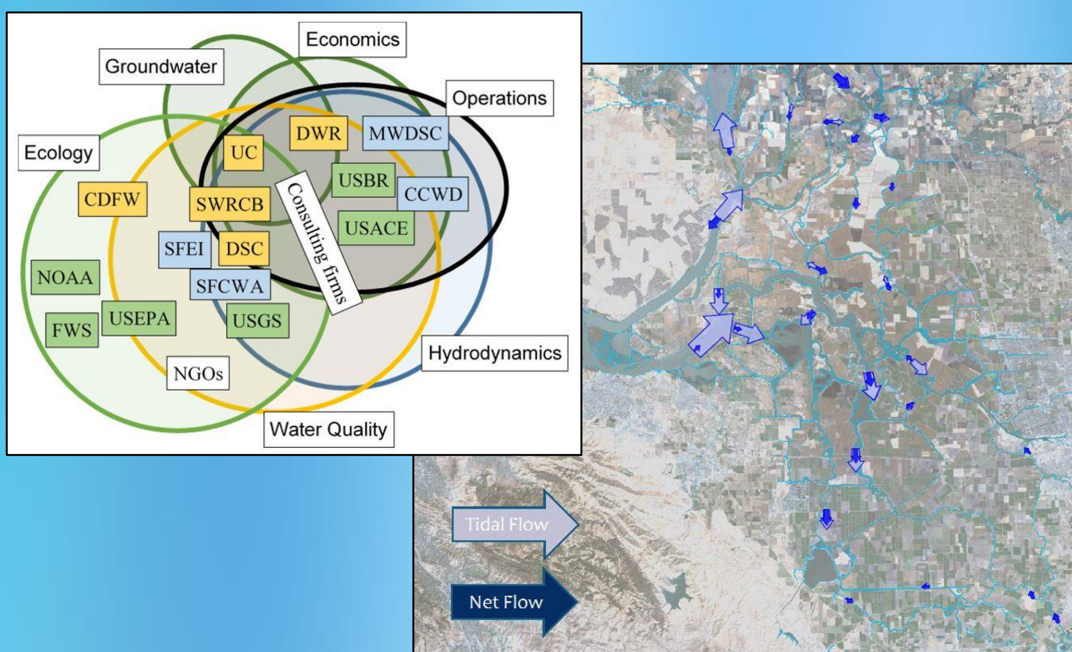
Integrated Environmental Modeling of Estuarine Systems: *Lessons for the Sacramento-San Joaquin Delta*



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Integrated Modeling of Estuarine Systems: Lessons for the Sacramento-San Joaquin Delta

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Summary

Complexity in estuarine systems calls for integrated and community-based approaches for using and developing models and data. Environmental and hydrodynamic models have helped organize and extend knowledge and predictions for physical, biological, and chemical aspects. However, specialization has often steered science and management to fragmentation among models, data, and management of estuarine systems. Integration of models and data in platforms that increase collaboration, interdisciplinary work, organization and transparency have been successful in other systems.

Large estuarine systems are often highly disturbed from diverse human activities, alterations locally and in contributing rivers and coastal areas. Estuaries are also highly dynamic and complex, with landscapes for farming, fishing, navigation, and recreation irreversibly changed such that restoration to some historical condition is impossible. Strict prescriptive management is largely futile due to uncertainties in the trajectories of ecosystem composition from changes in climate, population, major floods, droughts, additional invasive species, earthquakes, new contaminants, and other factors.

The best that can be done is to assess for major shifts in land use and ecosystem structure and function, develop understanding of expected changes due to catastrophic events and chronic stresses and changes, and steer management towards desirable outcomes to the extent possible. In much of the world management decisions in these rapidly evolving systems are made by a myriad of agencies and interests – often crossing geopolitical boundaries. For example, California’s Sacramento-San Joaquin Delta, a highly engineered system, potentially involves more than 230 agencies at various capacities in outcomes and major decisions.

