Appendix A: Assessment of the Narrative Temperature Standard in South Boulder Creek below Gross Reservoir

Enlargement of Gross Reservoir is not expected to increase temperatures in South Boulder Creek below the reservoir. Consequently, the usual concerns about exceedance of the numeric temperature standards or loss of assimilative capacity do not apply. Instead, attention is focused on alteration of the “normal pattern” of temperature variation in a stream, which is covered by the narrative temperature standard. Assessing attainment of the narrative standard depends on having a definition for “normal pattern” of temperature variation in a stream, but no specific assessment protocol for the narrative standard is available in current listing methodology. These impediments, which have caused previous assessments to limit attention to the potential for impacts that can be evaluated with numeric standards, do not remove the Division’s requirement to consider temperature impacts in terms of the narrative standard.

The assessment consists of three parts, beginning with a characterization of the normal pattern of seasonal temperature variation. This is followed by a characterization of the existing pattern of seasonal variation in South Boulder Creek and a comparison to the expected normal pattern. Finally, modeling is used to predict how operation of the project will change the seasonal temperature pattern and what might be accomplished with mitigation.

Normal Pattern

Assessment of the narrative depends first on establishing a frame of reference for the normal pattern of temperature. The Division has been reviewing temperature data throughout the state in preparation for a rulemaking hearing that will include consideration of temperature standards. That work has contributed to a better understanding of the seasonal patterns of temperature variation in streams. Some general characteristics are relevant and helpful for the purpose of explaining what is “normal”.

Stream temperatures change seasonally in a sinusoidal manner with a maximum in late July. The pattern for streams mimics that of air temperature, and both are driven largely by solar radiation. For a pattern to be considered normal, stream temperatures should be warming from winter lows until July when the annual maximum occurs; June should be warmer than May, and July should be warmer than June. Similarly, stream temperatures should be cooling after August; September should be cooler than August, and October should be cooler than September.

The shape of the normal seasonal pattern is common to most streams, but the maximum temperature reached in the summer varies with elevation. In addition, winter temperatures may be truncated at or near zero degrees. Not surprisingly, stream temperatures increase with decreasing elevation. At the elevation of South Boulder Creek immediately below Gross Reservoir (about 6975 ft), daily average temperatures of 18 to 20 degrees would be expected in late July.

Current Pattern

Impounding a stream has important implications for temperature in the stream below the reservoir. For large reservoirs that are deep enough to stratify in the summer, typical operation (i.e., bottom release) will release cold water for some portion of the summer months. How cold the release temperature will be and how long it will stay cold depend on the volume of the reservoir and the rate of release.

Cold summer temperatures at the outflow are the result of releasing water from the bottom of a stratified reservoir. Lakes of sufficient depth (greater than about 10 meters) usually form distinct layers in the summer; there is a warm layer on the top and a cold layer on the bottom. The layering begins shortly after ice-out and it effectively traps the cold water on the bottom. The water released from the bottom will remain cold until the volume of cold water is depleted or replaced with warmer inflows. In any case, the alteration to the normal pattern tends to be quite pronounced with large deep reservoirs.

Gross Reservoir was completed in 1954, and reservoir operation changed the seasonal temperature pattern in South Boulder Creek. The temperature of water at the outlet of Gross Reservoir is now measured routinely as part of a condition for the current FERC license. The water is cold early in the summer and the temperature increases gradually until reaching a maximum of about 11 ^{o}C in mid-October (Figure 1). The seasonal pattern is much different than what would be considered normal in terms of both the magnitude and the timing of the maximum. It is obvious that September is now warmer than August, and October is warmer than September. That the stream continues to warm for two months after August is clear evidence that the normal seasonal pattern is not maintained.

