SOUTHERN CALIFORNIA COASTAL WATER RESEARCH PROJECT AUTHORITY

THEMATIC RESEARCH PLAN

FOR

INFORMATION TECHNOLOGY AND VISUALIZATION

Last Revised June 2015

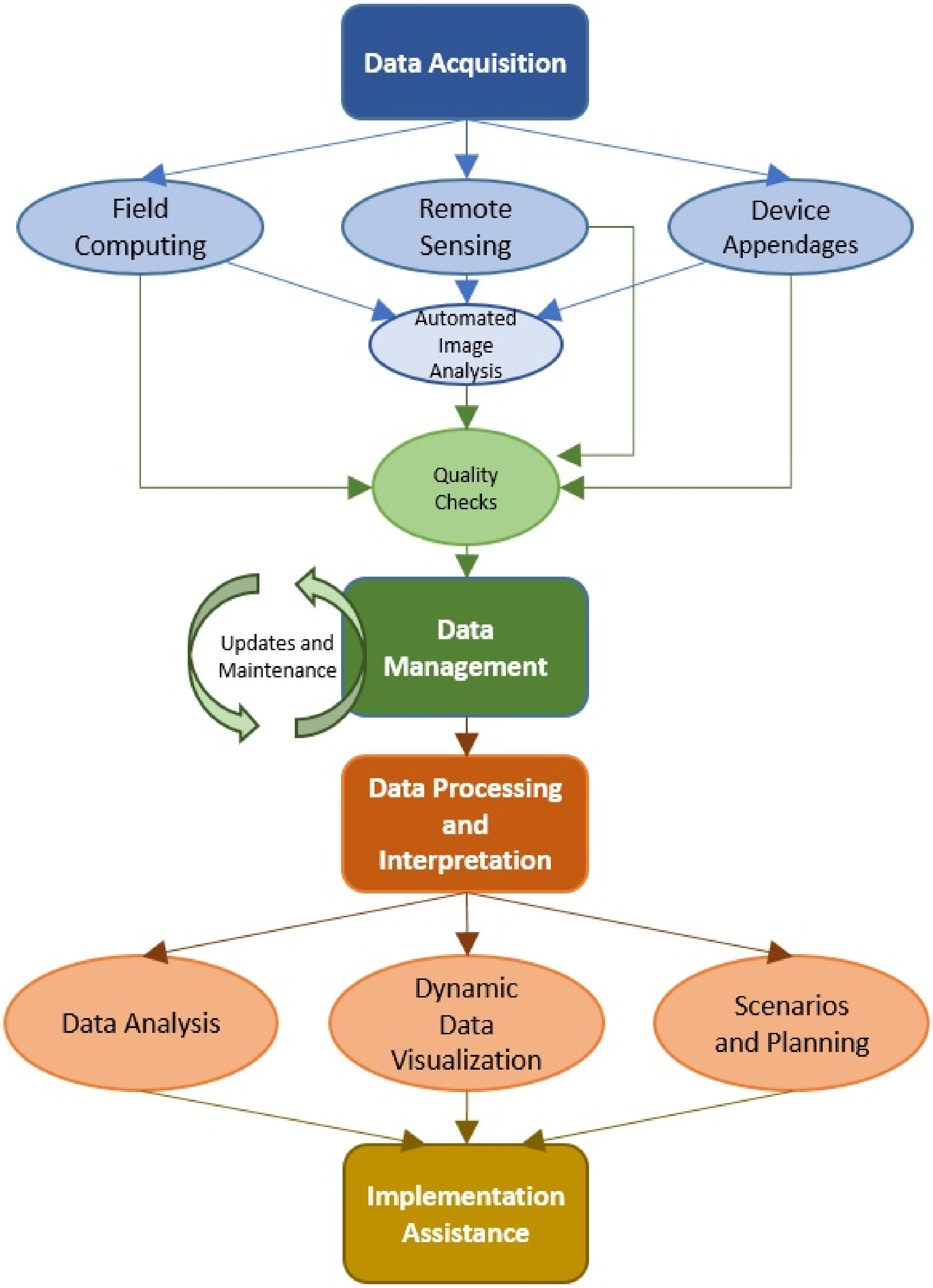
INFORMATION TECHNOLOGY AND VISUALIZATION

Monitoring, assessment and management of aquatic ecosystems is a data-driven process, with millions of dollars spent every year in Southern California on the collection of data. For the environmental management community to use these data effectively, collection protocols must be properly documented, highly reproducible, and comparable among the many groups that acquire, share and aggregate environmental data sets. Environmental managers also need sophisticated ways to analyze, visualize and interpret data to quickly and cohesively communicate big-picture ideas, draw out nuanced findings, increase interactivity, and support management decisions. Since 1994, when SCCWRP facilitated a technology-intensive ocean-monitoring pilot study that morphed into the multi-agency Southern California Bight Regional Monitoring Program, SCCWRP has been leading the development and transfer of next-generation technologies to its member agencies and outside collaborators.

Conceptual Model

SCCWRP's conceptual model for information technology and visualization focuses on two primary research areas: (1) data acquisition and (2) data processing and interpretation. Between these two areas is data management, a traditional SCCWRP support role that bridges the gap between acquisition and use (Figure 1). SCCWRP's priority is to continuously improve the full data lifecycle by adopting emerging technologies intended to ensure relevant, high quality environmental data can be collected as quickly and efficiently as possible, and to effectively analyze and visualize massive data sets in meaningful ways. SCCWRP evaluates new and emerging technologies through the lens of how they can improve the data workflow. SCCWRP's approach is to pursue a number of emerging technologies for data acquisition to improve quality, consistency and speed of data collection. Then, to allow environmental researchers and managers to analyze the data and evaluate potential outcomes based on various assumptions and hypothetical courses of action, SCCWRP pursues development of environmental index calculators, data visualization products, and scenario tools. SCCWRP works to provide environmental managers and the public with consistent and transparent analytical outputs, ensuring science developed by SCCWRP and its collaborators can be effectively used to inform management decisions.