Mathematical modeling developed in the past few decades to capture current understanding and inform immediate decisions and long-term strategies remains the most viable science-based

approach for supporting management of these complex systems. Changes and uncertainties require that such technical activities occur in a long-term adaptive management framework. However, strategies and responsibilities for selecting, developing, and employing models and data, selecting modeling questions, and making the best use of multiple modeling efforts among diverse institutions remain unresolved.

A new approach is needed to build and evolve scientific and technical understanding and analysis capability for policy and management for large estuarine systems across institutions, interests, and different areas of expertise. *A modeling* ***Collaboratory*** is proposed that has capacity to build, refine, maintain and upgrade models, compare and contrast different scientific approaches, quantify uncertainty in predictions, synthesize current data, and accelerate the discovery of knowledge to inform policy and management for these challenging problems. A Collaboratory will focus on specific problems with a defined time-line, with the intent of providing broadly credible information for the many parties involved in decision-making and management. For the Sacramento-San Joaquin Delta, a partnership of the federal government, the State of California, and contractors, perhaps hosted by an academic institution, would establish this center with access to computational and scientific resources from agencies, consultants, NGOs, and academics.

A Collaboratory would consist of a network of modeling experts and managers sitting in distributed and common meeting space and visualization and synthesis capability, leveraging elements of the National Supercomputing infrastructure and agency assets. Agencies such as the State Water Resources Control Board, California Natural Resources Agency, the California Department of Water Resources, Delta Plan Interagency Implementation Committee (DPIIC), Delta Water Master Office, Interagency Ecological Program, or others could request the support of the Collaboratory. The Environmental Protection Agency, NOAA Fisheries, and the US Fish and Wildlife Service could be both users and contributors of information. These and many other federal, state, and local governments, NGOs, and the private sector are expected to contribute to the Collaboratory with their experts and use of its products.

This approach would provide transparent processes to generate legitimate, relevant and credible results and insights while advancing the state of modeling and quantifying uncertainties, given the enormity of the risks and controversies facing California's water supply and ecosystem health. The research and development role and the operational role of models is recognized, and hence the need to maintain close connection and feedback loop. The National Weather Service approach (O'Lenic *et al.* 2016), and Chesapeake work group provide great examples of how this nexus can work successfully. Processes for identifying topics and how these modeling teams would function are described in the Delta Science Plan (Delta

Stewardship Council 2016). Funding from a variety of mechanisms would be required to support researchers, programmers and broad participation of agency and other members in these modeling activities.

Introduction and Background

Estuaries and coastal environments are complex systems of high economic, social, and ecologic importance (Barbier *et al.* 2011; Thessen *et al.* 2016). Many of the most populated areas in the world rely on services from estuaries and coastal environments, yet science and management of these systems often fall short in maintaining their long-term viability. These estuaries and deltas are also some of the most world's threatened regions due to sea-level rise, changing hydrologic regimes, and altered infrastructure (Giosan *et al.*, 2014).

California's Sacramento-San Joaquin Delta (Delta) provides natural habitat with extensive economic activities in its agricultural and urbanized areas. This estuary is also the major hub of California's extensive water supply system, which moves water across the state from north to south and east to west. The Delta is subject to large upstream diversions and discharges, in-Delta water diversions and discharges, water exports from the Delta and tributary basins, and disruptions to native fish populations (Lund *et al.* 2010; Hanak *et al.* 2013; Senn *et al.* 2014).