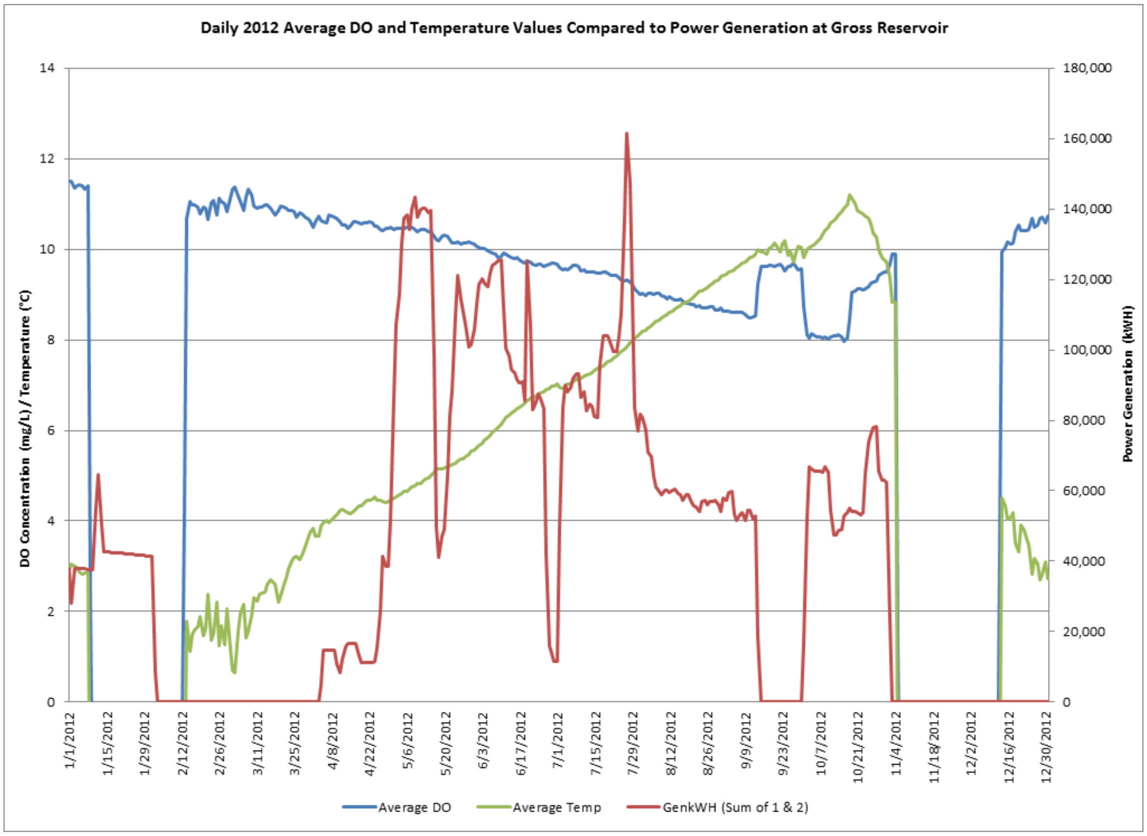

Figure 1. Temperature (green line) at the outlet of Gross Reservoir in 2012. Figure is taken from the 2012 annual report required by the FERC license.

A graphical comparison of temperatures in South Boulder Creek above and below Gross Reservoir would amplify the argument about alterations to the normal seasonal pattern, but adequate data are not available. An alternative is to use a surrogate stream at similar elevation where temperature data are available above and below a reservoir. Muddy Creek in Grand County is a reasonable choice for the comparison. It is impounded by Wolford Mountain Reservoir, and it is at an elevation similar to that of Gross Reservoir. In addition, real-time measurements of temperature are available above and below the reservoir (Figure 2). At the site above the reservoir, the seasonal pattern of temperature resembles a sine curve with a maximum in late July, which is the typical pattern for streams with minimal anthropogenic heat sources. Below the reservoir, however, the pattern bears little resemblance to the pattern observed above the reservoir. Summer temperatures below the reservoir can be 10 degrees cooler than they are upstream. Instead of the normal pattern where a maximum is reached in late July with temperatures decreasing after August, temperatures increase more or less linearly throughout the summer and into October. The maximum temperature below the reservoir occurs when stratification ends and the fully mixed lake is more or less isothermal. The effect of Gross Reservoir on temperature in South Boulder Creek is likely quite similar to the documented effect of Wolford Mountain

Reservoir on Muddy Creek.

