# Working Groups — Water Quality and Land Use/Land Cover

In the second part of the workshop, attendees were divided into two concurrent working groups, focusing on issues pertaining to water quality and land use/land cover, respectively. These discussions culminated in a plenary session designed to address how remote sensing could be applied to the goals and obligations articulated in the C2K agreement. The group reached a consensus that there are several existing technologies that can be used now, and several others currently under development that have potential applications. Several of the managers attending the workshop were already aware of some remote sensing capabilities that could be directed at their needs. However, there is still no systematic integration of remote sensing with managers' needs and data and information from remote sensing are not used extensively to further management goals. The following sections summarize discussions of the work groups and make recommendations for linking of new technologies to management needs.

## Water Quality Working Group

Participants agreed that remote sensing of water quality has direct applicability to broad goals of the C2K Agreement, such as:

- Achieve and maintain the water quality necessary to support the aquatic living resources of the Bay and its tributaries and to protect human health;

- Preserve, protect, and restore those habitats and natural areas that are vital to the survival and diversity of the living resources of the Bay and its rivers;

and to more specific goals, such as:

- Recommit to the existing goal of protecting and restoring 114,000 acres of submerged aquatic vegetation (SAV). By 2002, revise SAV restoration goals and strategies to reflect historic abundance, measured as acreage and density from the 1930s to the present. The revised goals will include specific levels of water clarity that are to be met in 2010. Strategies to achieve these goals will address water clarity, water quality, and bottom disturbance. By 2002, implement a strategy to accelerate protection and restoration of SAV beds in areas of critical importance to the Bay's living resources;

- By 2001, define the water quality conditions necessary to protect aquatic living resources and then assign load reductions for nitrogen and phosphorus to each major tributary;

- Using a process parallel to that established for nutrients to determine the sediment load reductions necessary to achieve the water quality goal;

- By 2002, complete a public process to develop and begin implementation of revised Tributary Strategies to achieve and maintain the assigned loading goals;

- By 2003, the jurisdictions with tidal waters will use their best efforts to adopt new or revised water quality standards consistent with the defined water quality conditions. Once adopted by the jurisdictions, the Environmental Protection Agency will work expeditiously to review the new or revised standards, which will then be used as the basis for removing the Bay and its tidal rivers from the list of impaired waters;

- By 2003, work with the Susquehanna River Basin Commission and others to adopt and begin implementing strategies that prevent the loss of the sediment retention capabilities of the lower Susquehanna River dams.

The water quality working group began its discussions by focusing on potential solutions to existing problems, emphasizing the emerging CBP criteria for *chl-a*, water clarity, and DO. Measures of light attenuation, primarily from the perspective of habitat suitability for SAV, were deemed very important. Managers Batiuk and Magnien praised the utility of simple measures of light attenuation, such as Secchi depth, to estimate $K_{par}$ on a Bay-wide basis. Secchi depth, a measure of the depth to which a white disk can be seen from the service, has been used to define light penetration in the main stem of the Bay and major tributaries for many years by calibrating readings with more sophisticated measurements from submersible irradiance sensors. There is a mismatch, however, between the sites where these measurements have been made and prospective SAV habitat. Several participants noted that shallow areas, representing historical and current SAV habitat, have not been sampled adequately by the set of monitoring stations now used to measure *in-situ* optical properties.

Participants discussed the potential to use remote sensing methods to address this deficiency. Past work using data from Landsat and AVHRR gave estimates of total suspended solids (TSS) from satellite data, but these products were primarily used to track sediment plumes in water bodies with strong land to sea gradients of TSS, such as Delaware Bay. The estimates of $K_{par}$ from these measurements had a stated accuracy of + 0.1 $m^{-1}$, perhaps sufficient to map optical conditions coarsely for large systems, but it is not clear that data from these sources would be useful for shallow waters. The spatial resolutions of Landsat and AVHRR are probably not suitable to characterize optical properties of SAV habitat, although retrievals of $K_{par}$ from both instruments deserve testing as they might be useful to estimate $K_{par}$ for the main stem of the Bay and large tributaries. K-products are now available from SeaWiFS and MODIS that permit estimates of $K_{par}$, but the accuracy of these products for specific regions of the Bay still needs to be ascertained.