Figure 1. SCCWRP's conceptual model for Information Technology and Visualization is intended to improve the quality, consistency and speed of the data workflow. SCCWRP's involvement spans from how data are collected through to their analysis and use by environmental managers.



Research Directions

Data Acquisition

The core of SCCWRP's mission is to gather environmental observations and field measurements to answer scientific questions that inform management decisions. To effectively achieve this objective, SCCWRP relies upon continually evolving technological advances in data acquisition. Data acquisition technologies include a broad range of tools and applications that reduce time-consuming data processing steps and that offer an end-to-end data workflow solution from the field to the office. Among the most promising data acquisition technologies:

- Lightweight, wirelessly connected mobile devices including smartphones and tablet computers that provide an integrated platform for data collection.
- Connected environmental sensors that can wirelessly transmit data.
- A portable field microscope that can capture detailed image data and videos on a smartphone.
- Unmanned aerial systems (UAS) that can provide highly customizable bird's-eye views of survey areas while in the field.

Although these technologies vary in data type, scale and collection method, what they all have in common is that they complement and enhance the utility of the existing methodologies and improve the ability to obtain increasingly high-quality data in easier, more cost-effective and more efficient ways.

Field Computing

Over the past few decades, data acquisition has advanced dramatically, from paper forms filled out by hand to computer-based field data collection systems, dramatically reducing data errors due to unreadable handwriting and transcription mistakes. With this shift to field computing, programs like the ongoing Southern California Bight Regional Monitoring Program have realized vast improvements in the quality of the field data that environmental managers rely upon to make decisions intended to protect local marine ecosystems. Indeed, since the Bight program was launched in 1994, SCCWRP has been coordinating data collection every five years for more than 60 agencies (Moore et al. 2008). The latest advances in field computing, developed for Bight '13, have moved field data collection to mobile platforms for use on a smartphone or tablet with integrated GPS, meaning the devices no longer require a connection to the ship's navigation system, thus allowing use of the field computer in new environments.

Accomplishments

SCCWRP initially developed the field computer for the Bight '98 project. At the time, a ruggedized laptop with a custom Microsoft Access database for direct field data collection represented a significant advance, introducing direct communication between the ship's navigation and the field computer as a component of data collection. The ability to accurately record position information was reduced to a simple click of a button, and paper forms and field data transcription were replaced with direct entry into a database (Kelly et al. 2003; Bight '13 Nutrients Committee 2013). Over the years, the field computer has been enhanced to process additional data types, including CTD (conductivity, temperature, depth) sampling and information about fish size class. One of SCCWRP's most important roles in data collection has been leading the fundamental task of developing agreement on a common format and submission process for Bight data collected on field computers (Allen et al. 1998, 2002 and 2011). Since the advent of mobile devices, SCCWRP has moved field computing into locations where a full-sized laptop computer was difficult to use, such as on beaches and while traveling in estuaries and smaller channels via inflatable boats. The integrated connectivity of mobile devices also has allowed for direct data submission, sending the newest data back to the office in near-real time whenever a connection to a cellular or Wi-Fi network is available. This has minimized the chances of data loss, even if a mobile device were to fall overboard, and also has provided real-time information on data collection efforts to project managers and scientists in the office (Bight'13 Field Sampling & Logistics Committee 2013). The latest generation of submission tools was developed using Web 2.0 technology, giving SCCWRP the ability to more rapidly build and deploy data submission tools. The Web 2.0 tools also feature project progress tracking reports, generated in real time as data flows continuously into the system.

Ongoing Research

SCCWRP's field computing research is centered on the many advantages of mobile-computing, which include the opportunity to significantly improve ease of data collection and the ability to collect data in new settings and among a broader array of study participants. For example, during SCCWRP's Surfer Health Study, SCCWRP developed a mobile application deployed to hundreds of surfers. The surfers used their own smartphones to provide weekly updates of epidemiological health data to SCCWRP over a 12-week study period (Figure 2). SCCWRP will build upon its mobile-computing successes as it continues to provide field computing support for environmental data collection.

Figure 2. A mobile app developed by SCCWRP to collect and transmit data from surfers on a weekly basis provided a unique opportunity for data collection from hundreds of study participants.

***Project:* Mobile apps supporting data collection for SCCWRP studies**
Mobile apps on cell phones and tablets have opened the door to unprecedented opportunities to collect data in support of scientific studies. For example, for a study in which SCCWRP will survey anglers in San Diego Bay to determine which species are being caught and consumed, SCCWRP is developing an app on a tablet computer that can collect survey responses and locations alongside photographs of fish, all stored within a single data record. The photographs provide a reference to confirm which species are actually caught by the anglers. Data transmission back to SCCWRP servers will allow continuous monitoring of survey progress throughout the year-long study. The purpose of the consumption study is to understand fish consumption patterns and potential health risks, depending on the species and amounts of fish consumed.

***Project:* Integrating data collection from web services**
With web services able to provide a wealth of real-time data (i.e. meteorological data, ocean condition parameters from buoys), SCCWRP is working to automatically integrate

these additional data into the environmental data collection process so such data do not need to be collected manually. For example, as part of the Surfer Health Study, SCCWRP designed its app to automatically capture ocean condition parameters from buoys that corresponded to every data point that was being generated by study participants (i.e. when surfers reported date, time and location of their surfing activity, the app would automatically log the corresponding buoy data). Armed with this ocean parameter data, project researchers had the opportunity to cross-reference conditions as reported by survey respondents with corresponding data obtained from the ocean buoys.

Priorities for Future Research

SCCWRP will continue to enhance the power and utility of mobile applications for use in environmental monitoring, and to diversify the expansion of this technology across all scientific disciplines.

Future focus area: **Harnessing the full (and future) capabilities of mobile devices**
Technology built into current smartphones offers every field technician an enormous range of capabilities, many of them untapped. Sensors on the average smartphone can measure temperature, light, humidity and device orientation, but these applications have not been calibrated and validated for use in environmental monitoring. For example, a built-in orientation sensor on smartphones could be used to obtain the angle of a stream bank, with the user simply placing the device on the side of the stream and clicking a button to record the angle. By incrementally harnessing the full and future capabilities of mobile devices, field data will be able to be more efficiently collected and incorporated into a single site record, with everything from field observations to microscopic imagery and site photographs stored together for instant retrieval.