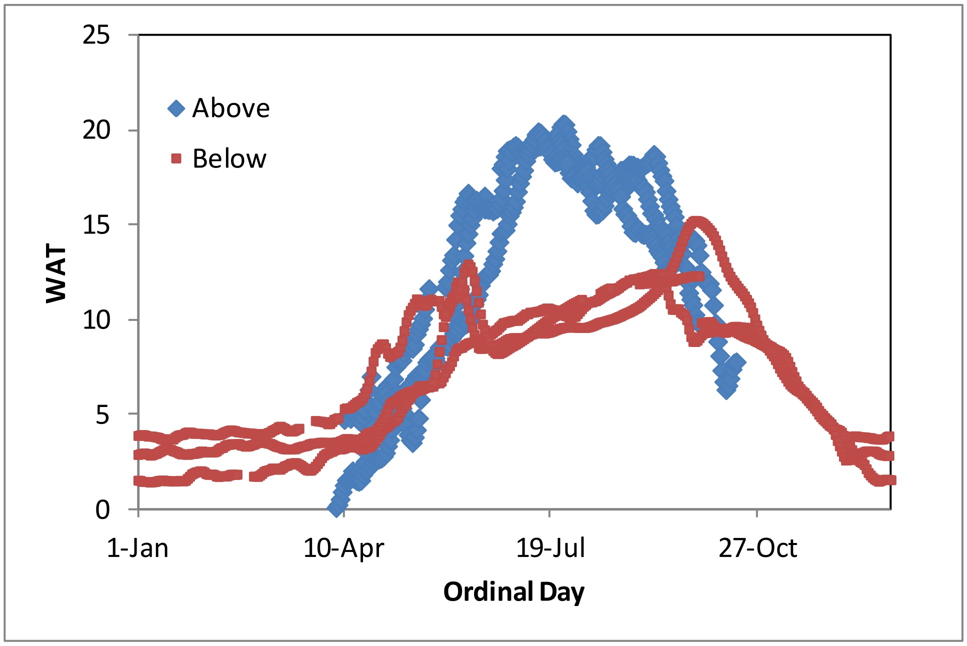

Figure 2. Weekly average temperatures in Muddy Creek above and below Wolford Mountain Reservoir. Data from WY2012-14 are plotted against ordinal day to highlight the seasonal pattern.

The Division concludes that construction of Gross Reservoir resulted in a significant alteration to the normal pattern of temperature variation in South Boulder Creek. The alteration is ecologically significant in that many degree days of warming have been lost in mid-summer, which would normally sustain growth of fish and other aquatic organisms. The alteration is sufficiently great to say that stream temperatures are no longer in attainment of the narrative standard. Although the existing impact of the reservoir is not the focus of the certification review, it is important for setting the stage for predicting the impact of the project.

Model Predictions

The Applicant has provided the Division with modeling results[1] that predict outlet temperatures before and after Gross Reservoir is enlarged. A comparison of modeled conditions with and without the project is the preferred basis for evaluating impacts because it is an apples-to-apples comparison that cannot be made with field data. Moreover, this type of comparison, which relies solely on modeled values, has been the principal basis for evaluating temperature impacts in the Fraser River.

[1] DRAFT Results of Preliminary Model Run of Selective Withdrawal in Gross Reservoir. Draft memo from Hydros Consulting, September 11, 2013.

When outlet temperatures are modeled for the base case (i.e., without the project), the maximum temperature is 13-15 degrees, and it occurs in late September (Figure 3). In contrast, the normal seasonal pattern for a stream at that elevation would likely reach a maximum in late July, and the maximum temperature that would approach 20 degrees. When the same scenario (hydrology and meteorology) is modeled with the project (Alt 1A), summer temperatures remain relatively constant at 7 or 8 degrees. In other words, the alteration of the pattern is sufficiently extreme that South Boulder Creek below the reservoir is likely to be in attainment the winter numeric standard throughout the year. That offers little opportunity for fish growth and would suppress productivity of the benthic invertebrates, which are an important food resource for the fish. The loss can be quantified in terms of degree-days, which is a metric frequently used for characterizing the thermal requirements for different life history stages. The model predicts a loss of about 260 degree-days with 1971 hydrology and 315 degree-days with 1972 hydrology. Operation of the project would reduce by about 30% the degree-days currently available for fish growth.