Continuous underway mapping of optical properties described by Gallegos could directly address this issue and more fully characterize the light environment for SAV. Several advantages accompany the measurements he described. These include collection of optical data near SAV beds, areas that are not generally sampled by monitoring cruises and that for various reasons (bottom reflectance, adjacency to land) are inaccessible to remote sensing. Local processes such as resuspension of bottom sediment, patchy plankton distributions, and inputs of SPM and CDOM from tributaries, affect *in-situ* optical properties on relatively small scales, amenable to measurements using instruments such as the ac-9. Two water quality criteria for the Bay, *chl-a* and water clarity, are retrieved by continuous underway measurements and linked to optical properties quantitatively, enabling a detailed examination of attainment of these criteria in SAV habitat in the context of light availability. This is an important step that has ramifications for the prediction of habitat suitability on an ecosystem scale.

Several speakers (Boicourt, Gallegos, Perry) addressed the usefulness of continuous underway sampling as a way to obtain data of high spatial resolution for a variety of water quality characteristics in key locations. Deployment of towed or autonomous bodies instrumented with sensors to measure *chl-a* fluorescence and other optical properties (SCANFISH™, Seaglider) could significantly augment spatial coverage from traditional sampling, and in the case of the optical package used by Gallegos, access shallow water. The Severn River example is another such application wherein a small boat equipped to make underway measurements continuously revealed spatial variability not resolved in the monitoring program. The limitation of this approach is temporal coverage. Instruments such as SCAN-FISH™ and Seaglider are more useful as mapping tools and require repeated deployment to generate a time-series. Supplementing data collection of this type with moored instruments would help achieve the goal to obtain data at more frequent intervals at sentinel locations and to address event-scale changes.

The working group also discussed the use of new technologies to quantify SAV in the Bay. The long-term monitoring of SAV abundance presently relies on photogrammetric data acquired annually from an altitude of 12,500′ using light aircraft. Several participants addressed the limitations of this approach, principal among them the lack of synoptic coverage. Flights occur over a period of several months at different stages in the plants' annual grow-out. As a historical record the data are consistent, but the lack of synoptic coverage lessens their usefulness to track changes of SAV distributions that are manifested locally and may not be captured by the existing approach. Other technologies include high-resolution commercial satellite data (IKONOS, Space Imaging, Inc.). IKONOS is a space-borne instrument that provides multispectral data at high spatial resolution. Unfortunately, the data are expensive and the quality is highly variable, depending on the level of processing purchased. For the purpose of characterizing interannual differences of SAV coverage, it is not clear that the existing SAV monitoring program would be improved by obtaining multispectral satellite data. Paired sampling using aerial photography and satellite data, however, should occur to determine advantages realized with new technologies.

Participants explored issues involved with *in-situ* and remote sensing of *chl-a*, one of the most important indicators of water quality in coastal and marine ecosystems and one that is highly responsive to nutrient loading, discussing *in-situ* measurements of *chl-a* from buoys, towed bodies, AUVs, and from instrument arrays on small boats. Several themes emerged: (1) fixed-station monitoring on a monthly to twice-monthly basis is very useful to provide context and addresses seasonal and interannual variability of *chl-a* quite successfully; (2) temporal variability of *chl-a* on scales from days to weeks is not well captured by this approach; (3) spatial variability of *chl-a* on scales from tens of meters to kilometers is not quantified by this approach; (4) high frequency measurements of *chl-a* using fluorometers on buoys can augment the frequency of sampling at individual moorings; (5) underway sampling from boats and ships, or with instrumented towed bodies and AUVs, offer approaches that increase spatial resolution.

Remote sensing approaches to measure *chl-a* were discussed in detail. Ocean color instruments have been flown on light aircraft in the Bay for 15 years, giving high spatial and temporal resolution for *chl-a* and SST. These data have direct applicability to assess compliance with water quality "criteria" as *chl-a*. Satellite data from several sources have also gained utility in the last three years. SeaWiFS data for 1998-present have been validated for the mesohaline and polyhaline regions of the Bay. The improved retrieval of *chl-a* from SeaWiFS has been made possible using semi-analytical models that use local optical data as inputs, rather than radiance-ratio algorithms used in bulk processing. These locally tuned semi-analytical models are now being implemented with the processing of SeaWiFS and MODIS data and coupled to new approaches for atmospheric correction, resulting in accurate retrievals of *chl-a* for a significant part of the main stem Bay.