Future focus area: **Incorporating data from web services in the field**
Existing technology has allowed data from web services to be integrated with environmental data, but thus far, this integration step has been taking place in the office, not in real time in the field. Mobile devices, which feature real-time connectivity, could change this, allowing for the user to leverage ancillary data while on site. Obtaining real-time data on meteorological, stream-gauge and ocean-buoy conditions could provide important information to field crews that could help them improve and refine their data collection efforts. Furthermore, field information such as local geology, vegetation, historic field data and imagery that web services can provide could be integrated into real-time web computations from which environmental indices and model outputs can be derived.

Remote Sensing

Remote sensing refers to data collection that takes place at some distance from the site of interest. Most commonly, remote sensing is accomplished with aerial platforms, ranging from satellites and airplanes to unmanned aerial systems (UAS). This data can also be collected from stationary platforms, such as a camera mounted to a tower. Remote sensing systems are important because they can provide temporal coverage of a site; such imagery can be used for time-series analyses, can be targeted at specific times and locations, and can offer a synoptic view of a site, a permanent record of which can be mined for data at any future time. To make comparisons over longer time periods, historical imagery can be used (i.e. aerial photographs of Southern California dating back to the 1920s, regional satellite imagery from the Landsat program dating back to the 1970s). Remote sensing data also can supplement data collected on the ground, offering a synergistic approach to deriving more useful data from imagery such as plumes, algal blooms, land cover classes, and changes in channel morphology.

Accomplishments

SCCWRP has used satellite and aerial imagery to support water quality research across multiple cycles of the Bight program. During the water quality component of the Bight '03 project, image analysis was used on satellite images to detect and quantify river discharges and plankton blooms. The information gleaned from the image analysis helped guide field sampling on the ground, which, in turn, served as confirmation of the satellite imagery analyses. Such images have been helpful in tracking river discharge plumes during storm events, as well as providing the basis for adaptive sampling to collect field data from the plumes (Nezlin et al. 2007; Schaffner et al. *In prep*).

Ongoing Research

SCCWRP is continuing to use satellite image data to derive regional parameters for coastal watersheds and ocean environments that can aid in developing environmental models. Satellite imagery is being used for assessments of land cover and change, plume modeling, and development of approaches to monitor harmful algal blooms. At the site scale, SCCWRP is assessing the utility of automated analysis of large-scale imagery collected from mounted camera systems and UAS.

Priorities for Future Research

Traditional remote sensing from satellite and aircraft platforms will continue to provide important data for studies at local and regional scales. SCCWRP intends to explore how to use these data to develop essential parameters for modeling and monitoring, including improving automated image analysis for rapid data development. At the site level, UAS could transform how large-scale, site-specific aerial imagery is collected. Given that UAS have become pervasive in all walks of life – ranging from hobbyists to applications in the movie industry, search-and-rescue, law enforcement and military applications – the potential for these devices' use in science is virtually unlimited. Coupled with mobile applications, UAS could provide investigators with real-time, bird's-eye-view photography of landscape features that could facilitate on-site decisions about how to most safely and effectively access field sites to acquire desired data. These devices could even transform how field technicians obtain direct measurements, such as those taken via a water quality probe; for example, a UAS could dip sensors into the middle of a wide channel, lake or estuary that is otherwise inaccessible to land-based field crews.

> ***Future focus area:*** **Use of UAS to estimate extent of algal mats and blooms**
> SCCWRP is interested in using UAS imagery to estimate the size and extent of algal mats or blooms in lakes and estuaries. Because algal mats are an important indicator of degraded conditions in fresh water systems, UAS imagery could allow for the extent of algal mats to be accurately measured and quantified.

***Future focus area:* Use of UAS in wetland assessments**

SCCWRP is interested in integrating UAS technology into CRAM (California Rapid Assessment Method) analyses of wetlands, the California Wetland Status and Trends program, and other wetland assessment methods. Given that sampling sites can have a number of parameters (including buffer widths) that may be difficult to assess on the ground, a UAS could fly over the site to capture images to efficiently gather required information, while field crews complete other components of the data collection. UAS also would be useful for identifying features of wetlands and other aquatic environments that are difficult to quantify from the ground.

Device Appendages

Adding appendages to field computers enhances their ability to collect additional data in the field that can be directly integrated into the site record. This eliminates the need to collect data using multiple recording methods and then tie them together manually after the fact. For example, SCCWRP is working on approaches to collect and integrate data from water quality probes and the CellScope, a microscope developed to obtain high-quality microscope images via a smartphone camera while in the field.

Accomplishments

SCCWRP has developed a prototype water quality probe appendage that communicates with mobile field devices via Bluetooth wireless technology. Wireless communication between sensors tied to an open-source hardware platform allows for direct water quality probe integration alongside other field observations as a component of the site record. The field platform, which was developed using an open-source computing platform, was designed to allow a wide variety of other sensors and devices to connect to it in the future; the platform also leverages software and data transfer protocols developed through current and ongoing mobile field computing efforts. SCCWRP separately has partnered with the University of California, Berkeley, to adapt a small, portable microscope originally designed for medical testing for use in environmental field work. The CellScope (Figure 3) serves as an appendage to a smartphone that captures magnified imagery. Through field testing of the original CellScope prototype, SCCWRP was able to provide important feedback and recommendations to the Berkeley lab for modifying this lab-quality microscope. The modified version of the CellScope can image samples on site, preventing samples from becoming degraded as they are dried, handled, preserved and transported.