This document presents findings, insights, and recommendations from a two-day workshop on Integrated Modeling of Estuarine Systems, held at the University of California, Davis on May 21 and 22, 2015. The workshop was sponsored by the National Science Foundation (NSF) and California's Delta Stewardship Council and convened academics, water and environmental modeling professionals, government agency staff and officials, and representatives from non-governmental organizations in plenary sessions, roundtables, and integrated environmental modeling demonstrations. The content has been supplemented through input from special sessions at the 2016 Delta Science Conference and 2016 California Water and Environmental Modeling Forum (CWEMF) Annual meeting. Innovative modeling approaches discussed at the workshop included:

- **Community modeling**, in which expertise across agencies, universities, NGOs and the private sector is integrated through software and data platforms and co-located working environments.
- **Public domain**, which improves availability, transparency, organization and usefulness of data and models to inform management and policy decisions on estuarine systems.
- **Integrated Environmental Modeling,** which employs information technologies to couple separately-developed models of hydrodynamic, water quality, ecological,

management, and economic processes in a common framework, for platforms ranging from desktop to high performance computers.

The workshop included plenary sessions on the state-of-the-science, the state of organization for integrated modeling in California, the US, Europe and Asia, directions for improvements, and a vision to improve integrated environmental modeling. Software and community modeling demonstrations included: The Nature Conservancy-ESSA (Delta EFT); OPENNRM and Baydeltalive.com, 34 North Inc. SCHISM (DWR Planning Division-Delta Modeling); HOBBES Framework (UC Davis); Earth Data Analysis Center (University of New Mexico) and Lab for Ecohydrology and Alternative Futuring (LEAF, Boise State University). Following the workshop, a group of attendees gathered to develop documents to summarize and extend thoughts from the workshop.

Findings

Collective insights from the workshop participants were compiled and summarized in preparation of this white paper (Medellín-Azuara *et al.*, 2016). Selected key findings of the workshop include:

1. **Estuaries involve many processes, objectives, disciplines and interests, which makes their analysis difficult technically and institutionally.**

About 22% of the world's cities rely on water and ecosystem services provided by estuaries (Thessen *et al.* 2016). Complexity is inherent in many estuarine systems involving combined physical, ecological and institutional processes, which challenge analysis.

Such complexity merits a major change in how models and data are developed and integrated to support a wider range of management decisions and scientific needs. Ecosystem complexity requires scientists and analysts from a wide range of disciplines to actively engage in improving understanding of diverse processes. Social, economic, and political complexity requires engaging stakeholders in a meaningful way and exploring management actions oriented to preserve and enhance the services provided by estuaries. The potential of scientific work practice to enable interdisciplinary research has been evaluated and investigated extensively during the past decade (for example, NRC 2005). This has resulted in recommendations on how teams of scientists can be organized to maximize effectiveness (NRC 2015). Further, there is an increasing recognition that many breakthroughs in science will occur at the convergence of different lines of inquiry and approaches (NRC 2014). Work across traditional academic disciplines and directing scientific enterprises towards the most pressing societal problems, often working with stakeholders, deserves special attention. These fundamental principles helped guide workshop discussions and recommendations in the workshop and in subsequent conferences.

2. **Modeling frameworks are helpful for understanding individual processes and aspects in estuaries, and for organizing information and discussions.**

Models combine ideas and data (Ganju *et al.* 2016) and are simplified representations of an object, process, concept or system. Models organize existing information to support technical and policy discussions, and are a framework for integrating new science and information. Vast scientific capital has been invested for decades on understanding estuary hydrodynamics and ecological processes. Dozens of peer-reviewed articles develop and compare existing frameworks, models, tools, and applications (Ganju *et al.* 2016, Gilbert *et al.* 2010, CWEMF 2005, Thessen *et al.* 2016).

Advances in computer processing capacity, connectivity, and data storage have facilitated use of larger multidimensional hydrodynamic models and finer spatial and temporal resolutions. Ecological modeling also has evolved rapidly. From the early work of Riley (1946, 1947) on mechanistic modeling, ecological modeling has grown from phytoplankton and zooplankton interactions to holistic simulations of estuaries and lakes with the addition of state variables, increasing resolution and dimensionality, and a focus on management. Such modeling involves tradeoffs among complexity, resolution, and increased parameterization and uncertainty, as well as added expense for modeling and data collection. An appropriate balance among processes is required (Ganju *et al.* 2016 and Grimm *et al.* 2005).

