Appendix B-8

LAKE TAHOE RESTORATION PROJECTS
ESTIMATED DIRECT COSTS & KEY MILESTONE DATES

Project Name: Monitoring Water Quality with Remotely Sensed Data **Agency:** USGS-Sponsored NASA/JPL

Prepared by: Simon J. Hook **Phone:** 818-354-0974 **EIP #:** 627, 667

Identify estimated costs of eligible reimbursement expenses:

1. **Planning, Environmental Assessment and Research Costs** (specialist surveys, reports, monitoring, data collection, analysis, NEPA, etc.)	$		%
2. **Direct Labor (Payroll) to Perform the Project**	$	365,400.00	%
3. **Project Equipment** (tools, software, specialized equipment, etc.)	$	75,000.00	%
4. **Travel** (including per diem where official travel status required to carry out project, such as serve as COR, experts to review reports, etc.)	$	21,000.00	%
5. **Official Vehicle Use** (pro rata cost for use of Official Vehicles when required to carry out project)	$		%
6. **Cost of Contracts, Grants and/or Agreements to Perform the Project**	$	557,000.00	%
7. **Other Direct Costs** (direct labor for agency personnel to do project procurements; COR; PI; personnel assigned as NEPA lead; personnel assigned to review contracted surveys, designs/drawings, reports, etc.; project manager and/or project supervisor; and contracted costs for project manager and/or project supervisor if contracted separately	$	297,800.00	%
TOTAL*:	$	1,316,700.00	%

Estimated Key Milestone Dates:

Milestones/Deliverables:	Date:
Delivery of 1 year of data, with interpretation and report. Results will include data from Hydrorad.	**9/26/2005**
Delivery of 2 years of data, with interpretation and report. Results will include data from Hydrorad and Hydroscat	**9/26/2006**
Delivery of 3 years of data with interpretation and report	**9/26/2007**
Delivery of 5 years of data with interpretation and report	**9/26/2009**

Final Completion Date:	**9/26/2009**

COMMENTS:

NASA cost sheets are organized differently than SNLPA cost sheets and include an annual breakdown as well as total breakdown (NASA cost sheets are attached as pdf for your convenience). NASA direct costs [Mulitprogram Support (MPC) & Allocated Direct Charges (ADC), Facilities and Administrative Costs, Award Fee] were included with the "Other Direct Costs" in the SNPLA budget. In summary

FY2005

Labor: Scientist 0.27 out of 1 time; Engineer 0.18 time out of 1
Travel: 4 trips to Tahoe for 1 week, 2 people
Subcontracts: Subcontract to UCD
Equipment: Hydrorad optical sensor

FY2005

Labor: Scientist 0.27 time; Engineer 0.18 time
Travel: 4 trips to Tahoe for 1 week, 2 people
Subcontracts: Subcontract to UCD
Equipment: Hydroscat backscattering sensor

FY2006

Labor: Scientist 0.27 time; Engineer 0.18 time
Travel: 4 trips to Tahoe for 1 week, 2 people
Subcontracts: Subcontract to UCD
Equipment: Maintenance only

FY2007

Labor: Scientist 0.27 time; Engineer 0.18 time
Travel: 4 trips to Tahoe for 1 week, 2 people
Subcontracts: Subcontract to UCD
Equipment: Maintenance only

FY2008

Labor: Scientist 0.27 time; Engineer 0.18 time
Travel: 4 trips to Tahoe for 1 week, 2 people
Subcontracts: Subcontract to UCD
Equipment: Maintenance only

FY2009

Labor: Scientist 0.27 time; Engineer 0.18 time
Travel: 4 trips to Tahoe for 1 week, 2 people
Subcontracts: Subcontract to UCD
Equipment: Maintenance only

SCIENCE, RESEARCH & MONITORING
TAHOE PROJECT PROPOSAL

Project Name: Monitoring Water Quality with Remotely Sensed Data **EIP #** 627, 667

Lead Agency: NASA/JPL with USGS Partner

Contact: Dr Simon J. Hook
Phone Number: 818-354-0974
Email Address: simon.j.hook@jpl.nasa.gov

Threshold: Water Quality
Threshold Standard: WQ-1 (nearshore clarity), WQ-2 (pelagic clarity); WQ-3 (algal growth)

Total Project Cost: 1.31 M (5 years)
Round 6 Funding requested: $ 1.31 M
Is this a multi-year project? Yes

Project Description (Include a specific list of tasks and subtasks to be accomplished that will facilitate Basin agencies in writing a detailed scope of work):

Synthesize remotely sensed data and in-situ measurements to provide regular lake-wide assessments of changes in near shore and offshore water quality. Use these assessments to address the primary management question related to the Lake Clarity, Air Quality and Water Quality, namely *"Which factors (N, P and sediment/fine particles?), in what magnitudes, from which sources are causing the decline in the clarity of Lake Tahoe?"*

