CCAMP is providing potential contractors with the following section from the Central Coast's Cooperative Monitoring Program (CMP) 5-year evaluation, as context for Task 3. Power Analysis.

This is an example power analysis developed for a monitoring program with a design and objectives similar to CCAMP. This document is provided to illustrate the general approach, level of rigor, and types of questions we are interested in addressing. While our program differs in some specifics, we are ultimately seeking a comparable assessment tailored to our monitoring design, including evaluation of sampling frequency and the ability to detect meaningful trends in priority analytes. Please consider this as a reference, not a template, and feel free to suggest alternative or improved analytical approaches based on your expertise.

Monitoring Program Efficiency

An assessment of monitoring efficiency should consider whether the program is progressing adequately toward its intermediate and long-term objectives and whether program resources are appropriately allocated to best achieve those objectives. The benefits of considering modifications to monitoring include making more program resources available to support achieving those objectives through efforts other than monthly monitoring. For example, shifting resources (e.g., time and money) from monitoring well established problems or water quality characteristics to monitoring or outreach focused on identification or evaluation of solutions, or on evaluating potential new areas of concern. There are a number of specific alternative uses of budget currently allocated to monitoring that could provide larger benefits and progress toward CMP objectives, including:

- Increased outreach, education, and management that has the potential to increase the rate of water quality improvement.
- Additional targeted monitoring focused on identifying more specific causes of toxicity or other water quality problems.
- Evaluation of which management and farming practice alternatives result in the most water quality improvement.
- Statistical analysis to characterize other environmental factors that affect variations in water quality (e.g., rain, stream flows, site-specific factors, etc.). Potential benefits include reducing unexplained variability and improving the CMP's statistical ability to detect and characterize trends, and identifying water bodies or conditions for more focused investigation.
- Additional "real-time" or "continuous" monitoring to characterize short-term variability in selected parameters of concern (which could also potentially contribute to increased statistical ability to detect trends).

Power to Detect Trends

The ability of the CMP to meet the objective of detecting future long-term trends in water quality was evaluated using statistical power analysis. Statistical power is defined as the probability that a statistical procedure will detect a significant difference at a specified confidence level. In other words, it is the ability to detect a trend if one exists. Power analysis is a method used to determine the minimum effects (or differences) detectable by a specific statistical test or procedure. In this case power analysis is used to predict the probability that a trends analysis will detect a statistically significant trend in CMP monitoring data, given an assumed level of improvement in water quality over a given period of time.

Although the results of the trend analyses presented previously in this report are based on a non-parametric statistical method, the following power analysis was based on standard parametric regression. Although parametric regression methods require additional assumptions about the data structure and distribution, power analysis for parametric regression provides the significant advantage of explicitly considering the magnitude of the trend (i.e., the rate of change) and the length of the time period to be evaluated. Both of these factors are important considerations in evaluating and optimizing the effectiveness of monitoring and other CMP program elements.

The ability of power analysis to predict a statistically significant trend in water quality is dependent primarily on the following factors:

- the variability (noise) in the data,
- the number of data points ("sample size") available,
- the magnitude of water quality changes to be achieved by the management efforts,
- other significant effects on water quality (such as increased development), and
- the statistical criteria applied to the analysis.

High data variability and low numbers of data points both serve to limit the statistical power of trends analysis. The statistical power is also lower when the actual water quality trend over time is small relative to the variability of the data. Other significant influences on water quality, such as climatic trends, increased population or the effects of other regulations beyond the scope of the Ag Waiver, may serve to mask or enhance water quality improvements achieved by the program. Such effects are difficult to predict and account for in the trend analysis; the power analysis may therefore over- or underestimate the significance of a trend attributable to the Ag Waiver. Finally, the application of more or less stringent statistical criteria to the power analysis will affect whether the projected trend is considered to be statistically significant.