The advantages of satellite data are frequent, synoptic coverage. For example, there are data from about 14-18 monitoring cruises per year, depending on the year, 20-30 flights per year, and ~100 cloud-free SeaWiFS scenes per year for the Bay. The spatial resolution is also much improved by remote sensing of *chl-a*. Airborne sensors generate products with an along-track resolution of ~5 to 50 m and satellite sensors have pixel sizes ~1 km or finer. Two current instruments, Terra MODIS and Aqua MODIS, offer improvements to SeaWiFS with a number of additional products of direct interest to managers and scientists, including data from multiple passes per day, K and PP products, additional bands in the red region of the spectrum that may extend the useful range of recoveries to high *chl-a* in blooms, and bands at finer spatial resolution that are promising for highly dynamic coastal waters.

Working group participants also discussed novel approaches that may be useful to monitor water quality. Some have been used in Chesapeake Bay and other systems as a part of ongoing research initiatives. These include moored $NO_3^-$ sensors such as those deployed in the Choptank River as part of the CBOS and CISNet programs (Boicourt), the IFI used for tracking the Mississippi River plume in the Gulf of Mexico (Campbell), automated vertical profilers described for Puget Sound (Perry), and the Dataflow system described for the Severn River (Magnien). These approaches extend the products we can generate using *in-situ* and remote sensing approaches.

Water quality criteria for *chl-a*, light attenuation, and DO provided an important context for the working group's discussions. One element of monitoring that has not received sufficient attention is the extent to which fixed-station measurements provide the spatial and temporal resolution needed to determine if a specific tributary or region is in compliance with water quality criteria. Participants discussed the strengths and limitations of spatial "interpolation" of monitoring data to address compliance, i.e., how well does the current station grid serve the need to quantify water quality properties when spatially explicit solutions are "derived" rather than measured. Current attention is being given to interpolation methods applied to several data sources, including fixed-station shipboard sampling, underway sampling, and remote sensing from aircraft and satellite instruments to ascertain if more highly resolved data are useful to address compliance. This is an important use of the data from a management perspective.

Other aspects of sampling the Bay fall more in the "research" arena and have value to managers in explaining processes, but less clear links to their immediate needs. An important example would be SCANFISH™ surveys conducted in the LMER TIES program from 1995 through 2000 (Boicourt and Roman). The results have provided highly resolved data on salinity, temperature, density structure, *chl-a*, zooplankton, and DO for dynamic regions of the Bay. The data Perry presented for Monterey Bay also demonstrate the rapid changes in distributions of key properties that demonstrate fixed-station sampling may be inadequate to characterize an ecosystem. Some small-scale, rapid changes are relevant to both scientists and managers, however, as discussed for examples of ephemeral "events" including harmful algal blooms (HABs) and pulsed nutrient inputs.

## Land Use/Land Cover Working Group

Specific goals of the C2K Agreement in the areas of wetlands, forests, land conservation, development, and transportation have potential remote sensing applications. These include:

### *Wetlands*

- By 2010, achieve a net resource gain by restoring 25,000 acres of tidal and non-tidal wetlands. To do this, we commit to achieve and maintain an average restoration rate of 2,500 acres per year basin wide by 2005 and beyond. We will evaluate our success in 2005;
- Provide information and assistance to local governments and community groups for the development and implementation of wetlands preservation plans as a component of a locally-based integrated watershed management plan;
- Establish a goal of implementing the wetlands plan component in 25 percent of the land area of each state's Bay watershed by 2010. The plans would preserve key wetlands while addressing surrounding land use so as to preserve wetland functions;
- Evaluate the potential impact of climate change on the Chesapeake Bay watershed, particularly with respect to its wetlands, and consider potential management options.

### *Forests*

- By 2002, ensure that measures are in place to meet our riparian forest buffer restoration goal of 2,010 miles by 2010;
- By 2003, establish a new goal to expand buffer mileage. Conserve existing forests along all streams and shorelines. Promote the expansion and connection of contiguous forests through conservation easements, greenways, purchase and other land conservation mechanisms.