Hydrodynamic and ecological modeling have limitations in representing mixing and physical conditions at small scales in large systems, and in representing biological system complexities. Linkage of physical and ecosystem processes in modeling may follow various configurations depending on the desired feedback and simultaneity. Ganju *et al.* (2016) recommend to:

- Use intermediately complex and simple models in concert with more complex and highly resolved models to improve accessibility to stakeholders and others,
- Evaluate model formulations and parameter values against field observations,
- Cross-fertilize observational and modeling techniques by training across disciplines and agencies,
- Maintain long term observational databases infrastructure with data standards,
- Employ multi-model ensembles, in which model are viewed as a whole instead of individually, with varying spatiotemporal resolution and complexity to advance heuristic and management applications.
- Translate models into user-accessible decision support tools,
- Integrate models into educational curricula and activities to increase public literacy on models.

Alas, modeling for California's Central Valley and Delta has usually been fragmented among diverse modeling groups and agencies without adherence to a common modeling or decision support strategy. The evolution of fragmented models can be explained by the different missions, questions, and interests of the many entities which fund modeling activities. In some areas, such as hydrodynamics or operations planning models, the California Water and Environmental Modeling Forum (www.cwemf.org) has made headway in conducting peer review, technical comparisons, and facilitating training on the use of these models. But even here, and despite the benefits of peer review there are few examples of shared data, standard scenarios or common prioritization of model development efforts.

3. **Newer technical and institutional approaches are available to model more complex problems, and may reduce disciplinary and institutional fragmentation of science, management, and policy discussions.**

Difficulties occur in employing computer models to better inform management decisions. These difficulties arise from the complexity of the estuarine problems, management institutions, interests (which may offer challenges in representing system constraints), and the lack of a consistent and agreed upon conceptual framework to support quantitative modeling.

Several challenges have been identified for using models to better inform management of estuarine systems. Among these challenges, organization, fragmented efforts, and lack of a common vision often overwhelm technical and computational aspects of modeling. Some issues are:

- **Fragmentation and inefficiency**. Modeling today often must serve more than one agency. Much modeling today is sponsored or done by single agencies from their individual perspectives, when the modeling results would have insights for many agencies and interests, and would arguably better inform regulatory and policy, planning, and operating purposes if done with broader agency involvement. Isolated and separated modeling practices often result in costly overlap of efforts and create additional controversy with fewer and less credible insights for management.
    - Lack of a technical and science strategy. A comprehensive and coherent strategy that agrees on high-level efforts, such as the Delta Science Plan, can help overcome these issues.
    - Disintegrated talent pool. Poor access and development of technical talent due to difficulties in contracting and movement of financial resources and expertise.
    - Missed challenges and opportunities. Some problems such as real-time forecasting, scaling and cumulative effects of restoration, and emergency response faced by estuarine systems can be better addressed with thorough quantitative modeling and ready access to data across institutional barriers. Such opportunities are often missed.
- **Cost of analysis.** Agencies have challenges financially and technically supporting institutional capacity across a range of modeling areas of broad state need. This often results on outsourcing of modeling efforts and data management with poor oversight.
- **Declining agency technical capability.** Loss of senior staff and leaders and inadequate professional development for mid-level and senior staff can diminish technical

leadership and capacity in state and federal agencies, jeopardizing technical understanding of estuarine system problems.

- **Intellectual property.** Proprietary models with closely-held data, which can be appropriate for some applications, can also reduce transparency, communication and advancement of technical capabilities and understanding of the system. This also can inhibit peer review and credibility of findings of modeling studies.
- **Slow pace of model improvement.** The pace of changes in problems of estuarine systems and resulting modeling often exceed the pace of model development and application, delaying needed insights. More flexible organizational schemes better match continued model adaptation to contemporary problems.