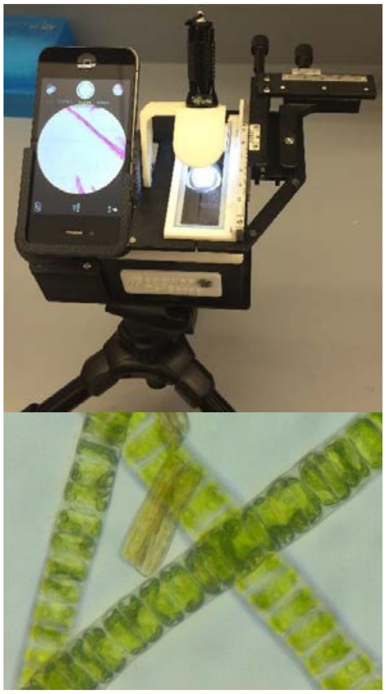


Figure 3. The SCCWRP CellScope, developed in collaboration with UC Berkeley, and a sample specimen image captured with an iPhone.

Ongoing Research

SCCWRP is continuing to explore how to integrate wirelessly connected field data collection devices and probes with the mobile field platform. Open-source hardware and sensors – often referred to in popular media as the "Internet of Things" (IoT) – offer a variety of low-cost, robust opportunities to deploy environmental sensors in both site-specific and long-term settings. SCCWRP is using its low-cost, Bluetooth-enabled water quality probes as the basis for its exploration process. Meanwhile, technicians and citizen scientists are being invited to perform field testing on the CellScope to ascertain its utility for real-world applications.

> ***Project:*** **Integration of deployable environmental sensors**
> Field measurements taken with environmental sensors are typically stored on the sensors themselves; this data must be manually extracted and integrated with other field data after the fact. Working with low-cost, open-source hardware (e.g. Raspberry Pi and Arduino computing platforms), SCCWRP is developing small, low-powered data collection hubs through which a wide variety of sensors, cameras and other monitoring devices can be connected. Smartphones or tablets with wireless connectivity (i.e. Bluetooth or Wi-Fi) can then seamlessly integrate all field data collected by all attached sensors. The goal is to build a testable field unit that features water-quality probes that can measure common parameters (e.g. pH, temperature, dissolved oxygen, and electrical conductivity), so that the device can be deployed by member agencies and partners for real-world testing.

> ***Project:*** **Adapting a portable cell phone microscope for environmental field work**
> SCCWRP is working with member agencies and other partners to deploy CellScope prototypes into the field to refine protocols for collection of high-quality data, and to compare results obtained from these images to data obtained via traditional field collection and preservation methods. The long-term goal is to be able to integrate images obtained via the CellScope with the site data record, and then to transmit this data to the office in real time for immediate evaluation and follow-up by taxonomists (see Automated Image Analysis).

Priorities for Future Research

SCCWRP is interested in exploring new opportunities to connect field sensors and data loggers directly to the data workflow using smartphones and tablets. As this technology continues to evolve, SCCWRP expects to be able to improve the platform's utility as a hub for data collection, integration and submission. Furthermore, as SCCWRP and member agencies learn about this technology's potential, SCCWRP anticipates receiving additional requests for field data collection capabilities that SCCWRP will need to prioritize.

Automated Image Analysis

Automated image processing, which is the final step in the data acquisition process, spans multiple types of data acquisition, from field computing to remote sensing to device appendages. The goal is to speed up the process by which relevant, desired data are extracted for further analysis. Traditionally, image processing for environmental research has relied upon georeferenced images obtained via satellites and aircraft. The level of spatial detail and temporal resolution in these image sources provided for relatively straightforward and well-understood image processing methods. As SCCWRP continues working with high-frequency and high-resolution images (including images obtained with the CellScope), there will be growing demand to take advantage of the automated image analysis technology being used effectively in other fields, including security image analysis and medical image analysis. By focusing on feature characteristics including shape, movement and pattern recognition, valuable data from environmental images will be able to be rapidly extracted and classified. For example, if stream samples can be photographed by a field technician using a CellScope, the images will no longer need to be sent to a taxonomist for manual identification.

Accomplishments

SCCWRP has worked to implement automated image analysis for a variety of satellite and other aerial images over the years. During the water quality component of the Bight ’03 project, computer-assisted image analysis was used on satellite images to detect and quantify river discharges and algal blooms. The information gleaned from the image analysis helped to guide field sampling on the ground, which, in turn, served as confirmation of the satellite imagery analyses. SCCWRP also has experimented with computer-controlled stationary cameras (Figure 4) to collect high-frequency still images for change detection. Deployments in Ventura and Orange counties were used to estimate the number of birds that visit target beaches throughout the day over several weeks, then SCCWRP developed an algorithm to automate counting birds that appeared in a given frame. Automated processing of video images also has been explored as a means to detect high-frequency changes, using publically available web video footage to detect surfers in the ocean. From these experiments, SCCWRP has been able to develop a successful workflow by which researchers reviewing available images can directly assist in building an algorithm to correctly classify features of interest.

Figure 4. A computer controlled, high-frequency DSLR camera system deployed at Doheny State Beach collected images every three minutes to assess bird activity and density on the beach via change detection algorithms developed in MATLAB.

Ongoing Research

None at this time.

Priorities for Future Research

Although images typically need to be transmitted from mobile devices to an office computer for image processing and analysis, the increasing power of mobile devices will pave the way for these steps to take place directly on the device while in the field. As this technology evolves, SCCWRP's goal will be to leverage existing field images from various environmental monitoring efforts to build digital libraries of examples and features for a particular interest area, and then to develop an algorithm that can match future images to the image library. For example, a computer algorithm could be developed that matches harmful algae in water samples to a library of known images of harmful algae.

> ***Future focus area:*** **Automated identification of CellScope images**
> Developing an algorithm that can autonomously identify images captured with the CellScope will make it possible for non-expert field personnel to accurately capture taxonomic information in real time. This will mean that the laborious work of taxonomists manually identifying organisms in the images would become a thing of the past. Furthermore, by using the wireless transmission capabilities of mobile devices, the autonomous identification of CellScope images could be confirmed by a taxonomist in the office while the technician is still in the field (e.g. tele-taxonomy).