### *Land Conservation*

- By 2001, complete an assessment of the Bay's resource lands including forests and farms, emphasizing their role in the protection of water quality and critical habitats, as well as cultural and economic viability;
- Permanently preserve from development 20 percent of the land area in the watershed by 2010.

### *Development, Redevelopment, and Revitalization*

- By 2012, reduce the rate of harmful sprawl development of forest and agricultural land in the Chesapeake Bay watershed by 30 percent measured as an average over five years from the baseline of 1992-1997, with measures and progress reported regularly to the Chesapeake Executive Council.

## *Transportation*

- By 2002, the signatory jurisdictions will promote coordination of transportation and land use planning to encourage compact, mixed-use development patterns, revitalization in existing communities and transportation strategies that minimize adverse effects on the Bay and its tributaries.

The discussion of land use and land cover detailed a number of advances in the use of remote sensing data that have clear applicability to these C2K goals. Fortunately, there are tremendous regional capabilities in the academic and government communities (i.e., the RESAC at the University of Maryland). A number of analyses are currently being pursued that include land use and land cover mapping with a variety of airborne and satellite sensors. Both the RESAC and UMCES have developed strong working relationships with state and federal partners.

Specific C2K mandates and goals that pertain to land use and land cover are implicitly associated with remote sensing data and information. A clear consensus developed in the working group to support more effective application of land use and land cover data to track changes in the Bay's watershed. Most analyses to date have used data and information for specific periods of time separated by a decade or more, a temporal resolution that is probably inadequate to track changes. Verification of riparian buffers, agricultural uses, and urban expansion are examples of changes that cannot be detected with occasional analysis of Landsat data alone. A recurrent request we heard expressed was to obtain Landsat ETM+ imagery for the Bay's watershed annually, and to develop the capability at CBP to analyze these data and track changes.

Participants in the working group agreed that another essential role of remote sensing is to follow changes in land use and land cover that have ramifications for water quality. Recurrent analyses of Landsat data should, therefore, be coupled to efforts in total manageable daily loads (TMDL) and in modeling runoff. We reached a consensus that it is essential to test model predictions with observations, yet this has often been done inadequately or not at all, particularly for water quality projections and despite the availability of a strong monitoring program. Model scenarios need to include "what if" approaches wherein impacts of specific actions on nutrient inputs are assessed, i.e., adding buffer strips to particular locations, removing agricultural fields, upgrading wastewater treatment facilities. The endpoints of such efforts should include assessments of the impacts of specific management practices on key properties, such as *chl-a* and SAV, thereby quantifying ecosystem responses to specific actions.

An explicit goal of the C2K Agreement is the permanent preservation from development of 20% of the land area in the watershed. Agriculture, as opposed to sprawl or increased impervious substrate, might be viewed as "preservation," despite the fact that agriculture can have a significant negative impact on the Bay by increasing nutrient runoff. Preservation, in this case, might be viewed as negative, absent improvements to control nutrient runoff from this land use. On the other hand, if the alternative was development or sprawl, it might be viewed as positive step.

The amount of impervious cover in the watershed has a direct bearing on the movement of pollutants into receiving waters of the estuary. Participants agreed that quantifying impervious cover is essential to gauge inputs of nutrients and pollutants from urban and suburban areas to streams, rivers, and the Bay. Remote sensing has proven valuable to identify and quantify impervious cover and is thereby relevant to language of the C2K Agreement on development, redevelopment, and revitalization. We need analytical tools that will allow local governments to conduct watershed-based assessments that aid in making informed decisions about development, transportation, and growth that entail limits to impervious surfaces. Regular Landsat ETM+ acquisitions are applicable to quantify impervious surfaces and could be augmented with higher resolution imagery from IKONOS to improve the validation and interpretation of the coarser resolution ETM+ imagery. Participants suggested that a good approach for CBP would be to focus on priority urban watersheds identified in the C2K Agreement, such as the Anacostia River, Baltimore Harbor, and Elizabeth River, which are designed to be models for urban river restoration in the basin.