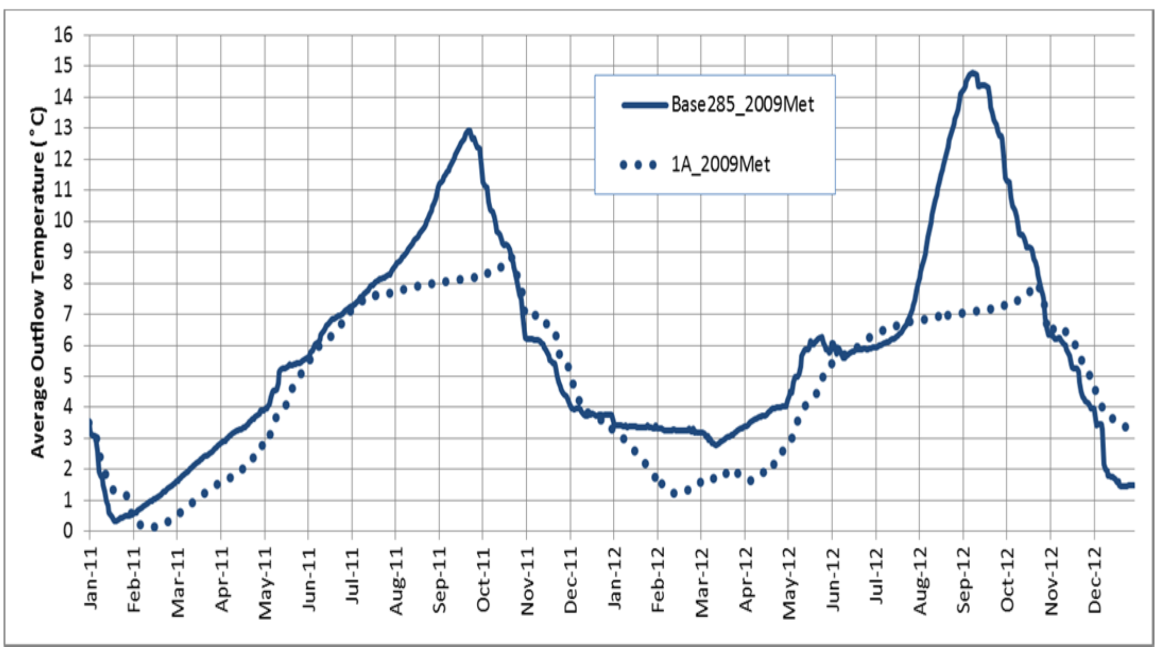

Figure 3. Simulated Outflow Temperatures from Gross Reservoir for Base285 and Alt1a, 1971 – 1972, 2009 Meteorological Inputs. From 2013 Hydros Draft Memo: "DRAFT Results of Preliminary Model Run of Selective Withdrawal in Gross Reservoir"

Operation of the project would essentially eliminate the small amount of warming that now occurs in late summer. By reducing summer temperatures and delaying the annual maximum compared to current conditions, operation of the project would further erode the seasonal pattern of temperature variation. The predicted impact is significant because it would contribute to an existing impairment. The impact could be greater with the Environmental Pool[2] because it would increase the volume of the reservoir. The Environmental Pool was not included in the modeling.

The Applicant has evaluated several engineering mitigation options based on a selective withdrawal concept, as discussed in the Division's Rationale document. One design scenario involving installation of a multi-level outlet works (MLOW) was selected for modeling. Results of the modeling show that the MLOW could fully mitigate the temperature impact predicted for the project (Figure 4). In addition, release temperatures with the MLOW would get warmer sooner and stay warm for more days than is the case today.