Task 1 – Acquire and make available to the Tahoe research community remotely sensed satellite data from the Advanced Spaceborne Thermal Emission and Reflectance Radiometer (ASTER), the Landsat Enhanced Thematic Mapper Plus (ETM+), the Moderate Resolution Imaging Spectrometer (MODIS) and the Advanced Along Track Scanning Radiometer (AATSR) over Lake Tahoe. MODIS data are available multiple times per day, AATSR data are available every 4 days and ASTER and ETM+ data are available every 16-days over Lake Tahoe. All data are available at no charge for scientific research except for ETM+ data which cost between $400 and $600 per scene. Dr Hook is a member of the NASA ETM+ science team. ETM+ data over Lake Tahoe are used by Hook for his work as an ETM+ science team member and will be made available to this project at no charge.

Task 2 – Process the data from ASTER and ETM+ to extract information on changes in near-shore clarity. Preliminary research by Hook has demonstrated that the point of lake bottom extinction can be derived from ASTER and ETM+ data and when combined with a high resolution digital elevation model used to determine the maximum penetration depth (MPD) around the lake. The MPD varies around the lake depending on changes in the amount of sediment and chlorophyll in the water and therefore provides a measure of near shore clarity. The MPD is also affected by changes in the bottom reflectance so care must be taken to correctly account for any changes in the reflectance of the bottom substrate, such as the change from areas dominated by sand to areas dominated by silt. As part of this it work it will be necessary to correct the satellite data for atmospheric effects in order to allow comparison between the data acquired on different days. The data will be atmospherically corrected using radiative transfer codes available at NASA/JPL. The results will also be compared with in-situ measurements, when they are available.

Task 3 – Deploy a Hydrorad (optical) sensor and a Hydroscat (backscattering) sensor on one of the four NASA buoys (Figure 1). The Hydrorad is a hyperspectral spectrometer that measures the change in the incoming solar radiance (light) at various depths. These data can then be used with measurements from the Hydroscat which provides information on optical backscattering to determine changes in the number/size of particles and chlorophyll in the lake on a near-real time basis. Information is available at multiple depths from optical collectors placed on a vertical boom suspended beneath the buoy. The costs for the Hydrorad and Hydroscat are included in the budgets for Year 1 and Year 2 respectively.

Task 4 – Augment the existing atmospheric samplers on the Tahoe buoys with Minivol Samplers. These samplers are available at no cost from the California Air Resources Board. They will provide the first air sampling data from the lake that is spatially distributed. Depending on the number available, they will be

deployed on a combination of the NASA and UCD buoys, and provide both N-S and E-W transects. Filter analysis will be performed by UCD.

Task 5 – Incorporate the near-real time data from the Hydrorad and Hydroscat with the other data in the NASA-UCD near real-time data network. This network already provides information on lake temperature and meteorological conditions every hour from the NASA and UCD buoys over the World Wide Web.

Task 6 – Develop algorithms for extracting water quality information from the remotely sensed data over deep water using the measurements from the Hydrorad and Hydroscat for calibration. This would include secchi disk depths, chlorophyll abundance etc.

Task 7 – Synthesize the data from all the sources to address the primary management question related to the Lake Clarity, Air Quality and Water Quality, namely "Which factors (N, P and sediment/fine particles?), in what magnitudes, from which sources are causing the decline in the clarity of Lake Tahoe?"

For Science & Research Projects briefly summarize the current state of knowledge of this subject matter:

The current understanding of the decline in water clarity at Lake Tahoe CA/NV is primarily based on the interpretation of data from two deep-water measurement sites maintained by UCD referred to as the Midlake and Index stations (Figure 1). Measurements are made at these sites approximately every 10 days from the UCD Research Vessel John leConte and include primary productivity, nutrient concentration (various forms of nitrogen and phosphorus), chlorophyll concentration, light penetration, temperature distribution and secchi disk transparency. These measurements provide a measure of what is happening on the lake but are lacking in both the temporal and spatial detail needed to be able to model and understand the changes taking place over the entire lake. For example, measurements made at the two sites provide little information are how nutrients and sediments are transported throughout the lake and the 10-day temporal sampling is insufficient to capture changes that take place on the scale of a few days, such as upwellings or storm events, which can have a profound effect on the lake clarity measured at these stations. Remotely sensed data has the potential to provide a synoptic overview of what is happening over the lake at a given instant in time which when coupled with in-situ data can provide lake-wide assessments of changes in both near-shore and offshore water quality.