4. **Problems of management and policy for estuaries usually must involve many interests and disciplines. No single discipline or model is sufficient.**

Today's issues and solutions for large estuaries require the development of technical information which is credible across many agencies and interests, and which addresses a range of management interests. The organization of technical work on the Delta is more centered on disciplinary science and single agency interests than in organizing broader, more complex problems so they can be better understood and solved by the broader community. Institutional and educational barriers to more integrated modeling are formidable, beginning with education and reinforced by the narrowly defined responsibilities of institutions or programs.

Training of technical staff and researchers would benefit from cross-fertilization of disciplines (Ganju *et al.* 2016). Developing more common interagency and cross-program frameworks for modeling and data development also could help. Recommendations of approaches to transition towards more transdisciplinary approaches being considered in other branches of science are discussed in the Delta Science Plan (Delta Stewardship Council 2016).

5. **Several approaches are available for developing an interdisciplinary modeling framework for estuarine policy and management problems.**

The workshop explored several approaches to establishing more effective modeling within the larger scientific, technical, and management community.

Senn *et al.* (2014) evaluated various modeling frameworks for supporting nutrient management in San Francisco Bay by considering peer-review processes, learning curves for end-users, support for technical continuity, adequate resolution and features to cover transport, and scalability. These criteria could be employed for other estuary management issues. The group convened by the San Francisco Estuary Institute (SFEI) for the study, recommended the Deltares framework to support analysis for nutrient management decisions for the San Francisco Estuary. The framework was considered sufficiently robust with a growing user-base, a commitment to open-source codes, and introduction of new modules. A community modeling approach for supporting nutrient management is proposed. NOAA's FVCOM modeling and monitoring effort in operation for the San Francisco Bay and NOAA's Ecological Forecasting Roadmap can help with funding and an existing science program.

The USEPA Chesapeake Bay Program maintains a modeling workgroup that includes federal, state, consulting, and academic expertise (Figure 1). It addresses and integrates a wide range of information for analysis of a wide range of solutions and outcomes, illustrated in the figure below.

