dashed line), and RA3 (August 2014 – solid green line).

Boxplots were drawn to show the median (P_{50}) with a box around the 50% prediction interval (25th and 75th percentiles [P_{25} and P_{75}]) and whiskers around the 80% prediction interval (P_{10} and P_{90}). The *y*-axis shows the four different risk criticality numbers: probability × cost, probability × time/schedule, probability × scope, and probability × quality, and the *x*-axis denotes RA1, RA2, or RA3.

Example boxplots for External Risk No. 11 (negative publicity from other carbon, capture, and storage [CCS]; oil and gas; or EOR projects leads to requirements for more detailed site characterization) are shown in Figure 7. The lower median scores in RA3 show that the risk scores for this particular risk have decreased since RA1. The narrower box and whiskers for RA3 also show that there was less uncertainty in RA3 as compared to RA1.

Boxplots were used to assess changes in specific risks across RA1, RA2, and RA3 and to evaluate whether there was a change in not only the median score but also in the uncertainty (i.e., the width of the boxplot).

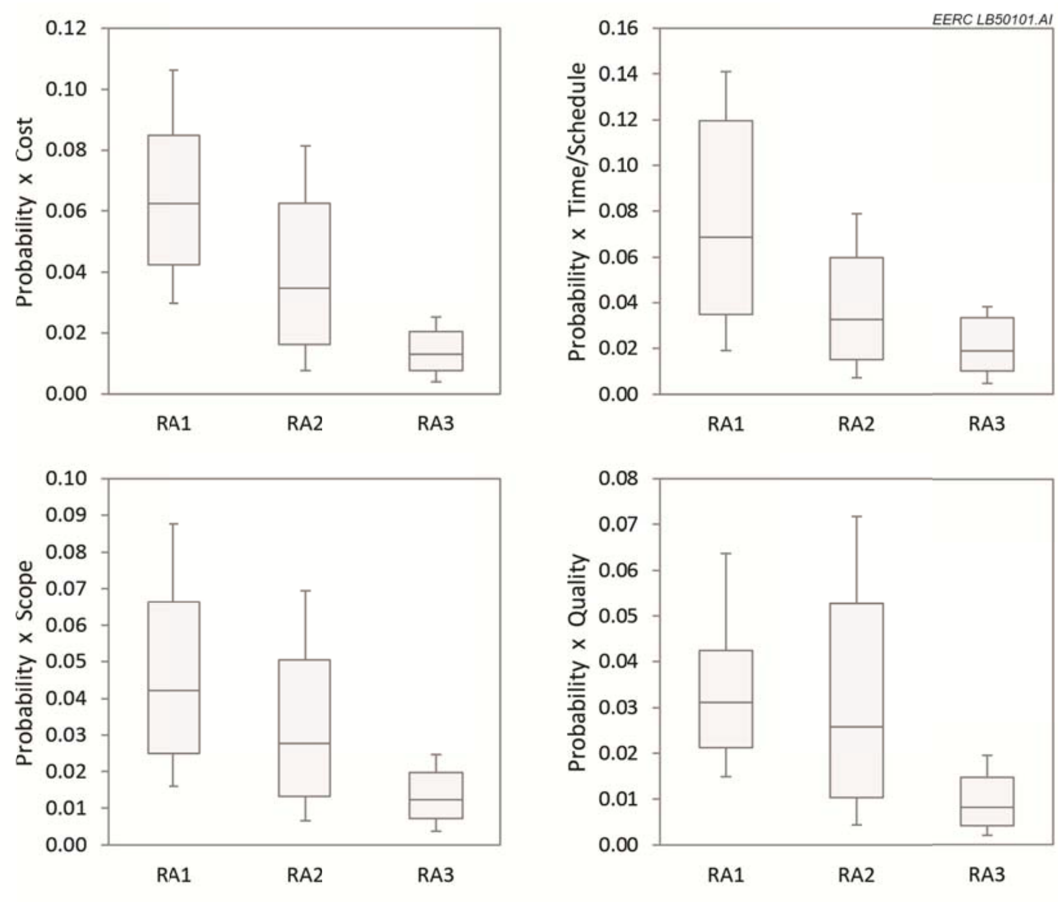

Figure 7. Risk criticality numbers for the external risk: "Negative publicity from other CCS, oil and gas, or EOR projects leads to requirements for more detailed site characterization." Boxplots show the median (horizontal line), 50% prediction interval (P_{25} to P_{75}, gray box), and 80% prediction interval (P_{10} to P_{90}, whiskers).