It is possible to directly increase the effective statistical power of monitoring data in several ways. In the context of the CMP, variability of the monitoring data that is unrelated to program objectives is controlled by selecting sites and parameters with a minimum of non-agricultural influences. Variability unrelated to trends can also be reduced by modeling effects of other factors to "explain" causes of the variance. Since statistical power to detect trends is also a direct function of sample size and magnitude of the trend, power can also be increased by collecting more samples (i.e., increasing frequency), by increasing the length of the monitoring period, or by increasing the rate of change (e.g., by increasing management, outreach, and education efforts, assuming these result in water quality change). This last option would also speed progress toward the Ag Waiver objective of improving water quality.

In the context of evaluating the effectiveness of the CMP, the effect to be evaluated is the percent change in water quality characteristics resulting from continued implementation of the Waiver over time. The following parameters were used as inputs to the power analysis:

- The statistical confidence level for the power analyses was set at 95%.
- Sample size was evaluated at monitoring frequencies of up to 12 monitoring events per year.
- A period of up to 20 years of monitoring was set as the term of implementation and evaluation of the CMP's power to detect trends.
- Monitoring was assumed to continue at the core sites for each monitored event.
- Data variability was characterized by standard deviations of the water quality data for each parameter and site.

The principal underlying assumptions of the power analysis are as follows:

- the data are approximately log-normally distributed,
- the change in concentrations evolves exponentially over time, and
- observations from individual monitoring locations and events can be treated as independent data.

The assumption of an exponential change in water quality over time was based on the typically log-normal distribution of water quality concentration data in general, and a consistent annual percent change in quality over time. Although this assumption cannot be confirmed using statistical methods prior to collecting the data, the power analysis was found to be relatively insensitive to changes in the assumed pattern of water quality improvement because an exponential change is nearly linear for the time frame and percent changes evaluated (Figure 17).

The analysis was also based on an assumption that samples would be uniformly distributed over the monitoring period (i.e. the same number of samples would be collected every year).

Power analysis can solve for any of the possible input variables (statistical power, confidence level, sample size, independent and covariate variability, magnitude of trend) when given estimates of the other inputs. For the purpose of this evaluation, the power analysis was set up to estimate the sample sizes needed to detect trends of improvement in water quality from 10% to 50%. That is, the power analysis solved for the following question: Assuming a certain change in water quality over a 20 year period (for example, a 30% decrease in nitrate concentrations), how many samples should be collected per year to have at least an 80% chance to detect a trend at a statistically significant level (in this case, at a 95% confidence level)? A statistical power (the probability of detecting the trend) of 80% is considered to be fairly high for comparisons involving variable environmental data. For this analysis, a statistical power of 80% was considered to indicate that trends in monitoring data could be reliably detected over a monitoring period of 5, 10, or 20 years.

The primary limitation of this type of analysis is that additional data may change the error parameters of the trend regression or underlying data, and therefore change the power to detect trends. However, additional data generally allow for development of better models of water quality and provide better characterization of the factors responsible for variability in runoff quality data. Even models as simple as seasonal averages can provide substantial additional statistical power. Because statistical models of water quality data can provide additional statistical power by reducing unexplained variability, the results of this power analysis can be considered a conservative estimate of the statistical power of the CMP to detect trends in water quality.

Results of the Power analysis

The results of statistical power analyses are summarized in Table 10. The basic findings of the power analyses for sample sizes needed to detect trends can be summarized as follows:

- The high variability of nutrient parameters and chlorophyll-a substantially limit the ability of the CMP to detect trends in these data. At a monitoring frequency of 12 times per year, a 50% percent reduction in ammonia, nitrate, orthophosphate and chlorophyll over 5 years can reliably be detected at fewer than 10% of CMP sites. A 50% percent reduction in orthophosphate over 10 years can reliably be detected in approximately 25% of sites at a monitoring frequency of 12 times per year. Reductions of 30% over 20 years can reliably be detected at 75-100% of sites for all four of these parameters at a monitoring frequency of 6 times per year. Trends of 10% or less cannot reliably be detected using simple regression methods, even at a frequency of 12 times per year over a 20-year monitoring period.
- Turbidity also exhibits relatively high variability that limits the power of trend analyses. Even at a monitoring frequency of 12 times per year, a 50% percent reduction in turbidity over 5 or 10 years can be reliably detected at fewer than 10% of CMP sites. Over a 20 year period, a 30% percent reduction in turbidity could be reliably detected at about 90% of sites at a monitoring frequency of 12 times per year, and at 50% of sites at a monitoring frequency of 6 times per year. Over a 20 year period, a 50% percent reduction in turbidity could be reliably detected at nearly 100% of sites with a monitoring frequency of 5 times per year
- Variability of conductivity, salinity, and TDS data is lower than for nutrient parameters and turbidity, and the ability to detect trends is consequently better. For the purpose of the power analysis, changes up to 30% were considered an optimistic upper limit to achievable reductions. At a monitoring frequency of 12 times per year, a 30% percent reduction can reliably be detected at about 40% of CMP sites over 5 years. Over monitoring periods of 10 and 20 years, a 30% reduction could reliably be detected at more than 50% of sites by monitoring at reduced frequencies of 8 or fewer times per year. Reductions as low as 10% can reliably be detected at more than 75% of sites by monitoring at reduced frequencies of 6 or fewer times per year over 20 years, or at 40% of sites by monitoring at frequencies of 12 times per year over 10 years.
- Dissolved oxygen data are about half as variable as conductivity data. Because of the variety of other environmental factors that control oxygen concentrations, increases of 10% were evaluated as a reasonable upper limit to achievable improvements. At a monitoring frequency of 12 times per year, a 10% percent

increase could reliably be detected at fewer than 10% of CMP sites over 5 years. Over a monitoring period of 10 years, a 10% increase could reliably be detected at about 25% of sites by continuing monitoring at frequencies of 12 times per year. Over a 20 year period, a 10% percent increase in dissolved oxygen could be reliably detected at more than 90% of sites with a monitoring frequency of 6 times per year.

- pH is the least variable of the parameters monitored, and is also one of the parameters that is most often influenced by factors other than agricultural activities. Changes of 10% were considered an upper limit for the purpose of the power analysis. Because of the low variability, changes of 10% over 5 years would be detected at 100% of sites at a monitoring frequency of 12 times per year, and over 10 years, could reliably be detected at all sites at reduced monitoring frequencies of ~7 times per year. Changes of 10% over 20 years, would be detected at 100% of sites at a monitoring frequency of less than 6 events per year.
- Pesticides and aquatic toxicity were not explicitly evaluated using power analysis. To date, pesticides have been infrequently monitored by the CMP, and most pesticides were not detected at ay sites. Of the few pesticides that were detected, only one (diazinon) was detected in more than 40% of samples. The small data set, sparse data and low detection rates make the pesticide data unsuitable for a robust power analysis. However, it can reasonably be assumed that variability in pesticide concentrations would typically be fairly high and that ability to detect trends would be no better than for nutrients. While the toxicity data set is larger and is not limited by non-detected results, toxicity data are fundamentally different from concentration data. Average responses for survival for fish and invertebrates or growth for algae at individual sites are less important than frequency of significant toxicity. In any case, reductions in the underlying sources and causes of toxicity are expected to be more efficient measures of the ability of management efforts progress toward CMP objectives.

One overall conclusion to be drawn from these analyses is that significant trends even as large as 50% would be detected at only a low percentage of sites over a 5 year period due the high variability of the data. This is based on power analysis of simple linear regression analyses for trends, but is also supported by the results of non-parametric analysis presented above. However, the ability to detect and characterize trends could be improved by considering other sources of variability in the analyses, including flows, weather conditions, and site-specific factors. A multi-factor trend analysis such as multiple linear regression or analysis of covariance (ANCOVA) could reduce unexplained variability and allow grouping of similar sites to increase statistical power.