Data Management

In addition to acquiring data, data integrity is extremely important in building sustainable data systems. SCCWRP has developed and improved upon a number of web data submission tools, performed ongoing maintenance for databases, and created web-based data quality checkers to validate the consistency in naming conventions, required fields, and other business rules. The goal of all of these tools is to ensure the highest possible quality for all of the data collected.

Data management is not a formal research area at SCCWRP, in that current database and data management technologies are well-developed and unlikely to undergo dramatic change in the foreseeable future. Still, maintenance of existing data and development of improved data management capabilities remains an essential SCCWRP function. Effective data storage and management is essential to every scientific study and monitoring program involving SCCWRP and its member agencies. Successful receipt and storage of high-quality, error-free data using up-to-date web (and even over-the-air) submission methods will remain core support functions. Furthermore, for databases to remain useful, high-quality resources, they must be actively managed and updated over the long term. For example, routine updating of look-up-lists (e.g. controlled vocabulary, P-codes for bioassessment calculations, etc.) is essential to ensuring databases remain well-documented with appropriate metadata.

Quality Checks

When numerous scientists collaborate to answer questions about the overall status of an ecosystem, it is essential the data are collected, stored and documented so they are comparable to that of other investigators in the project, and to future investigators. Individual scientists historically have struggled to express their data in ways that are meaningful to other investigators; they typically adopt their own unique naming conventions and sometimes fail to annotate their data with key supporting information, such as units or analysis method. SCCWRP has developed a powerful solution for these challenges with web-based data quality-checking tools. These tools allow each investigator to integrate data into the unified data set, with data-quality checks automatically performed to ensure the data are submitted in agreed-upon formats and conventions. To ensure these tools are developed appropriately and for maximum utility, SCCWRP facilitates and builds consensus around development of a guidance document for information management; the tool that is built codifies the structures described in the guidance document.

Accomplishments

Prior to the development of online data quality checkers, data were submitted manually as discrete files and validated manually, a time-consuming and potentially error-prone process. SCCWRP first developed an online data checking tool for Bight ’98. The checker featured an easy-to-use web interface that allowed dozens of participants to submit project data in a standardized format, using lists of constrained values for the various data types.

Ongoing Research

Given that web-based data submission tools remain useful for large-scale collaborative projects such as the Bight regional monitoring program, SCCWRP is working to continuously improve and implement these tools for other projects. As new data acquisition technologies have made the data submission process a connected, real-time experience, checkers will continue to evolve to allow for improved transmission of data and more precise feedback on data quality and potential errors.

Project: **Regional Data Center support for the California Environmental Data Exchange Network (CEDEN)**
As a Regional Data Center for the California Environmental Data Exchange Network (CEDEN), SCCWRP provides ongoing support to data providers in the preparation and submission of their data to CEDEN. SCCWRP assists with completion of data templates for supported data types (Chemistry, Field Collection and Results, Taxonomy, Tissue, Toxicity and Bioassessment) and data submission and loading to the CEDEN database. SCCWRP also assists in reviewing and updating data parameters (controlled vocabulary) within the existing CEDEN structure.

Project: **Support for California’s Beachwatch ocean water-quality database**
SCCWRP provides ongoing support to data providers in the preparation and submission of beach water quality data to the Beachwatch database that was developed by SCCWRP. Beach bacteria and beach notification data status data are submitted to SCCWRP for most of the coastal counties in California on a monthly basis. A live connection between the SCCWRP database and the Water Quality Monitoring Council’s “Safe to Swim” portal provides access to the data. Furthermore, all data are submitted annually to Environmental Protection Agency databases: Bacteria data go to the Water Quality Exchange (WQX), and beach closure data go to the PRAWN system. SCCWRP provides system support and training of county staff on an as-needed basis.

Priorities for Future Research

Given SCCWRP's experience with data management though multiple cycles of the Bight program, SCCWRP has and will continue to leverage its expertise to plan and lead large scale environmental data management projects alongside partners and collaborators. Future versions of web submission portals will feature expanded capabilities that include not only being able to accept data submissions directly from users, but also accepting automatic feeds from multiple mobile devices and sensors simultaneously.

> ***Future focus area:*** **Enhancements to data checkers to detect more subtle errors**
> Web-based data checkers have proven to be a valuable asset in large, multi-provider data management systems such as the Bight projects. They provide a means to aggregate project data into complete, consistent data sets. However, current checkers are limited in their ability to screen data for more subtle data relationships and dependencies (e.g. data in Toxicity Batch vs. Toxicity Results data). SCCWRP will continue to take advantage of opportunities presented through Bight and other projects to add these and other more subtle data checks to further enhance data quality and time-to-availability.

Updates and Maintenance

Database Updates

SCCWRP employs relational database systems – commercially available and open-source database products – to store its large environmental databases. These data structures serve as the foundation for robust data collection practices and effective data analysis. SCCWRP will continue to examine new opportunities to ensure that the most appropriate tools are selected for a given system and that, where feasible, open-source software is used to minimize cost and maximize opportunities to share systems with member agencies and collaborators. SCCWRP's decision to make its large-scale environmental databases available online ensures that data can be uploaded, accessed, discovered and retrieved through online interfaces. In this way, SCCWRP can be responsive to requests for assistance and to continually update and improve its data loading and retrieval systems. Additionally, sometimes small errors are detected in a database during the course of its use that need to be corrected. SCCWRP provides this service for all databases it manages. SCCWRP will continue to post large-scale data sets as they become available, in accordance with the data release policies for each project. And finally, many data sets contain taxonomic and chemical data that use nomenclature that changes over time as the state of the science evolves. These nomenclature lists are referred to as lookup lists. SCCWRP's priority is to keep the lookup lists updated with the most current taxonomic and chemical names available.

Historical Data

SCCWRP maintains historical data going back as far as 1977, when surveys of Santa Monica Bay were first conducted. These older data sets are of particular value because they provide baseline data necessary to look at multi-decade trends in chemical contamination levels and biological system responses. SCCWRP has not only preserved these historic data, but it has also developed metadata to allow users to access the complete set of information attached to the data set. In particular, SCCWRP has published all of its Bight data to the web as the data are released. The interface allows investigators to read the metadata and search keywords to discover data applicable to their research. These data also can be downloaded or viewed through a map interface on the SCCWRP website. Where feasible, SCCWRP is working to capture additional, high-priority historic data that have not been digitized.