The C2K Agreement stipulates both retention and restoration of wetlands, accentuating the need to use the "best tools" to quantify their extent, composition, and health. Participants discussed several current examples of how airborne and satellite instruments are used to map wetlands, distinguish plant types, and detect plant stress in the flora. The use of multispectral and hyperspectral instruments provide greatly improved resolution in UV, visible, and IR regions of the spectrum, offering the potential to distinguish healthy from unhealthy plants in wetlands. An essential tool to project the long-term stability of wetlands is the accurate determination of elevation using LIDAR. This may be impractical for the entirety of Bay wetlands, but quantifying the elevations of intertidal wetlands relative to mean sea level would be a reasonable beginning to assess marsh stability. High-resolution DEMs can be constructed for this purpose and also have applicability to local and regional issues such as flooding. C2K also commits to promoting the expansion and connection of contiguous forests through conservation easements, greenways, etc. Remote sensing imagery is essential to quantify the distribution of forest and its fragmentation, but in a watershed such as that of Chesapeake Bay, it is essential to differentiate actual forests from similar land covers, i.e., forest strips around housing developments, whose functions may differ significantly in terms of nutrient sequestration.

## Recommendation Steps

Here, we restate the specific recommendations emerging from the workshop that we presented at the beginning of the Report, and develop specific steps relevant to each recommendation as bullets.

- **Expand and Better Integrate *In-situ* Technologies.** *In-situ* technologies have been in use by the scientific community for many years and a variety of high-resolution data products are currently available. Expanding the use of a range of methodologies, from continuous underway sampling to deploying new sensors on buoys, will greatly enhance monitoring capabilities, particularly in tributaries and the shallow reaches of the estuary.

  - Expand the use of high resolution, continuous underway sampling *in-situ* to augment long-term, fixed-station monitoring, particularly in areas of the Bay, such as shoals and tributaries, that are not well sampled in the core monitoring program;

  - Integrate high-resolution data from *in-situ* "mapping" with contextual data provided by long-term monitoring to improve the usefulness of both data streams;

  - Add capabilities to *in-situ* sampling with new sensors that can be deployed on buoys, towed bodies, and AUVs, particularly to measure *chl-a*, optical properties, and nutrients;

  - Increase the use of high-resolution data from the research community that has developed CBOS, SCANFISH™, Dataflow, and underway optical mapping;

  - Use *in-situ* and remote sensing data to gauge improvements of water quality associated with mandated nutrient reductions in concert with model projections by validating the models with actual data;

- **Expand the Use of Aircraft and Satellite-based Sensors.** Remote sensing from aircraft and satellite platforms offers great promise to expand synoptic measurements and to examine under-studied regions of the Bay. Partnerships with key agencies (NASA and NOAA) and better utilization of multiple data products, many available at no cost, should be pursued.

  - Make better use of airborne remote sensing of *chl-a* and SST for the Bay in the context of criteria attainment and compliance;

  - Deploy airborne sensors for key properties in regions of the Bay that are under-sampled at present, such as the tributaries;

  - Develop partnerships with scientists in academics and government agencies to facilitate the use of satellite data on *chl-a*, K, SST, and PP for the Bay;

  - Increase awareness of the multiple products that are available at no cost from the GSFC DAAC in Maryland from new earth observing satellite instruments;

  - Pursue partnerships with operational and research agencies, such as NOAA and NASA, to facilitate the delivery of calibrated and validated products on water quality to managers and decision-makers;

- **Increase the Use of Landsat Imagery.** Acquisition of Landsat images (e.g., Enhanced Thematic Mapper (ETM) and finer scale commercial imagery) for the Bay watershed, and increased use of processed imagery for specific applications will improve our understanding of changes on several spatial and temporal scales.

  - Acquire Landsat ETM+ imagery consisting of 22 scenes for the Bay watershed at least every 2-3 years to analyze land cover in the context of C2K Agreement preservation clauses;

  - Facilitate the use of processed Landsat ETM+ imagery for a variety of specific applications, e.g., to quantify forest areas, riparian buffers, and nutrient inputs;

  - Selectively purchase commercial imagery of high resolution to augment coarser Landsat imagery to improve land cover characterizations for representative sites;

  - Improve and expand wetlands mapping: A variety of existing and new technologies can be used to examine and predict changes in wetlands. Both LIDAR altimetry and multi- and hyperspectral imaging should be pursued.