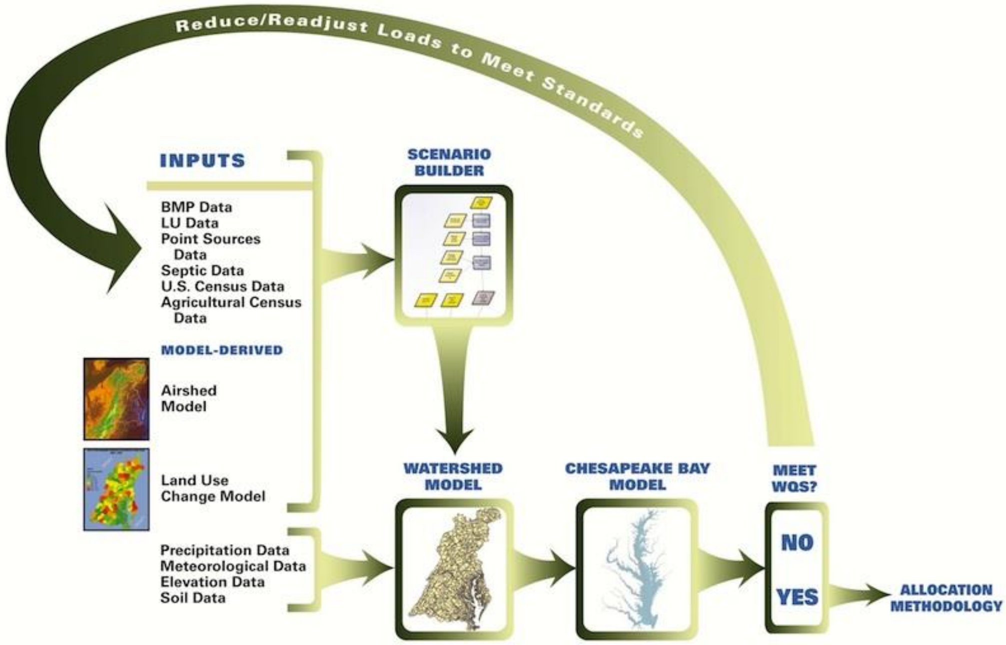

Figure 1. Chesapeake Bay Program

Another example of a hub for interdisciplinary and collaborative research is the University of Illinois National Center for Supercomputing Applications. Research areas include the sciences, engineering and humanities. The facility provides room and workplace arrangements for collaborative research in addition to the supercomputing and digital data capabilities. Activities likely to make the most significant contributions are selected by competitive peer-review.

Conceptual models can help organize and simplify representations of poorly understood or access-restricted environmental systems (Argent *et al.* 2014). However, excessive simplifications can reduce conceptual model usefulness to support predictive models. Argent *et al.* (2014) provide recommendations on conceptual modeling for environmental software development. Desirable practices include:

- Open and transparent model and data development
- Effective communication of concepts
- Establishment and maintenance of simpler models, as well as more complex models
- Create robust and adaptable models
- Use a formal approach to model representation
- Test and re-test models

- Explore model behavior through scenarios
- Ensure conceptual models can be converted into an operational form

Conceptual models have been developed over decades for ecological restoration in the Sacramento-San Joaquin Delta (DiGennaro *et al.*, 2012). This suite of models captures current thinking of experts for a wide range of the contemporary issues, but these models require regular updating to capture new scientific knowledge and physical changes in this rapidly changing system.

Modular approaches often are preferred for modeling complex systems. Modular modeling allows separate processes to be simulated independently and combined as linked modules in simulation of the whole system. Modular modeling allows separate processes to be simulated independently and combined as linked modules in simulation of the whole system, yet appropriate translators can work over multiple operating systems, data scales and formats. Peckham *et al.* (2011) highlight the potential of component-based frameworks in geosciences through the Community Surface Dynamics Modeling System (CSDMS). This tool is open-source and supports serial and parallel computation. The CDSMS framework also allows visualization capabilities through one of their modules, a scientific data open-source visualization tool called Vislt.

Data-centric synthesis is valuable to 1) test hypotheses, 2) support baseline monitoring, 3) give historical perspective, and 4) forecasting in estuarine and coastal systems (Thessen *et al.* 2016). Case studies highlight a framework for data assembly such as discovery, data access, and data integration. Some requirements for building effective data infrastructure which support syntheses are:

- Data providers need incentives and credit
- Data consumers require advanced search and browse features
- Community data standards are needed
- Accommodate and integrate datasets of heterogeneous size and type
- Paths to digitize and preserve data
- Support automated metadata generation and data set indexing
- Link data sources, data repositories, and data consumers in meaningful ways
- Ensure data quality and fitness for use
- Ability to connect with the original data providers when appropriate

CWEMF (2005) makes similar conclusions in recommending criteria for development of data infrastructure and communication tools:

- Integrated broadly-based strategic network for future water problems in California.
- Transparency in data and models, with public data available.
- Technical Sustainability. Models should be able to evolve to accommodate new technology and advances in scientific knowledge. A modular approach can aid sustainability.
- Coverage, spatial resolution should be broad.

- Accountability and quality control.

Challenges in data infrastructure include integration, institutional firewalls, and lack of direct communication between software developers and scientists. Formalizing data distribution standards after project completion may be challenging and are better achieved through data management plans developed at the start of a research project or initiation of a new program. This calls for funding strategies involving agencies and institutions, perhaps involving a provider-pays model and charges for enhanced services. *Enhancing the Vision for Managing California's Environmental Information*, a companion workshop in 2014 provides similar recommendations for data including governance, web services to improve accessibility, shared data sources, and development of business cases to improve prospects for sustainability in data systems and modeling.