Describe the purpose and need for the project: (Describe how this project will guide future management activities**.** This description should include a quantitative estimate of the anticipated gain in management information and describe how the research and/or monitoring project may inform the development and understanding of additional Key Management Questions (one page recommended)**:**

The purpose of this project is to utilize both in-situ and remotely sensed data to quantify the types and amount of particles entering Lake Tahoe from atmospheric deposition and river input and how these particles are then distributed and impact water quality. This project is needed in order to determine how particles are distributed over the entire lake and to identify changes taking place over shore time scales e.g. storm events, not captured with the existing measurements. The results will be used to answer the primary management question related to the Lake Clarity, Air Quality and Water Quality, namely *"Which factors (N, P and sediment/fine particles?), in what magnitudes, from which sources are causing the decline in the clarity of Lake Tahoe?"* Given this information it should be possible to develop effective management approaches to mitigate the decline in clarity at Lake Tahoe.

Within this primary question fourteen more specific questions have been identified by the Science Advisory Group and the EIP I Team responsible for Lake Tahoe. The research described in this proposal will help answer eight of the fourteen questions. The eight questions that will be addressed by this work are:

Q1.1. *What and where are the sources of these pollutants and in what quantities and relative contributions are they entering Lake Tahoe? (What are the watershed loadings? Within each watershed, what are the major sources?)*

– The remotely derived water quality maps and the in-situ measurements will provide information on what pollutants, in what quantities, are entering Lake Tahoe. The minivol samplers will provide information on the true atmospheric contribution to particle and nutrient loads.

Q1.2 What *is the linkage of human disturbance and nutrient loading to Lake Tahoe?*
– The near-shore clarity maps will provide information on the linkage between human disturbance and nutrient loading, as the spatial resolution will be sufficient to resolve contributions from all stream inflows and the intervening areas.

Q1.3 *What are baseline values for nutrient and sediment loading from Lake Tahoe watersheds?*
– The in situ water and atmospheric measurements will provide baseline values for nutrient and sediment loadings from the Lake Tahoe watersheds.

Q1.6 *How important are shoreline and benthic processes to the Lake's nutrient and sediment budgets?*
- The water quality maps, in-situ measurements and maps of lake circulation will provide information on the importance of shoreline and benthic processes to the Lake's nutrient and sediment budgets.

Q1.7 *What spatial and temporal factors affect the deposition of air pollutants to the lake and forest, and ultimately how do these pollutants contribute to lake clarity reduction?*
- The in-situ atmospheric samplers on the buoys coupled with underwater backscattering and optical sensors beneath the buoys will provide information on the spatial and temporal factors affecting the deposition of air pollutants to the lake, and ultimately how do these pollutants contribute to lake clarity reduction.

Q1.8 *What are the specific sources that contribute to atmospheric deposition of nutrients and sediment to the surface of Lake Tahoe?*
- The in-situ atmospheric samplers on the buoys will allow the identification of the specific sources of nutrients and sediments that are deposited from the atmosphere on the surface of the lake.

Q1.9 *How are air-borne pollutants transported and distributed throughout the basin?*
- The existing meteorological network will contribute to our understanding of how air-pollutants are transported through the basin, the specific pollutants will be captured with the air-samplers on the buoys.

Q1.13 *What are the limnological watershed and atmospheric processes that affect lake clarity and water quality?*
– The in-situ atmospheric samplers on the buoys coupled with underwater backscattering and optical sensors beneath the buoys will provide information on the spatial and temporal factors affecting the deposition of air pollutants to the lake, and ultimately how do these pollutants contribute to lake clarity reduction.

In all cases quantitative values for the various particles/pollutants will be provided from the in-situ measurements which will be used to calibrate the remotely sensed data. The remotely sensed data will provide an understanding of the lake processes operating on these particles/pollutants. Together this information will provide a 90% improvement in existing management information. This estimate based on the fact we know the processes exist but do not understand their impact on water quality.

Describe the goals and objective of the project (Describe Key Management Questions being addressed--Recommended 2-3 pages):

<u>1.Objectives: List the objectives of the proposed research being tested during the project, and briefly state why the intended research is important.</u>

The overall objective of the proposed research is to synthesize remotely sensed satellite data with in-situ measurements to develop a methodology for providing regular lake-wide assessments of changes in near shore and offshore water quality. This research is important to understand which factors e.g. sediment/fine particles, in what magnitudes, from which sources are causing the decline in the clarity and quality of Lake Tahoe. Five key objectives of this proposal are:

1. Develop the algorithms to derive the optical properties related to water quality from remotely sensed satellite data acquired over Lake Tahoe.
2. Couple the remotely derived optical properties with in-situ measurements to derive lake wide estimates of a variety of lake properties including turbidity, suspended sediment, chlorophyll, colored dissolved organic matter (CDOM), photosynthetically active radiation (PAR), temperature and inherent and apparent optical properties. [Satellite-sensor derived surface temperature maps are already being produced by NASA-UCD].
3. Incorporate the appropriate measurements in the NASA-UCD realtime data network accessible over the World Wide Web.
4. Synthesize the lake-wide assessments with other data (meteorological, atmospheric, biological) to identify how lake water quality is changing and what sources are causing the changes.
5. Provide the data to UCD for use in the Lake Tahoe Clarity model.