Frequency of monitoring

On a qualitative level, the CMP has already conducted monitoring sufficient to characterize baseline conditions, variability, and water quality concerns at the 50 sites and 37 water bodies that currently comprise core monitoring. On a quantitative level, it is difficult to define an objective criterion for “adequate” characterization. In a regulatory context, identification of water quality concerns could be considered completed after only a few samples to confirm elevated concentrations of nitrate, or an unacceptable frequency of toxicity. The confidence in estimates of average conditions are dependent on data variability, but can be improved by collecting and analyzing more samples. However, the benefit of increasing the sample size decreases substantially after about 40 samples, and most of the benefit is derived with the first 20 samples. After 50 or 60 samples (approximately the size of the CMP data set for a core site), even large increases in the sample size provide only small increases in the confidence of the estimate of the mean. This is illustrated in Figure 18 with a power analysis curve for a hypothetical parameter with a standard deviation equal to the mean (e.g., a coefficient of variance of 1.0). The actual percentage increases are dependent on the coefficient of variance, but the pattern holds true for any parameter. In the context of program effectiveness, this means that the cost effectiveness and benefit of collecting additional samples to improve characterization of water quality decreases dramatically after about 40 samples. Another factor to consider is that water quality problems that are not apparent after 40-60 samples are unlikely to be identified by conducting more of the same type of sampling. If the CMP determines that additional locations or water bodies should be characterized, or if new parameters are monitored at existing locations, any of several possible modified strategies discussed below would provide sufficient characterization over a 5-year period.

Consideration of Alternate Monitoring Strategies

From 2005 through 2010, the CMP core monitoring strategy has been to conduct regular monthly sampling with the addition of 2 targeted storm events that substitute for the scheduled events in the months they occur. A total of twelve events were conducted per year. This strategy ensured adequate sampling of relatively infrequent storm events and other seasonally variable conditions of weather, agricultural activity, crop cycles, and in-stream flows. It has the advantage of being fairly unbiased, other than possibly over-representing rare storm conditions in the data set. The monitoring strategy has produced a large and robust data set that has met the core CMP objectives of characterizing conditions and identifying problems in agricultural areas, and provides a strong foundation for tracking improvements in water quality over time. The data have provided the basis for identifying problem areas for more targeted studies of sources, and information needed to provide meaningful outreach and feedback to growers.

Continuing the same core monitoring strategy will provide incremental increases in understanding of the water quality in the CMP region. The main drawback is that these incremental increases in the quality of characterization and improvement in understanding will be relatively small and will come at a high price compared to the benefits gained in the first 5 years of the CMP. Because the intermediate CMP objectives of characterizing status and identifying problems have largely been completed, it may make sense to consider shifting some of the program resources from routine monitoring to activities that may provide greater benefits in understanding and managing water quality problems. There will continue to be a need to monitor and track water quality improvements, so if such a shift in resources were to be considered, an alternate strategy for continued monitoring would need to be identified.

Several alternatives to the current strategy were considered in the interest of increased monitoring efficiency. These alternatives include a seasonally stratified strategy, reduced-frequency regular monitoring, and event-based monitoring. Each of these alternatives was evaluated on the premise that some decrease in monitoring frequency is reasonable and potentially desirable from the standpoint that this would free financial resources for efforts more directly related to improving water quality without reducing the CMP's ability to characterize water quality in agricultural areas:

- An example of a seasonally stratified sampling strategy would be to sample more frequently during seasons of greater variability (e.g., monthly during "wet season") and less frequently during periods of lower variability in water quality characteristics (e.g., semi-monthly during a defined "dry season"). Depending on how seasons are defined, this could reduce the sampling frequency to 7 or 8 events per year. Other definitions of "season" could include crop production cycles (e.g., planting, growing, harvest, pesticide applications), or flow regimes for monitored water bodies (e.g., high increasing flows, declining flows, stable flows, etc.).
- Reduced frequency regular monitoring (e.g., semi-monthly, quarterly, every six weeks, etc). This strategy retains the advantage of the current CMP approach in monitoring in that it is relatively unbiased and is straightforward to implement and manage. The only disadvantage is that a purely regular monitoring schedule may not adequately characterize importantant but relatively infrequent types of events such as storms and periods of high runoff or high flows. This risk increases as the frequency is reduced.
- Event-based monitoring: This alternative is designed to provide information about specific conditions or events that might not be efficiently characterized by a regular unbiased schedule. Examples of possible events of interest include storm events, certain infrequent hydrologic conditions (rising or declining hydrographs, or seasonal peak flows), and extreme weather conditions (high wind, extreme temperatures, heavy rains). The initial challenge with this strategy is identifying events or conditions that are likely to affect water quality and have some relevance to agricultural practices. There are several unavoidable risks to this strategy, however: (1) the targeted conditions will be over-represented and will bias the characterization of overall water quality, (2) the targeted conditions may not be very important in an annual context, and (3) other potentially important non-targeted conditions will be excluded. The number of samples collected per year would depend on the specific events selected, with a minimum and/or maximum number per year set by the program.

Various combinations of these strategies are also possible. The current CMP monitoring strategy is actually a hybrid of regular monitoring and seasonal stratified event-based monitoring, with the events of interest being wet season storm events. A simple modification of this strategy would be to incorporate some seasonal stratification by reducing monitoring frequency during the dry season when hydrological and weather variability is relatively low. This would avoid the primary disadvantages of a purely regular or event-based strategy, and maintain the advantage of being relatively unbiased. Perhaps more importantly, the data produced would be most consistent with the current data set and would allow unbiased tracking of changes in water quality over time. This modification would be simple to implement and would achieve the objective of allowing some monitoring resources to be shifted to other CMP objectives. If a four or five month "wet season" is designated, and sampling during the dry season is reduced to bi-monthly, there would be an overall reduction of 33% percent of total monitoring events. Total reduction in monitoring costs would be somewhat less if the same number and type of toxicity and bioassessment analyses were continued, as costs associated with these activities are much higher than for other parameters.

Conclusions and Recommendations

Based upon the metrics examined in this report, the CMP has been effectively and successfully implemented as required by the MRP for the Ag Waiver. Specific conclusions and recommendations are as follows.

- The CMP has been successfully implemented, and all monitoring and reporting requirements of the program through 2009 have been completed.
- The monitoring conducted for the CMP has exceeded the completeness requirements of the QAPP. The data produced by the CMP generally meets the requirements of the QAPP, and the overall high quality of the data is more than adequate to meet the objectives of the program.
- The CMP core monitoring conducted to date has allowed identification of specific water quality issues associated with agricultural activities. Focused Follow-up Monitoring has been conducted to further characterize problem areas and parameters, and to better understand sources of impairment. This information has been incorporated into outreach and education efforts, and has been used to provide specific directed feedback to growers in problem areas.
- The parameters monitored by the CMP to date have been appropriate to support progress toward achieving CMP objectives. Several potential changes in parameters were recommenced for consideration, including:
    - Changing Total Dissolved Solids (TDS) from a lab-analyzed parameter to a calculated parameter based upon field-measured Conductivity
    - Incorporating Total Suspended Solids (TSS) measurement (or calculation from field-measured Turbidity) to provide sediment loading data
    - Re-evaluating the approach to assessing aquatic algae, in which the only current fully quantitative measure is chlorophyll-a
    - Switching invertebrate and fish toxicity tests from chronic to acute durations, to better match episodic discharge patterns
    - Re-evaluating the approach to assessing fish toxicity, which is not as sensitive a parameter as invertebrate toxicity, and harder to interpret for sources
    - Conducting risk-based analysis of pesticide-related toxicants for improved focus and prioritization in toxicity-related followup monitoring