Recommendation for Estuarine System Modeling

The Sacramento-San Joaquin Delta serves as the major hub for California's intertied water supply system and provides diverse habitat and ecosystem services. This fragile ecosystem has been stressed by many natural and anthropogenic changes, which have drastically transformed it from pre-development conditions (Yarnell et al., 2015). This diversity of interests, benefits and losses has shaped research supported by government agencies, private and non-governmental organizations, and academics.

This has led to substantially siloed, disorganized, and fragmented efforts that have hindered consolidation of advancing science, data infrastructure and management, modeling, and insights for management in the estuary. Technical capabilities of California's modeling community are at the highest level, yet long-term coordination and integration of efforts lag. The Delta Science Plan (Delta Stewardship Council 2016) and other initiatives seek to close this gap.

We recommend establishing a Delta Modeling Collaboratory, a place for integrating modeling activities across agencies, non-governmental organizations, academia, and consulting firms. The Collaboratory would include a physical location, virtual capability to engage interested parties, and a network of expertise and resources governed by a strategic coordination committee and supported by a common modeling fund. Involvement of stakeholders in providing input on data, modeling needs, and decision support tools is expected. Some comparative benefits of this approach are summarized below.

Concern	Current	Collaboratory
Financial costs and financing	Project-specific modeling and long debates drive high costs and limited usefulness. Competing or duplicative	Economies of scale for general capability, staff, organization, and discussions; reduce duplicative modeling and increase use of

	efforts often involve considerable re-work and expense or confusion.	common datasets. Financed by agencies.
Fragmentation and its inefficiencies	Current costs of fragmented modeling are high due to repetition and confusion in modeling process	Reduce fragmentation and its inefficiencies. Develop insights that span agency and program needs. Common forum to resolve issues.
Maintaining model capabilities	Costly for each entity to maintain separate models, long lags in updates	Lower costs distributed across entities and decision needs; common core and standards
Timeframe of information to decision makers	Drawn out – model selection, model set up, small group directing effort, debates over details, usually informs only one agency	Common models and data more quickly complete studies, better understood. Coordinated modeling delivers collective opinion (and minority opinions)
Integrated understanding	Discipline specialization and dispersed entities challenge integration	Integrated modeling develops links of solution options and water supply, quality, and ecological effects
Prioritizing model and data needs	Difficult to prioritize across dispersed entities with different objectives	Problem-based teams address specific common issues. Coordinated pursuit of priorities. Data management and oversight linked to models.
Expertise and resources	Institutional barriers limit access; require more time	Broad access, available resources, rapid to deploy, enhanced training
Build and retain expertise	Limited career paths within agencies, retirements, fragmented training	Opens career path, collaboration builds expertise, supports agency and program responsibilities.

Community modeling hubs like the proposed Collaboratory exist elsewhere, such as Deltares (Netherlands), DHI (Denmark), HR Wallingford (UK), the Southern California Coastal Water Research Project (SCCWRP), and the US Army Corps of Engineers Hydrologic Engineering Center (HEC, Davis, CA). Other estuaries have established common modeling efforts at regional or federal agency offices (for Southern Florida, the South Florida Water Management District and US Army Corps of Engineers and USEPA for Chesapeake Bay). This philosophy does not advocate for a single model or institution, but rather encourages a range of models of the same genre and of interfaces between discipline specific models.

Modeling for short-term response to flood and drought should be high on the priority list. Major initial tasks would also include establishing data infrastructure and web interfaces with visualization and descriptions of data and modeling results. Permanent areas of work would include model development, refinement, application, and identification of knowledge gaps for hydrodynamics, water quality, fish and ecosystems, water operations, and economics. Model outcomes for the areas of work mentioned above will be reported with uncertainty and sensitivity analysis.