2.Approach: Outline the research design, methods, and techniques that you intend to use in meeting the objectives stated above.

Remote sensing has been used for monitoring water quality since the launch of the multi spectral scanner (MSS) on the first Earth Resources Technology Satellite-1 (ERTS-1), later renamed Landsat-1 in 1972. MSS passively scanned the surface of the Earth in several bands (wavelength intervals) and recorded an integrated spectral signature from the reflected portion of the solar and sky radiation that impinged upon the Earth. Several Landsats have been launched since 1972 and in 1984 the MSS instrument was replaced with the Thematic Mapper (TM). The TM instrument acquires data with spatial resolutions of 120 m or better, in seven spectral bands and has a temporal resolution (revisit time) of 16 days. At the same time that the Landsat satellites were being launched, other instruments were being flown with different spatial, spectral and temporal resolutions such as the Advanced Very High Resolution Radiometer (AVHRR). The AVHRR instrument has a spatial resolution of ~ 1km at nadir, fewer bands than Landsat and a much higher temporal resolution with data acquired over the same target at least once per day. The daily revisit afforded by AVHRR coupled with its 1 km spatial resolution was ideal for ocean studies and AVHRR data were rapidly adopted by the oceanographic community. Today AVHRR-like data are routinely used in oceanographic studies for measuring ocean productivity and predicting El Nino/La Nina events.

The early data from Landsat were less rapidly adopted by the limnological community because the Landsat spectral resolution was often insufficient to separate the more complex optical signature of inland water into its individual components. Inland water typically contains a much wider variety of organic and inorganic substances than deep ocean water, which requires higher spectral resolution data to resolve the various components. Further, the 16-day revisit time of Landsat (time between satellite overpasses) was often insufficient for assessing limnological processes such as upwellings. Although copies of the instruments flown on the early AVHRR and Landsat satellites continued to be flown through the nineties, there was little improvement in the available instrumentation until the launch of the first Earth Observing System (EOS) satellite Terra at the end of 1999. The EOS is a constellation of satellites with multiple instruments designed to monitor the Earth. The Terra spacecraft has several instruments including the Advanced Spaceborne Thermal Emission and Reflectance Radiometer (ASTER) and the Moderate Resolution Imaging Spectroradiometer (MODIS). At approximately the same time as the launch of Terra, the Europeans launched the ENVISAT satellite, which includes the Advanced Along Track Scanning Radiometer (AATSR) and the Medium Resolution Imaging Spectrometer (MERIS) and NASA launched the Enhanced Thematic Mapper plus (ETM+). ETM+ is a next generation Thematic mapper like sensor. Together these instruments provide a very powerful instrument suite for studying changes in inland water quality.

A key goal of the EOS is to monitor the Earth as an integrated system and to be able to detect change. In order to achieve this goal, special emphasis was placed on ensuring the instruments were carefully calibrated pre-flight and then monitored in-flight so any changes that were detected were due to changes on Earth, rather changes in the satellite instruments. The ideal target for monitoring the stability of instruments that measure surface temperature is a target that is at a known temperature and whose surface temperature is homogenous. The most suitable natural target is a water body since its temperature is homogenous compared with land. The water body needs to be large so instruments with different spatial resolutions can be validated, and should be located at high altitude to minimize the effect of the atmosphere on the surface radiation received at the satellite. For these reasons, coupled with the excellent research infrastructure developed by UCD, Lake Tahoe was selected by Hook and his colleagues to validate the thermal infrared (temperature) measurements made by ASTER, ETM+, MODIS and AATSR. A consequence of this work was the installation of a variety of monitoring equipment on Lake Tahoe (4 large 2-3 m research buoys) coupled with the increased acquisition of satellite data over the lake (Figure 1). Each research buoy costs approximately $100,000 and makes a variety of measurements including surface skin and bulk temperature and a range of meteorological equipments providing wind speed, wind direction, air temperature, relative humidity and net radiation. The development and deployment of the research buoys has been entirely funded by NASA. The data from the buoys has been made available to the Tahoe Research Community at no cost.

The availability of a wide variety of remotely sensed data coupled with an in-situ data network provides an ideal infrastructure that can be enhanced with the additional in-situ equipment to make the critical measurements required to address many of the key management questions related to Lake Clarity, Air Quality and Water Quality identified by the Science Advisory Group and the EIP I Team responsible for Lake Tahoe.