> ***Project:*** **Supporting digitization of high-priority historical data**
> SCCWRP is supporting CTAG's ongoing efforts to identify and prioritize non-digitized monitoring data. SCCWRP's role is to assist a CTAG historical data subcommittee in the creation of structured and consistent databases that are discoverable and retrievable for future research. Capture of historic data requires compilation of documentation regarding the data values and all associated metadata, including collection methods, detection limits and QA/QC details.

Data Processing and Interpretation

A primary focus of SCCWRP research over the next decade will be on improving tools for data processing and interpretation, which are accomplished through next-generation analysis and visualization tools. These tools come in a variety of forms and sizes, from online calculators that produce reports and compute environmental indices, to customizable data dashboards that allow users to track environmental conditions and patterns in real time, to map-based and scenario-driven "what if" tools that allow users to enter and/or change parameters to examine hypothetical outcomes. From this research area could come virtual-reality simulations that allow users to experience and perhaps even become immersed in their environment. To make the most meaningful impact possible with all of these technologies, SCCWRP's philosophy is to take advantage of existing, commercially available technologies wherever possible, and to form outside partnerships with technology leaders.

Data Analysis

Data analysis tools offer the ability to dramatically simplify the laborious, highly technical tasks associated with data crunching. Much of SCCWRP's progress in this arena has been on building and deploying environmental index calculators that remove guesswork and error-prone manual calculations out of generating index data. For these indices, users now have a single place to go to ensure their computations are done consistently and correctly, using the same methods as their peers. That means no longer needing to read the published literature and then use their own unique spreadsheet or statistical software package or database program to interpret and develop a computer algorithm based on this literature. An additional advantage is the ability to compare current data to that collected during previous surveys, giving the user a regional perspective regarding changes over time.

Accomplishments

The first index calculator developed by SCCWRP was the Benthic Response Index, which provides an easy, quick way for users to obtain a Benthic Response Index (BRI) score for a stream site. The BRI is calculated using the abundance weighted pollution tolerance score of organisms present in a benthic sample (Smith et al. 1999, 2001 and 2003). The higher the BRI score, the more degraded the benthic community represented by the sample. Another SCCWRP-developed index, the algaeMetrics Calculator, calculates the three main benthic algal indices of biotic integrity (IBIs) for a stream and indicates the stream's condition relative to the algal species collected there. This tool requires the user to simply fill out a data template and was developed primarily for bioassessment applications in Southern California wadeable streams (Fetscher et al. 2014); however, preliminary analyses (Fetscher et al. 2013) suggest that the IBIs may also have applicability in other parts of the state.

Ongoing Research

For the index calculators already developed, SCCWRP is exploring the best means to review and test each one using the member agency as beta testers. The algaeMetrics tool, which has been fully vetted with member agency support, serves as the template for this process. The goal is for the tools to be refined in ways that improve usability and functionality and that are appropriate to the import and export of data and results – and, of course, that allow these tools to be successfully transferred to the user community.

Priorities for Future Research

SCCWRP will continue to prioritize development of calculator tools that can process and report results of computations and allow for data visualization.

> ***Future focus area:*** **Next-generation calculators to aid in report writing**
> Many regulated entities are required to produce lengthy reports each year as part of their permit requirements. SCCWRP is interested in greatly simplify the process and decrease the time required to produce the reports by providing a common set of tools that could be used by multiple agencies to integrate the data obtained from calculators to derive relevant indices and statistical computations.
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> ***Future focus area:*** **Increased open access to index calculator programming**
> SCCWRP is interested in providing its end users with greater access to the backend of SCCWRP-developed index calculators. This would further enhance the usefulness of the tools and relieve SCCWRP of the responsibility to facilitate revisions and changes to every tool. For example, the Benthic Response Index calculator tool allows only the scientists who originally developed the tool to modify assigned P values as new information becomes available, with SCCWRP still required to update the list on the back end.

Dynamic Data Visualization

Dynamic data visualizations allow users to generate real-time data snapshots in ways that draw out and highlight complex trends and other big-picture phenomena. The goal is to make key environmental data points accessible and translatable into messages that are understandable by the environmental managers who depend on these data.

Accomplishments

SCCWRP has developed an initial set of dynamic data visualization tools that serve as proof of concept for pursuing development of additional, real-time data acquisition and visualization tools. A near real-time beach status tool was created for San Luis Obispo County that uses an open-source web mapping application to visualize beach bacteria data. The tool draws its beach bacteria data directly from the SCCWRP-developed Beachwatch database application, which is the statewide program that allows beach managers to manage beach bacteria data and transmit this data to the state. A similar visualization tool was developed as part of the Bight '13 program to provide real-time tracking on which sites had collected field data and which data sets had been received by SCCWRP.

SCCWRP also is moving into the 3D visualization arena via the **oceanMetrics 3D Visualizer**, which allows users to dynamically generate and interact with 3D maps of specified ocean parameters. This improves upon flat 2D maps traditionally produced to view such data (Gregorio and Moore 2004) in that the user can interact with an animated, 3D image of data and modeled plumes, to view data from multiple perspectives on the map. Initially developed in MATLAB, which is a commercially available, relatively expensive software package, the oceanMetrics 3D Visualizer was redeveloped by SCCWRP using the free, open-source R Statistical Package.