Median Value Line Graphs

As noted above, boxplot comparisons could only be made for risks that were retained from RA1 through RA2 and RA3, and risks unique to a particular RA were not compared using boxplots. However, several risks were either added or removed from the risk register between RA1 and RA3, and the scoring for these risks could affect the observed trends for the risk group over time. Therefore, the risk trend analysis also evaluated the effect of these added or removed risks by using line graphs of the median (P_{50}) risk criticality numbers for each risk.

An example median value line graph for organizational risks showing the risk criticality number of probability × cost is shown in Figure 8. Because of changing risk register entry numbers across RAs, the line graphs display an aligned risk register order so that identical risks have the same number and added or removed risks may be clearly identified. For example, Figure 8 shows that Organizational Risk No. 6 was present for RA1 but was removed for RA2 and RA3. Conversely, Organizational Risks Nos. 10 and 11 were added to the risk register for RA2 and RA3 and were not present during RA1.

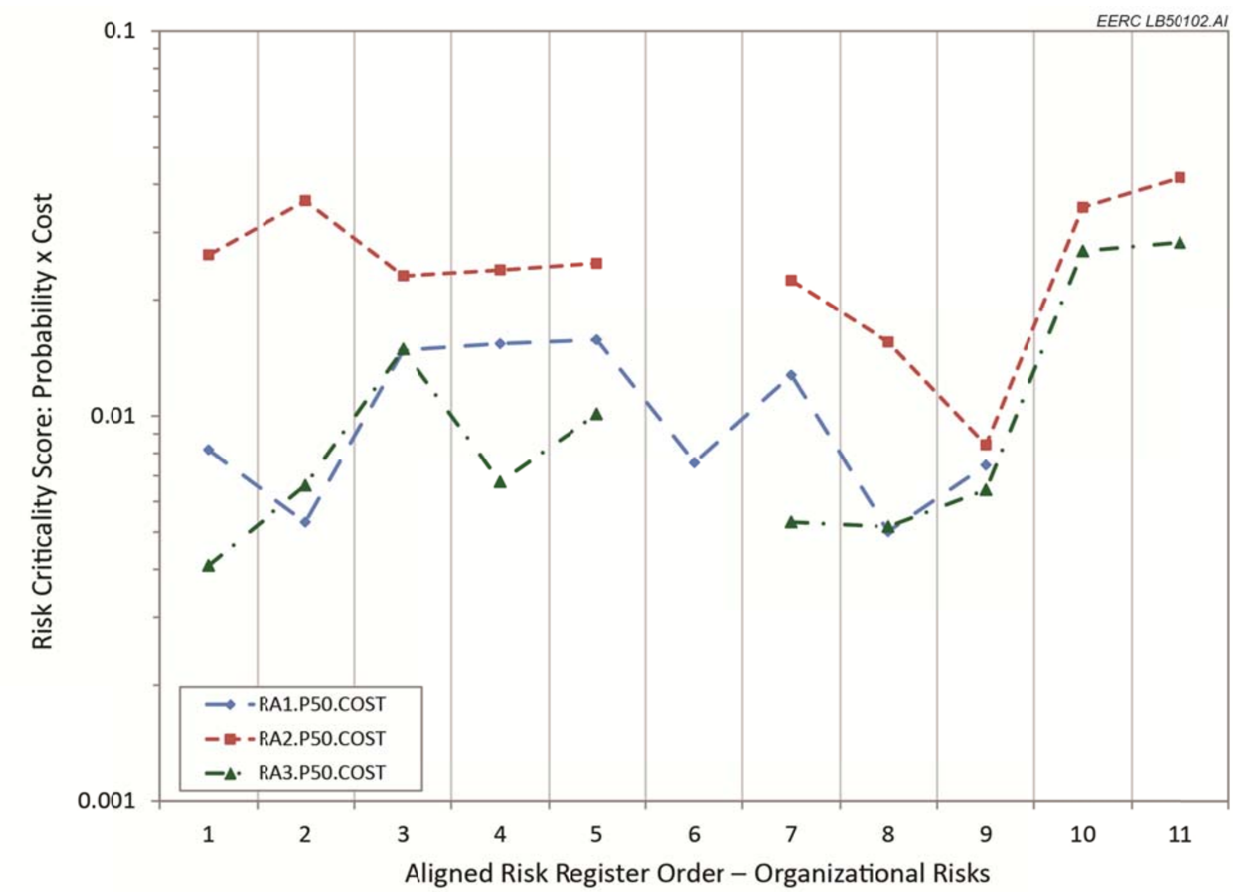

Figure 8. Organizational risk criticality numbers for probability × cost for PCOR Partnership Programmatic RA1, RA2, and RA3. The symbols show P_{50}.