In order to address the 5 key objectives of the proposal the first step is to add a backscattering and an optical sensor to one of the NASA Tahoe buoys (Figure 1), most likely TB3. The backscattering sensor (Hydroscat-6) is a multispectral sensor, which measures both backscattering and fluorescence. Backscattering is measured at six wavelengths and fluorescence is measured at two wavelengths. The backscattering data can be used to derive the two fundamental inherent optical properties (IOP's) absorption and the volume scattering which in turn can be used to find the total backscatter function, backscattering coefficient and beam attenuation coefficient. Instruments that derive IOP's utilize an internal calibrated light source and reject changes in ambient light. IOP's depend only on the water and other substances that are dissolved or suspended in it. Fluorescence is also considered to be an IOP although it is usually treated separately from the fundamental properties mentioned above. Together the backscattering and fluorescence data can be used to obtain quantitative estimates of turbidity, suspended sediment concentrations, chlorophyll concentrations and colored dissolved organic matter. The optical sensor is a spectrometer that can measure three radiometric quantities (plane irradiance, scalar irradiance, radiance), over a broad spectrum and with high resolution. These data can be used to determine the photosynthetically active radiation (PAR), remote sensing reflectance and diffuse attenuation. The diffuse attenuation is an apparent optical property (AOP) because it depends not only on the water properties but also on the sun angle, sky conditions, depth, and shadowing by the measurement platform or the measuring instrument itself. The optical sensor utilizes several optical collectors which measure the radiation beneath and above the surface. The above surface measurement is the same as that made by the satellite sensor, except, the satellite data are acquired from a greater distance away. The in-situ data can be used to calibrate the satellite data and then the satellite data can be used to derive equivalent quantities to those measured by the buoy sensors elsewhere on the lake.

In addition to the optical and backscattering sensor, a variety of atmospheric monitoring equipment would be added to each buoy this would include deposition samplers as a well as minivol air samplers. A recent

study by the California ARB that relied primarily on shore-based measurements to study atmospheric deposition was unable to significantly narrow the uncertainty of the atmospheric loads. They concluded that on-lake measurements were the best way to proceed in the future (A. Lashgari, pers. comm.). By locating air samplers and traditional wet bucket samplers on the buoys, we will obtain spatial information for both types of collectors.

The high sampling frequency of all the measurements allows lake changes related to dynamic events such as wind storms or upwellings to be quantified as well as more gradual changes over time.

The data from all the sensors that provide realtime readouts will be incorporated into the existing data streams and made available ever few minutes over the World Wide Web using the NASA-UCD realtime data network.

The second step is to use the field data to calibrate the satellite data. Incorporated in the satellite sensor measurements are contributions from the atmosphere. These atmospheric contributions need to be removed in order to derive the surface measurement, equivalent to that made by the in-situ sensors. Any atmospheric contributions can be removed by using a radiative transfer model which models the radiative contribution from the atmosphere and removes it from the data or the satellite data can be corrected directly to the field data e.g. by regression. Both approaches will be used in this study; the model approach has the advantage it can be applied elsewhere without in-situ data, the in-situ approach has the advantage that any biases present in the data that would not be corrected by the model, will be removed when the satellite data are adjusted to match the insitu data. The necessary computing/modeling infrastructure is already available at NASA/JPL.

Once the satellite data have been corrected they can be used to provide lake-wide information on changes in water quality, including information on lake circulation. For example data from ASTER can be used to produce a near-shore clarity map. ASTER has three imaging bands in the visible-infrared region 15 m spatial resolution. If an image is constructed from the data from the shortest wavelength band, which has the maximum depth penetration, the bottom of the lake is seen as a fringe around the edge of the lake eventually disappearing in deep water. The maximum bottom depth that can be observed depends on how clear the water is or the near shore clarity. If these data are combined with a digital elevation model, the maximum penetration depth (MPD) around the lake can be determined (Figure 2). The MPD provides a measure of the near shore clarity of the lake. Clearly the amount of penetration varies around the lake depending on the clarity at any part of the lake. The other wavelengths can then be added (which have different penetration depths) to provide a map of how the penetration varies over this near shore region to provide a clarity map. The clarity map represents a snapshot of the clarity over the entire lake for an instant in time from a single satellite acquisition. Since ASTER and Landsat have a temporal resolution of 16 days, these data could be used to monitor changes in the near-shore clarity every 16 days provided the weather is clear.

A clarity map such as the one in Figure 2 is very useful but care must be taken not to over-interpret such a map which is dependant on a variety factors. For example, the MPD will depend on the state of the surface of the lake, the amount of incoming radiation, and any variation in the bottom reflectance or the properties of the atmosphere above the lake at the time of data acquisition. All of these factors must be carefully taken into account if the data are to be used in a quantitative manner. One of the most common approaches for addressing these concerns is to periodically make in situ measurements of near shore clarity at the same time as the satellite acquisition to obtain the benefits of an in situ measurement, which may include a profile of clarity change with depth, coupled with the synoptic view provided by the satellite data. In-situ data will be incorporated when they are available.