  - Improve mapping of tidal wetlands to include fine-scale topography essential to predict the future course of the wetlands;

  - Obtain higher resolution elevation data using LIDAR to improve predictions of the movement of water and solutes, particularly on local to regional scales where existing DEMs are too coarse;

  - Expand the use of multispectral and hyperspectral radiometry for assessing the health of wetlands.

## Postscript

Since this workshop convened in Annapolis in early 2002, there has been significant movement towards developing water quality criteria for Chesapeake Bay. Despite this progress, data from *in-situ* and remote sensing are not used to an appreciable extent by managers to assess water quality. We are now poised to use these technologies to gauge compliance with recently established criteria and strongly urge the expanded use data and information from routine monitoring with those from new technologies.

Sea Grant

Scientific & Technical Advisory Committee
Chesapeake Bay Program

**Present Status and Future Trends in Estuarine and Watershed Monitoring Using Remote Sensing Technology (Satellite, Airborne, *In-Situ*)**

7-8 January 2002
Duke of Gloucester Room, Maryland Inn, 16 Church Circle, Annapolis, Maryland

*Purpose:* This two-day workshop highlights the present and future capabilities of remote sensing technology, including satellite, airborne, and *in-situ* sensors, to assess water quality and land-use changes in estuarine environments, with specific application to the regulatory responsibilities of the Chesapeake Bay Program. It centers on presentations by experts in three thematic areas, and on a round-table discussion between managers and scientists on specific data needs to address the 2000 Chesapeake Bay Agreement (C2K).

*Rationale:* The 2000 STAC review of the Chesapeake Bay Program's monitoring strategy recommended that the Program embrace remote sensing technologies to replace or supplement existing monitoring efforts for water quality parameters. The existing monitoring program is presently under review and will likely be revamped. This workshop will provide timely information on future technologies for land-use and water quality monitoring towards existing and new regulations in the C2K Agreement.

*Agenda:*

**Day 1 - 7 January 2002 (Monday)**

**09:00 Welcome remarks and introductions - Jonathan Phinney, (ASLO and STAC)** (since relocated)

Each panel will consist of three panelists who will each speak for 20-25 minutes with 5-10 minutes for questions. There will be 15 minutes at the end of each panel for summary statements, if needed. The moderator will provide a brief overview of the topic in addition to a presentation on a specific topic.

**09:15 -10:45 Panel I – Observing water quality changes in bays and tributaries with *in-situ* sensors**
*Bill Boicourt,* Moderator (Horn Point Laboratory, University of Maryland Center for Environmental Science)
*Chuck Gallegos* (Smithsonian Estuarine Research Center, Smithsonian Institution)
*Mary Jane Perry* (Darling Marine Center, University of Maine)
*Rich Batiuk* (Chesapeake Bay Program, US Environmental Protection Agency)

**10:45 – 11:15 Break**

**11:15 – 12:45 Panel II – Detecting water quality changes remotely with airborne and satellite sensors**

*Larry Harding,* Moderator (Maryland Sea Grant and Horn Point Laboratory, University of Maryland Center for Environmental Science)
*Janet Campbell* (Ocean Process Analysis Lab, University of New Hampshire)
*Blanche Meeson* (Goddard Space Flight Center, NASA) (temporarily relocated)
*Rob Magnien* (Dept. of Natural Resources, State of Maryland) (since relocated)

**12:45 – 13:45 Lunch**

**13:45 – 15:15 Panel III- Detecting land-use changes with airborne and satellite sensors**

*Steve Prince,* Moderator (Department of Geography, University of Maryland, College Park)
*Tom Fisher* (Horn Point Laboratory, University of Maryland Center for Environmental Science)
*Jim Morris* (Dept. of Biological Sciences, University of South Carolina)
*Todd Schroeder* (Canaan Valley Institute, West Virginia) (since relocated)

**15:15 – 15:45 Break**

**15:45 – 17:00 General discussion and question-and-answer session**

**Day 2 – 8 January 2002 (Tuesday)**

**9:00 General discussion with all participants**

The focus of the discussion is on how to integrate the existing sensor technologies into the C2K and other regulatory mandates from the management agencies.

*Don Boesch,* Moderator (University of Maryland Center for Environmental Science)

**12:00-13:00 Lunch**

**13:00-15:00 Wrap-up discussion and summary**

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