The median value line graphs were used to assess individual risks that were not included in the boxplot comparisons and to identify unusually low or high risk criticality numbers for a particular risk.

Dashed lines are provided to aid in visual comparisons; each risk is independent. The *x*-axis is the aligned risk register order. Risks that plot in the same horizontal order (i.e., they are aligned vertically) are the same risk. Risks unique to a specific RA (e.g., RA1-aligned risk register order #6) do not have boxplot comparisons. Note: the *y*-axis is displayed on a log-scale.

Comparison of Risk Breakdown Group Assessment Results over Time

The pdfs and cdfs permit an examination of the temporal trends of the risk assessment results of the PCOR Partnership, beginning in April 2011 (Figures 3 through 6). The temporal trends in the risk assessment results for the period from April 2011 to the present for each risk breakdown group are summarized below:

- **External Risks (Figures 3a and 3b)** – The external risk scores for cost, time/schedule, scope, and quality show a dramatic shift to the left, indicating that external risks are significantly lower today (August 2014, RA3) than in April 2011 (RA1).

- **Technical Risks (Figures 4a and 4b)** – Both the scope and quality risk scores show a clear reduction in technical risk, i.e., a shift of the cdf curve to the left, moving from RA1 (April 2011) to RA3 (August 2014). At the same time, the risk scores for cost and time/schedule are essentially unchanged across all risk assessments.

- **Organizational Risks (Figures 5a and 5b)** – The cost, time/schedule, scope, and quality risk scores all show a slight shift to the left for RA1 as compared to RA3. This shift suggests that the organizational risks are slightly higher today (RA3) than in April 2011 (RA1); however, given the inherent imprecision associated with these responses, these differences are considered virtually indistinguishable.

- **Project Management Risks (Figures 6a and 6b)** – The cost, time/schedule, scope, and quality risk scores all show a slight shift to the left for RA3 as compared to RA1. This shift suggests that the project management risks are slightly lower today (RA3) than in April 2011 (RA1); however, given the inherent imprecision associated with these responses, these differences are considered virtually indistinguishable.

In general, the above trend analysis indicates that the overall risk of the PCOR Partnership is decreasing, and/or remaining stable over time. However, a more in-depth analysis of the individual risks in each risk breakdown category is required to better understand what is driving the observed changes and, therefore, what mitigation strategies, if any, might be warranted. A more in-depth analysis of these observed risk trends is provided in the next section.

Interpretation of Risk Trends and Mitigation Strategies

The impact of individual risks on the observed shifts in the cdf curves of RA1 and RA3 were examined using the boxplots and median value line graphs. The risk trend interpretations are discussed below.

External Risk Trends

The pdf and cdf plots showed that external risks were significantly lower for RA3 than for RA1 or RA2. The boxplots and median value line plots were used to understand which risks were driving these changes.

The Fort Nelson Effect – Several external risks from RA1 were associated with the Fort Nelson CCS Project, and these risks were generally scored high. Since these individual risks were removed for RA2 and RA3 (i.e., the Fort Nelson Demonstration Test was placed on an indefinite hold), this resulted in a reduction in the external risk score for RA2 and RA3.

The Bell Creek Effect and Timing – At the same time, other external risks associated with the Bell Creek Demonstration Test were added for RA2 and RA3. These risks were generally scored high during RA2 and were scored low or average during RA3. The RA2 occurred in September 2013, which was relatively early into the CO_2 injection program at the Bell Creek site; therefore, uncertainty was greater, and the risk scoring was more conservative. In contrast, the risk scoring for RA3 occurred in May 2014, at which point in time almost 1 million tonnes of CO_2 had been successfully injected into the Bell Creek site. Therefore, RA3 risk scores were lower than RA2 for external risks that might affect the successful completion of the project, like changes in climate policy, U.S. Environmental Protection Agency Class II versus Class VI injection wells, and changes in project economics.