Satellite data have also been used to measure deep water clarity and water quality. Again the satellite data must be corrected for changes in the atmosphere. Measuring deep water clarity/quality can be difficult because the amount of change observed in the data is small, however, since equivalent measurements are made at the buoys with the Hydrorad and Hydroscat, regressions of selected ratios of spectral radiances to the in situ measurements can be used to derive both the deep water clarity/quality and changes in chlorophyll concentrations. These approaches work well in the oceans where the water is optically simple but often do not work well in inland water which is optically more complex unless there are in situ measurements. Fortunately the concentrations of chlorophyll and other components at Lake Tahoe are similar to the oceans so these approaches should perform well at Lake Tahoe.

The satellite data can also be used to monitor circulation in the lake together with current speeds. These data are important because they enable the processes taking place in the lake to be treated as a system rather than isolated changes which cannot be easily related to changes taking place elsewhere. Figure 3 shows a surface temperature image derived from a thermal infrared satellite image. The image shows a large upwelling where strong winds from the west have caused cold water to upwell on the west and be transported over to the east. This deep cold water is nutrient rich and affects both benthic and shoreline processes. Recent work using the satellite data has indicated these upwellings typically travel west to east with the cold upwelled water being funneled into a jet with a relatively narrow N-S extent that travels from the west to the east of the lake (Figure 3). These jets provide regular pulses of nutrient-rich cold water to the center part of the eastern shore and may explain the higher than typical rates of periphyton growth observed at certain locations on the east shore.

Lastly all the various datasets will be synthesized in order to provide a coherent interpretation of what is changing where and by how much. These synthesizes will be made available to UCD for incorporation into the Lake Tahoe Clarity model.

3. Identify the Key Management Questions being addressed and/or how the project may inform the development and understanding of additional Key Management Questions.

The Science Advisory Group and the EIP I Team responsible for Lake Tahoe has identified a set of key management questions that need to be answered in order to correctly characterize and understand the changes taking place at Lake Tahoe relating to Lake Clarity, Air Quality and Water Quality. These are:

1. Which factors (N, P and sediment/fine particles?), in what magnitudes, from which sources are causing the decline in the clarity of Lake Tahoe?

1.1 What and where are the sources of these pollutants and in what quantities and relative contributions are they entering Lake Tahoe? (What are the watershed loadings? Within each watershed, what are the major sources?)

1.2 What is the linkage of human disturbance and nutrient loading to Lake Tahoe?

1.3 What are baseline values for nutrient and sediment loading from Lake Tahoe watersheds?

1.4 What chemical forms of phosphorus (P) are biologically available; how does biogeochemical cycling of P influences its transport, fate, and bioavailability?

1.5 How is lake food web structure related to water clarity?

1.6 How important are shoreline and benthic processes to the Lake's nutrient and sediment budgets?

1.7 What spatial and temporal factors affect the deposition of air pollutants to the lake and forest, and ultimately how do these pollutants contribute to lake clarity reduction?

1.8 What are the specific sources that contribute to atmospheric deposition of nutrients and sediment to the surface of Lake Tahoe?

1.9 How are air-borne pollutants transported and distributed throughout the basin?

1.10 What is the fate of air pollution produced in the basin?
1.11 What is the relative contribution of in-basin versus out of basin pollutant sources at Lake Tahoe?
1.12 How reliable are the preliminary estimates of phosphorus and nitrogen loading to Lake Tahoe?
1.13 What are the limnological watershed and atmospheric processes that affect lake clarity and water quality?
1.14 What pollution is produced by vehicle emissions and from road surfaces and how do they affect lake clarity?

This overall study will help answer the primary management question related to the Lake Clarity, Air Quality and Water Quality, that is *"Which factors (N, P and sediment/fine particles?), in what magnitudes, from which sources are causing the decline in the clarity of Lake Tahoe?"* The specific answers that will be provided to eight of the fourteen sub questions are:

Q1.1 – The remotely derived water quality maps and the in-situ measurements will provide information on what pollutants in what quantities are entering Lake Tahoe.
Q1.2 – The near-shore clarity maps will provide information on the linkage between human disturbance and nutrient loading.
Q1.3 – The in situ water and atmospheric measurements will provide baseline values for nutrient and sediment loadings from the Lake Tahoe watersheds.
Q1.6 – The water quality maps, in-situ measurements and maps of lake circulation will provide information on the importance of shoreline and benthic processes to the Lake's nutrient and sediment budgets.
Q1.7 – The in-situ atmospheric samplers on the buoys coupled with underwater backscattering and optical sensors beneath the buoys will provide information on the spatial and temporal factors affecting the deposition of air pollutants to the lake, and ultimately how do these pollutants contribute to lake clarity reduction.
Q1.8 - The in-situ atmospheric samplers on the buoys will allow the identification of the specific sources of nutrients and sediments that are deposited from the atmosphere on the surface of the lake.
Q1.9 – The meteorological data from the buoys will provide information on how air-borne pollutants are transported and distributed throughout the basin.
Q1.13 – The water quality maps coupled with the in situ data will provide information on the limnological watershed and atmospheric processes that affect lake clarity and water quality

Describe the anticipated project accomplishments (provide a qualitative description of how the results of each task will reduce the uncertainty of predicting the behavior of the environmental processes being studied and may lead to solutions to environmental problems (one page recommended) to improve the agencies' abilities to protect the environment and achieve the management objectives.):

Task 1 – Acquire and make available to the Tahoe research community remotely sensed satellite data.