Ongoing Research

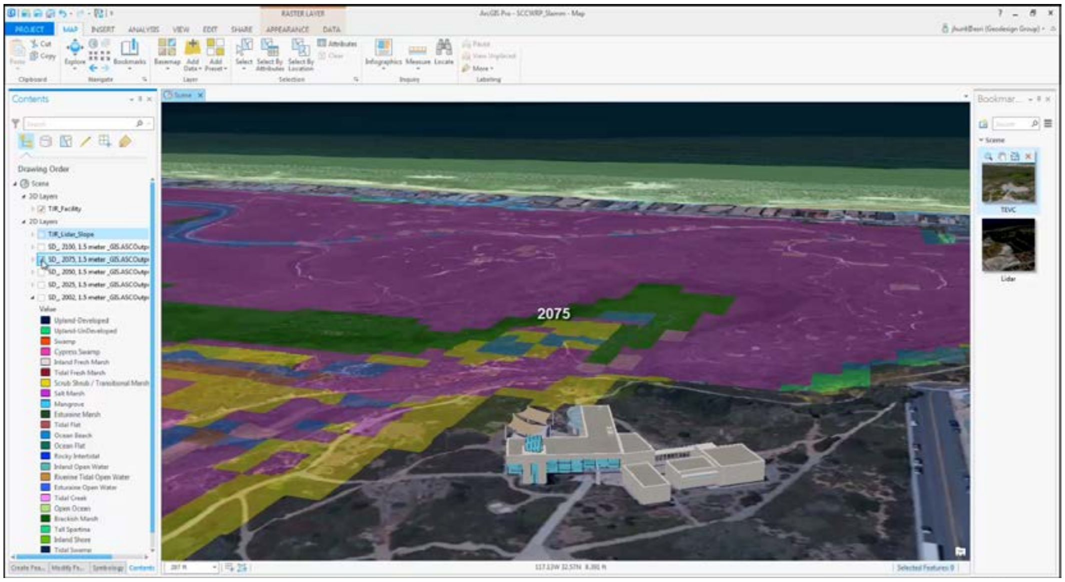
SCCWRP is working on projects that will increase data visualization capabilities in both the 2D and 3D arenas.

***Project*: Building a Stormwater Dashboard for California**
SCCWRP and its partners are developing a Stormwater Dashboard to help California stormwater managers obtain and analyze the data they need to assist in their decision-making and reporting processes. Managing environmental resources in California is challenging, in part, because consistency in obtaining and analyzing the needed data is lacking. In addition, stormwater monitoring assessments are often done independently and differently by environmental agencies throughout California. In an effort to standardize and involve end users in the process of creating analysis tools, stormwater managers across the state are being interviewed to identify the types of information they utilize (or would utilize if they had access to such information) for both short-term and long-term decision-making. The dashboard will be based on: (1) existing dashboards created by other entities surveyed; (2) information needs identified by managers in interviews, and (3) an online feedback forum of potential users. A mock dashboard will be developed that uses open-source, readily available tools and is customizable and easy to use.

***Project*: 3D visualization tool for the Tijuana River National Estuarine Research Reserve**
This project involves building a 3D visualization tool that will provide decision support for site-specific estuarine restoration and regional recovery planning for the Tijuana River National Estuarine Research Reserve. Given that the coastal wetlands of Southern

California reside in one of the most intensely urbanized settings in the country and that these systems are faced with numerous anthropogenic stressors intensified by climate change and sea level rise, an important part of determining projected losses and best practices for minimizing and/or restoring these areas is the creation of tools that can synthesize information both temporally and spatially to effectively reflect past, current and future changes to these systems. Therefore, the visualization tool is being developed within the context of altered landscapes, ecosystem services, and climate-induced changes (Figure 5). This work is being approached conceptually for adaption to all wetlands in Southern California, but using the Tijuana River Valley as a case study. Collaborative processes that bring the perspectives of diverse stakeholders to bear on this management problem is essential.

Figure 5. A 3D visualization of the Tijuana River estuary provides an interactive perspective that allows wetland managers to understand how the region has changed over time and what could happen to it in the future, based on modeled scenarios. The Esri software, which was originally designed for visualizing cities, is being adapted to integrate the Tijuana Estuary's many plants and geological characteristics through time.



Priorities for Future Research

Future efforts will focus on improving the value and utility of dynamically displayed data. By moving beyond the display of simple, raw data and into true data visualizations, scientists and managers can be alerted to important data issues and trends that might not otherwise have been apparent, at least not until long after the event and an opportunity to respond to it have passed. Dynamic data visualization also could prove valuable in coordinating data collection among multiple field crews, ensuring no gaps or overlaps occur. Additionally, data from external sources and web services could supplement field data in a dynamic process known as cross data set visualization. For example, an alert could be triggered every time precipitation levels from a remote meteorological station indicate the need to sample at a particular watershed.

> ***Future focus area:*** **Development of cross data set visualizations**
> Traditionally, monitoring agencies throughout Southern California have conducted sampling in a particular geographical area with little knowledge of how their data compare on a regional basis. Cross data set visualizations are an important way of looking at and integrating data from multi-agency projects such as the Southern California Bight Regional Monitoring Program surveys. Multiple sources of data from across an entire region, including from web services, could be pulled together to gain a holistic, integrated perspective.

> ***Future focus area:*** **Creation of additional dashboards**
> Dashboards like the stormwater data dashboard being developed by SCCWRP (see Project: Building a Stormwater Dashboard for California) offer an integrative, one-stop place for environmental managers to assess current conditions of areas they are responsible for. They commonly contain a series of graphics, charts, gauges and other visual indicators that can be monitored and interpreted on a continual basis. SCCWRP will pursue future opportunities to build dashboards. Because dashboards are useful in informing current conditions for a given area, they are best applied only in situations

where data are frequently changing. SCCWRP will prioritize creating dashboards that are useful, easy to use, and relevant. Dashboards also may integrate calculators, scenarios, and mapping tools.

Scenarios and Planning

Through recent advances in virtual- and augmented-reality scenario programming (as well as anticipated future advances), SCCWRP is seeking to build new ways of looking at data that help environmental managers better visualize specific environments and even interact directly with them. The goal is to design technology tools that allow users to alter aspects of a given environment and then to instantly see the impacts those alterations have. These “what if” scenarios have particular utility in the planning process that environmental managers must undertake as they design and review plans of all types, ranging from new construction to natural-habitat restoration.