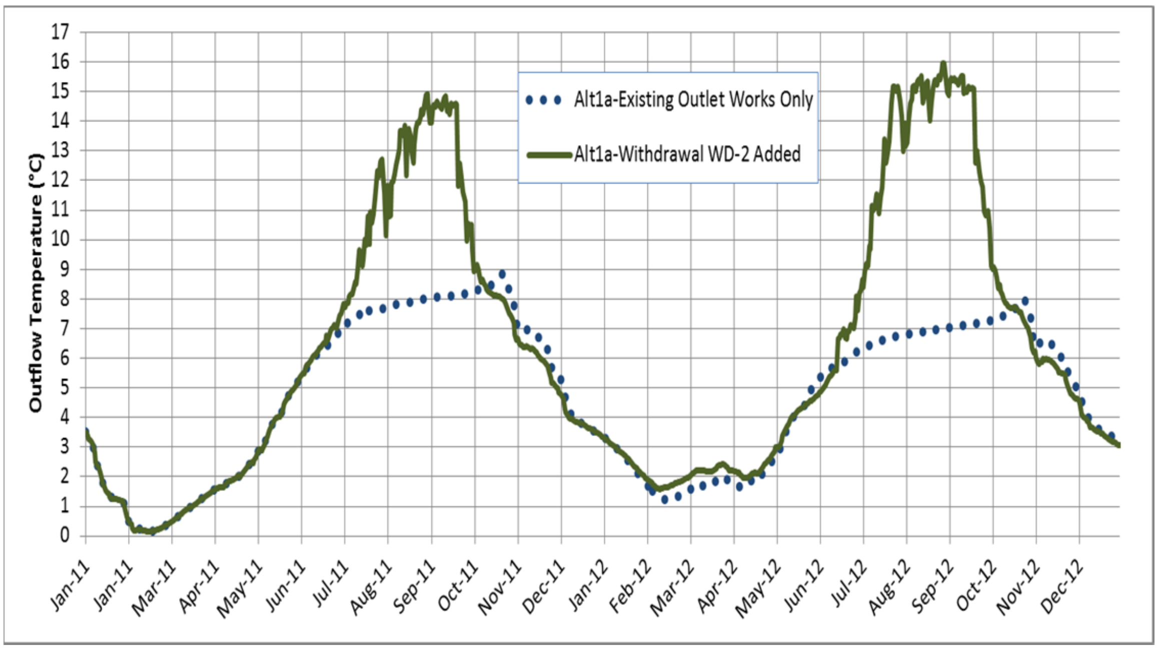

Figure 4. Simulated Gross Reservoir Outflow Temperatures for Alt1a With and Without Selective Withdrawal. From 2013 Hydros Draft Memo: "DRAFT Results of Preliminary Model Run of Selective Withdrawal in Gross Reservoir"

The comparison of current conditions (before) to future conditions with a multi-level outlet (after) can be sharpened by modifying[3] the original figures, as shown in the following two graphs. The first graph shows before-and-after with 1971 (Figure 5); Alt-1A is included for reference. The second graph shows the same comparison for 1972 (Figure 6). The two graphs suggest that the multi-level outlet could serve as both direct mitigation and enhancement, at least when hydrologic conditions are similar to those of 1971 and 1972. Maximum temperatures would be warmer than current conditions and would extend the time of warmer temperatures, although in neither case would a pre-impoundment temperature regime be restored. Operation of

[2] See the Rationale for a description of the Environmental Pool

[3] The original graphs had slight differences in time and temperature scales that were adjusted by re-sizing the figures.

the project with the MLOW would increase the degree-days by 176 in the 1971 scenario and 400 in 1972.