Remotely sensed data provide a snapshot of the current state of Lake Tahoe and the surrounding environment. They are useful for many studies from evaluating forests health to monitoring changes in lake clarity. Remotely sensed data require large amounts of storage together with special expertise to process the data to extract the critical information. This task will allow the remotely sensed data to be accessible by all researchers together with the necessary expertise on how to use the data to maximum effect. The remotely sensed data will also provide a record of the effectiveness of certain remediation efforts.

Task 2 – Process ASTER and ETM+ data to extract information on changes in near-shore clarity.

The results from this task will provide a quantitative estimate of lake clarity in the near shore environment and how it is changing over time. To be most effective these data should be coupled with in-situ measurements which are typically available less frequently but provide information on changes in specific particles as well as profiles of change.

Task 3 – Deploy a Hydrorad (optical) sensor and a Hydroscat (backscattering) sensor on one of the four NASA buoys.

This task will provide quantitative estimates of water properties including absorption, volume scattering, total backscatter function, backscattering coefficient and beam attenuation coefficient, plane irradiance, scalar irradiance, radiance. These data can then be used to obtain quantitative estimates of turbidity, suspended sediment concentrations, photosynthetically active radiation (PAR) chlorophyll concentrations and colored dissolved organic matter.

Task 4 – Augment the existing atmospheric samplers on the Tahoe buoys with Minivol air samplers and wet bucket deposition samplers.

This task will provide the only measurements to date of the spatially varying loads of nutrients and fine particles to the lake. All previous estimates have either been based on one lake sampling site, or most recently, a modeled estimate based on land measurements.

Task 5 – Incorporate the near-real time data from the Tasks 3 and 4 in the NASA-UCD near real-time data network. The NASA-UCD realtime network already provides information on lake temperature and meteorological conditions every hour over the World Wide Web. These data are made available to *all* researchers, and are currently used by the National Weather Service and US Coast Guard. By making these data available to all parties, any interested party can look for solutions to the various environmental challenges facing Lake Tahoe not just the UCD-NASA group.

Task 6 – Develop algorithms for extracting water quality information from the remotely sensed data over deep water.
In order to effectively manage Lake Tahoe and the surrounding environment it is necessary to both *characterize* and *understand* the changes taking place. Current research is focused on characterizing the changes take place rather than understanding the underlying processes responsible for the change. The remotely sensed data provide a means for studying the changes takes place over the entire lake at the same time rather than changes at a couple of points on the lake. These data are invaluable for understanding how a process is occurring in a lake, for example how many and how extensive are the upwellings which drive circulation, from what depths does the upwelled water come from, are the upwelled waters nutrient rich or nutrient poor etc.

Task 7 – Synthesize the data from all the sources to address the primary management question related to the Lake Clarity, Air Quality and Water Quality, namely *"Which factors (N, P and sediment/fine particles?), in what magnitudes, from which sources are causing the decline in the clarity of Lake Tahoe?"*
This is the ultimate goal of the project and should improve the agencies' abilities to protect the environment and achieve the management objectives.

Describe the "readiness" of this project to move forward (environmental documentation, etc.; for projects that are a continuation of previous projects, provide a quantitative measure of the actual gain in management information (one to two paragraphs recommended):

The success of the project described above depends on having the necessary infrastructure to deploy the equipment as well as facilities and expertise to process the remotely sensed data. Fortunately the primary infrastructure, the buoys and data network are already in place. Each of the 3 m buoys costs ~$100,000 fully equipped and NASA has provided that equipment for the satellite validation research undertaken by Hook. The additional equipment would be added to the existing infrastructure. This is also true for the realtime network which is already in place and would be augmented with the additional data. UCD and NASA together have the necessary equipment and expertise to deploy the new optical and backscattering sensors. It should be noted all the buoys have the necessary permits. Five different agencies had to provide permits and the process took over 1.5 years to complete.

Both institutes also have significant computing capabilities for conducting remote sensing research. This includes software licenses for a variety of data analysis packages such as ENVI (Environment for the Visualization of Images) as well as over 150 custom programs written in a variety of languages specifically for image processing.

Describe potential partnerships for this project and include supporting documentation.