Accomplishments

An exciting partnership with Esri, a leading commercial GIS software company, has allowed SCCWRP to move aggressively into developing “what if” scenario tools. SCCWRP is adapting Esri software for a variety of aquatic and environmental science research applications. The initial tool developed through the Esri partnership is an ArcGIS tool that can explore theoretical hydromodification scenarios, allowing managers to input their own data to explore sediment-yield scenarios under various development plan alternatives (Booth et al. 2010). The tool, developed using data for San Diego County, is a freely sharable ArcGIS Toolbox that can be easily added to Esri’s desktop software platform, supports decisions about appropriate actions based on the degree of hydromodification risk and downstream habitat sensitivity, and enables tailored solutions for each unique reach of a watershed.

Ongoing Research

SCCWRP is continuing to build and refine scenario tools using the Tijuana Estuary project as its prototype. As these tools are refined and expanded through SCCWRP’s highly productive, mutually beneficial relationship with Esri, SCCWRP will be well-positioned to share them throughout the region and to extend the capabilities of the tools to other analysis scenarios.

Priorities for Future Research

Just as SCCWRP pioneered the addition of a scenario tool to its hydromodification visualization tool, SCCWRP intends to continue this practice in the future for other scenarios and data types. SCCWRP will look to grow its partnership with Esri, as well as to create similar strategic partnerships with other researchers and organizations. Many inputs can be altered through scenario tools, from adjusting constants and other parameters used in the tool’s algorithm, to making changes to the data used as the input, such as excluding data of lower quality from the analysis and then comparing the outcome to when the lower-quality data are included. SCCWRP’s focus is on figuring out how to combine multiple technologies within the data processing and interpretation arena into integrated tools. For example, the data processing capabilities of index calculators could be integrated into scenario analysis tools, or a scenario component could be added to existing visualization tools. SCCWRP intends to make as many of these tools as possible available online.

Future focus area: **Developing a sea level rise decision support tool via the Esri partnership**

Planning for the effects of sea level rise under different scenarios will be supported through development of decision support tools for coastal managers. In partnership with Esri, SCCWRP is interested in developing an easy-to-use decision support tool that would be an extension of ***s***cenario tools. If deemed feasible to build, this decision support tool would provide opportunities to incorporate 3D visualization to explore data from multiple perspectives and to see how the resulting output varies with changes to inputs.

Implementation Assistance

When new technologies are used to more effectively obtain, manage and analyze data, this new knowledge must be transferred to users across a variety of levels for its value to be fully realized. As such, one of SCCWRP's roles in developing new technologies is to ensure that member agencies and partners gain full access to and are trained to use SCCWRP-developed technologies. SCCWRP also is committed to passing new tools to others who can support or modify the tool – and to provide sufficient training, support and documentation to ensure this goal is realized. SCCWRP facilitates the transfer and implementation of new technology in a variety of ways.

User Groups

To enable SCCWRP's member agencies to participate in the tool development process on a variety of levels, SCCWRP is establishing user groups to collaboratively identify and implement new technologies that enhance member agencies' and stakeholders' ability to use information effectively. These user groups also will assist in shaping and defining future research and development priorities.

Project**: Creation of pilot user groups with CTAG to aid in tool development**
Two pilot user groups are being formed with CTAG: (1) an Acquisition User Group focused on mobile applications and other technologies aimed at collecting data in the field, and (2) an Analysis and Visualization User Group tasked with developing strategies for creating tools to help member agencies meet their reporting requirements. A third user group for Data Management will follow at a later time. The focus of the user groups will be to develop priorities, goals and deadlines for tool development. Sub-groups may be formed, at the discretion of the group's membership, to work on specific project specific goals and tasks, including conceptualization, development, testing, documentation and training. SCCWRP, which will facilitate the creation of user groups, can lead the user groups and committees, but user group members will be encouraged to step up into leadership roles. Although participation by end-users and information technology personnel from all SCCWRP member agencies is being encouraged, it is voluntary. Once

the specific priorities of the user group/committees have been determined, outside participants may be encouraged to join.

Training

Training, an important step in passing a tool to the end user community, comes in the form of special classes, workshops, and conference presentations. Training materials, including documentation, test data and examples, are provided to assist in the transfer of tools. The objective is to develop a community of independent users who require minimum assistance once trained.

Documentation

Appropriate documentation is created for each tool, including user manuals, QA documentation, peer-reviewed articles/technical reports, and tool descriptions, which include information on the level of support SCCWRP will provide for each tool.

Distribution

Distribution packages are created to assist in easy sharing of all electronic tools. These packages include the code, a standard test data set, user documentation, QA documentation, disclaimer/license information, other technical reports/journals relative to the tool, and points of contact. Users may select any or all of the components of the package, depending on their expertise and level of use. For example, more technical users may find source code valuable as a basis for modifying the tool for their specific needs, while end users may simply want to view the user documentation. SCCWRP makes all components available in the distribution package to ensure maximum usability at all user levels, and also to provide transparency in the algorithms, software packages and techniques used to build the tool (Azimi-Gaylon et al. 2015).

Hardware/Software Support

SCCWRP is committed to finding opportunities to develop tools that are functional across any platform that may be used by a member agency, and that minimize the need to deal with hardware/software versioning. SCCWRP has traditionally worked with many of its member agencies to ensure tools work on a variety of platforms. For example, the Bight field computer, which was developed using a common database platform, has many different versions in use by different organizations today. This arena is becoming increasingly challenging as these platforms change and become more complicated, and as the IT personnel of each organization makes buying decisions that consider only the organization’s needs and preferences.

Version Control

A version control system is built into any new tool. This is accomplished via a shared site for code and/or is integrated into the final tool. Versioning is often controlled by a numbering system used with the tool name and can be used for easily determining if the version being used is the most current. SCCWRP always ensures that tools are documented, and works to minimize the amount of versioning for a given tool.

Customization

Customization is always a goal in the tool development process. SCCWRP works to ensure that users who have the technical abilities to change the code on their own have the ability to do so, especially as member agencies and others identify other uses for the tool – the potential for other uses. SCCWRP works directly with these partners to achieve desired customization features, even if it means procuring additional funding or securing a slice of member agency contributions.

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