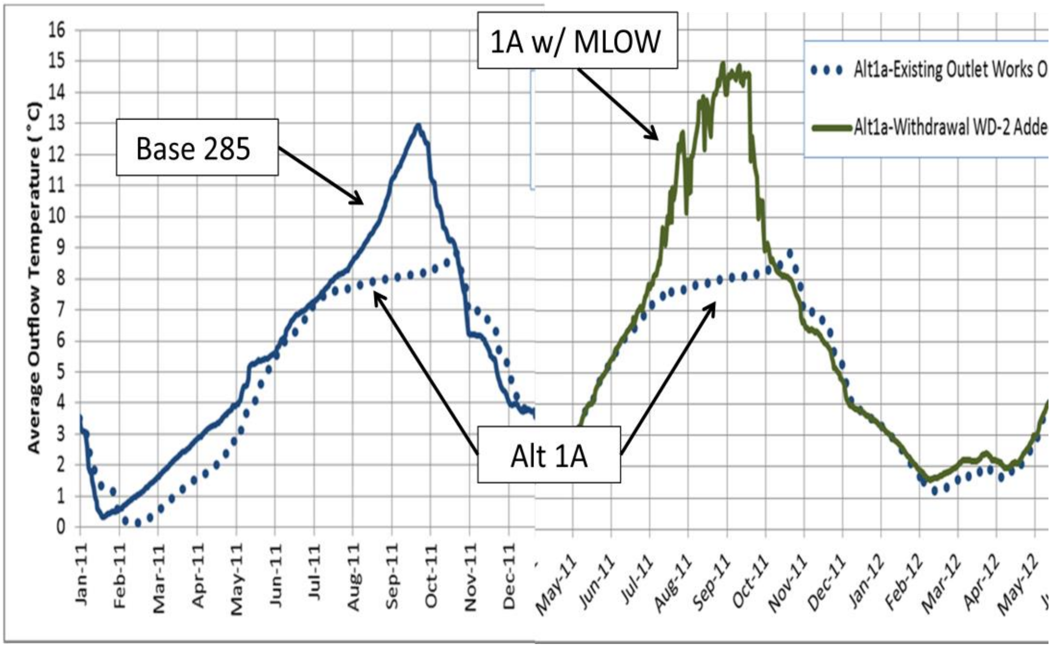

Figure 5. Comparison of outflow temperatures modeled with 1971 hydrology for current conditions (Base 285; left panel of graph) and project (Alt-1A w/MLOW; right panel of graph) plus multi-level outlet. Predictions without the MLOW are shown as dashed line on both panels. Composite of Figure 3 and Figure 4.

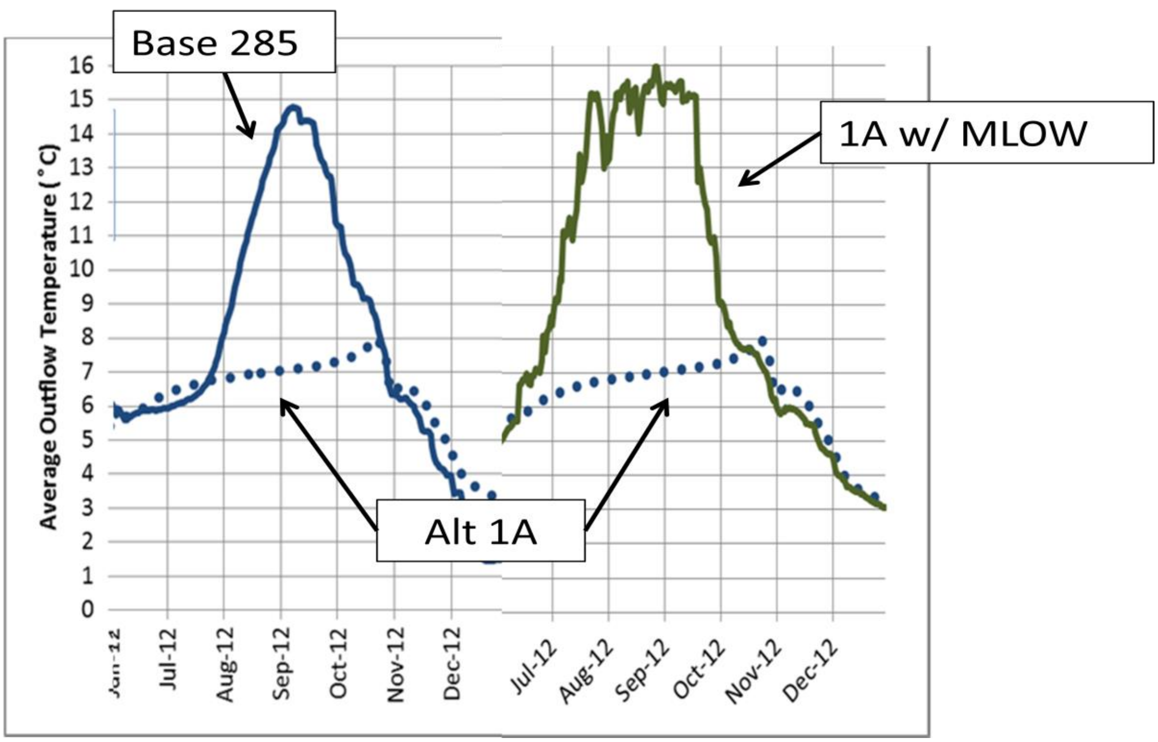

Figure 6. Comparison of outflow temperatures modeled with 1972 hydrology for current conditions (Base 285; left panel of graph) and project (Alt-1A w/MLOW; right panel of graph) plus multi-level outlet. Predictions without the MLOW are shown

as dashed line on both panels. Composite of Figure 3 and Figure 4.

Summary

With respect to the narrative standard, it is clear that temperature in South Boulder Creek below Gross Reservoir no longer shows a normal seasonal pattern, and operation of the project will further erode that pattern. However, this is only part of the information required to decide how this issue affects certification. Conclusions about conditions and the significance determination are presented in the Rationale document.