The US Geological Survey, along with the TRPA and the Tahoe Research Group have been the principle partners in the Lake Tahoe Interagency Monitoring Program since its inception in 1979. A key component of LTIMP has been to monitor lake water quality, as well as stream water quality. Any effort to improve our ability to effectively monitor water clarity on a whole-lake or synoptic basis is best viewed as an enhancement of the LTIMP mission. While the three principle partners, and especially the USGS and TRG, are charged with collection and evaluation of the LTIMP monitoring data, virtually all the agencies use the clarity data. The benefit to being able to accurately measure clarity over the entire lake will be of invaluable use to our partners involved in current and future management plans (e.g. US Forest Service, States of California and Nevada and other projects being under taken by the USGS including the building of the Tahoe Decision Support System).

Describe how this project will guide future management activities:

This project will help guide future management activities by providing regular lake-wide assessments of changes in near shore and offshore water quality. These data can be used to address the primary management question related to the Lake Clarity, Air Quality and Water Quality, namely *"Which factors (N, P and sediment/fine particles?), in what magnitudes, from which sources are causing the decline in the clarity of Lake Tahoe?"*

In addition the data will provide a reference point from which the effectiveness of certain remediation efforts on lake clarity can be assessed. For example, if the nutrient input to the lake from rivers is reduced how long does it take before any reductions manifest themselves at MidLake.

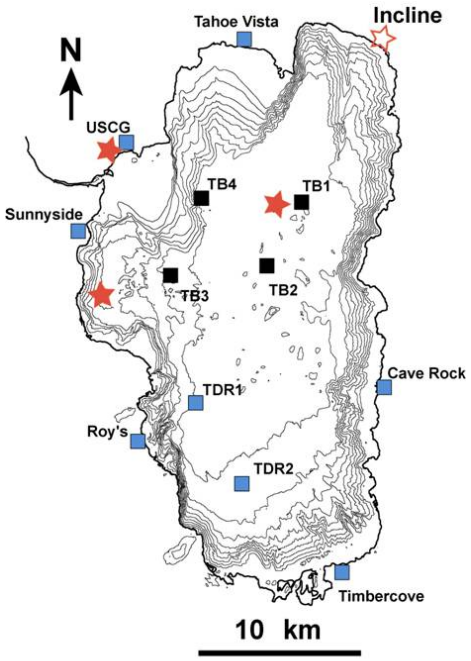

Figure 1 Equipment location map. TB1-TB4 are NASA buoys. TDR1 and TDR2 are UCD buoys. Midlake

station is red star by TB1, Index station is red star south of Sunnyside. Solid boxes around lake are onshore meteorological stations.

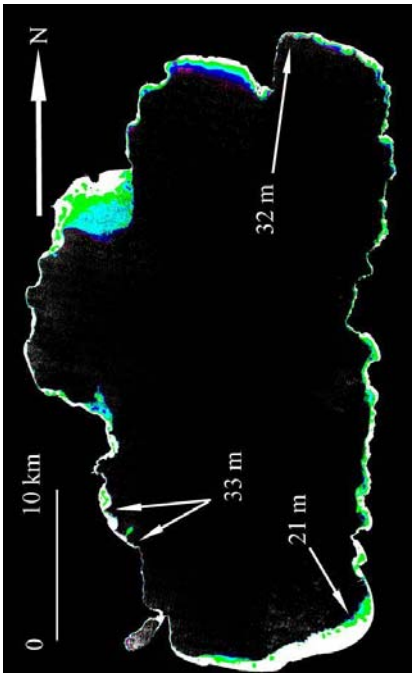

Figure 2 Near-shore clarity map derived from ASTER data. Different colors represent different maximum penetration depths. Greatest depth obtained from west shore in south (33 m).

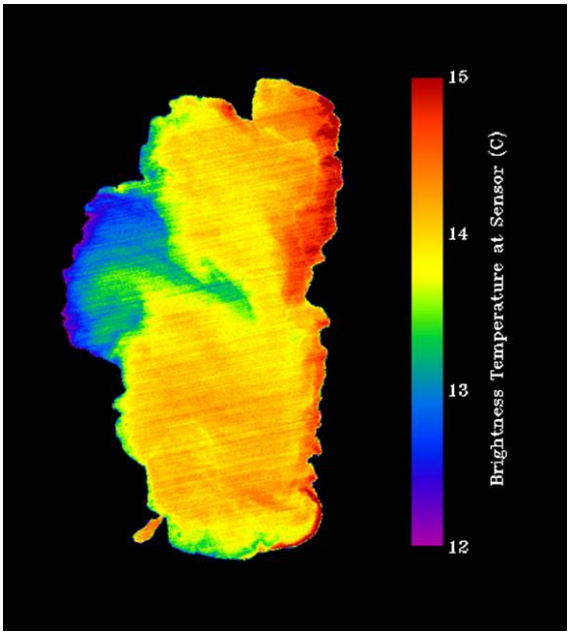

Figure 3 Surface temperature map derived form ASTER data showing strong upwelling of cold (blue) water from the west traveling east.