The net effect of the Fort Nelson and new Bell Creek risks was that the RA2 external risks scores were higher than RA1 and RA3, but RA3 external risks scores were lower than RA1.

Technical Risk Trends

The pdf and cdf plots showed that technical risks (scope and quality impacts) were slightly lower for RA3 than for RA1 or RA2. The boxplots and median value line plots were used to understand which risks were driving these changes.

The Bell Creek Effect and Timing – Analogous to the external risks, the RA2 occurred in September 2013, which was relatively early into the CO_2 injection program at the Bell Creek site, and therefore, uncertainty was greater. In contrast, the risk scoring for RA3 occurred in May 2014, at which point in time nearly 1 million tonnes of CO_2 had been successfully injected into the Bell Creek site. Therefore, RA3 risk scores were lower than RA2 for technical risks like injectivity, leakage, oil recovery, miscibility pressure, and other technical failures.

One technical risk related to facilities disruption causing a loss of CO_2 supply was scored lower in RA1 than in RA3, indicating that the supply of CO_2 to the facility remains a concern.

Organizational Risk Trends

The pdf and cdf plots showed that organizational risks were more-or-less indistinguishable between RA1 and RA3 but were scored higher during RA2. The higher scores in RA2 likely reflect the attitudes and perceptions of the respondents at that time, as the Bell Creek Demonstration Test was rapidly ramping up and the demands on the staff were significant. However, following this somewhat stressful period, the risk scores in RA3 returned to RA1 (April 2011) levels.

More significantly, two individual risks were added in RA2 and RA3 related to data management and data security that were not in RA1. These risks were added at a time when the data collection efforts associated with the Bell Creek Demonstration Test were rapidly escalating, and both of these risks had relatively high risk criticality numbers. In recognition of these risk assessment results, the PCOR Partnership instituted a mitigation strategy by initiating a Bell Creek Data Management Project. This project was completed in May 2014 and resulted in the revamping of the data management plan for the Bell Creek Project. It is likely that these individual risks will be scored quite differently during the next update of the PCOR Partnership Programmatic RA.

Project Management Risk Trends

The pdf and cdf plots showed that organizational risks were more-or-less indistinguishable between RA1 and RA3 but were scored higher during RA2. The higher scores in RA2 likely reflect the attitudes and perceptions of the respondents at that time, as noted above for the organizational risk evaluation.

More significantly, one risk was added in RA3 that was not in either RA1 or RA2. This risk was associated with potential health and safety incidents which could result in lost time accidents and schedule delays. This risk was scored high as field activities at the Bell Creek Demonstration site were becoming more extensive. To mitigate this risk, the PCOR Partnership has implemented training for individuals working in the field, is ensuring that its health and safety plans are current and that means for implementing these plans in the field are in place and working.

Risk Trend Analysis Summary

This analysis of trends shows that the PCOR Partnership integrated strategy for CCUS project implementation (Figure 4) is working. The programmatic risk assessments, RA1, RA2, and RA3, were implemented as part of that strategy and, as demonstrated in this update of the programmatic RMP, has resulted in the effective identification and management of risks over the course of the PCOR Partnership Program plan being executed. During that time, individual risks have been identified, other risks have been added or deleted over time reflecting the dynamic nature of the program, and mitigation strategies have been put in place for those risks which demonstrated elevated risk criticality numbers. This implementation strategy will be continued until the PCOR Partnership Program is complete and had achieved its objectives.

PROGRAMMATIC RISK MANAGEMENT PLAN – NEXT STEPS

This RMP recognizes that risk management is an active process, one that takes place iteratively over the lifetime of a program (see Figure 2). The relevant risks can change for a specific CO_2 geologic storage project as it matures and moves from one stage to the next (i.e., preinjection, to injection, to closure, and to postclosure). With each stage of development, increasingly more data become available, and the uncertainty associated with the risk assessment decreases over time. The PCOR Partnership intends to continue to implement this RMP and envisions that additional iterations, as necessary, will be completed as the PCOR Partnership Program and field-scale demonstration tests continue to move toward completion. Ultimately, the risk management process described in this RMP has provided, and will continue to provide, the framework and data for the development, implementation, and updates of MVA plans for all aspects of the PCOR Partnership Program.

REFERENCES

Fenton, N., and Neil, M., 2013, Risk assessment and decision analysis with Bayesian networks: Boca Raton, Florida, CRC Press.