Pooled funding from the major agencies involved in the Delta will secure an operating fund to support base infrastructure for the Collaboratory. Additional resources for special activities can be requested from federal programs (including NSF), state programs, NGOs, and private foundations. A similar approach for modeling and data development collaboration would likely benefit groundwater management among state and local agencies under the California 2014 Sustainable Groundwater Management Act.

Establishing a Collaboratory

A successful Modeling Collaboratory for the Sacramento-San Joaquin Delta would require:

- Funding
- Leadership and collaborative governance
- Physical infrastructure
- Business capability, including contracting and interagency agreements
- Intellectual property policy for models and data
- Acquisition of staff by hiring, loan or joint appointments

Several approaches could be taken to establishing such a modeling Collaboratory.

The development and application of models and data would need to involve a broad network of potential collaborators. An incomplete list of potential participants includes:

- State Agencies: Department of Water Resources, State Water Resources Control Board, Delta Stewardship Council, Department of Fish and Wildlife, Delta Conservancy, Delta Protection Commission, Department of Boating and Waterways
- Federal Agencies: US Bureau of Reclamation, Fish and Wildlife Service, National Marine Fisheries Service, US Geological Survey, US Environmental Protection Agency, US Army Corps of Engineers, DOE National Laboratories
- Universities: University of California, California State University, Stanford University, University of the Pacific
- Non-Governmental Organizations: San Francisco Estuary Institute (SFEI), The Nature Conservancy, California Trout, Natural Resources Defense Council, Environmental Defense Fund, Public Policy Institute of California,

- Local and Regional Governments and Water Contractors: Sacramento Metropolitan Sanitation District, State and Federal Contractors Water Agency, Contra Costa Water District, Metropolitan Water District of Southern California
- Private consultancies: which offer a range of specialized and general modeling, technical, and management expertise and would be an essential component of a successful and sustained collaborative modeling effort.
- Stakeholders: input on research questions, data and modeling needs.

Governance would be a major issue to be worked out, as would responsibilities for funding. A modest base funding for building space and central administration would be supplemented by funding for specific projects by agencies and research grants.

Although much of the work would be done in a decentralized way, a central location is needed for much of the detailed work and coordination. It is expected that the location will include workspace for individuals assigned to work on specific problems, visualization and smart meeting space (to allow active participation for individuals not physically present). Computational and data storage could be provided by an entity such as the UC San Diego Supercomputing Center. The Collaboratory would have a small permanent staff, with substantial rotating staff from agencies and other entities involved in modeling projects, to support development and maintenance of modeling expertise in member agencies and organizations and improve the abilities of agencies to collaborate on a range of technical and scientific issues. The physical location of the Collaboratory could be in Sacramento or West Sacramento (nearest most of the major modeling agencies), near the UC Davis campus (in or near Davis), or at SFEI in Richmond, California, with the hosting institution being responsible for providing (but probably not funding) physical infrastructure. One of the agencies, a joint powers authority (JPA), UC, or SFEI could be employed to provide the needed business services.

CWEMF (2005) identified some immediate actions for managing water systems in California that also apply to the Delta:

- Establish and coordinate modeling purposes and objectives through a collaborative process
- Conduct critical reviews of data development efforts and assess uncertainties
- Acquire and maintain modular models and communication tools
- Develop a plan for long-term institutional and financial support

Common standards of practice and modeling will be an initial building block for improving transparency and organization of data and models. Initial workshops can brainstorm and improve prospects for adoption of such standards.

Implementation of a Collaboratory should include short term and long-term actions. Within the first year, an initial step would be development of a Collaboratory proposal under the authority of DPIIC in consultation with major stakeholders. This step could include a pilot project to demonstrate the value of the Collaboratory. Contemporary topics for this Pilot could be the prediction and estimation of Delta Outflow or the real-time simulation of temperatures in Shasta Reservoir and the Sacramento River (e.g. NMFS temperature models). Governing boards and formalization of funding agreements will follow based on the experiences developed in the Pilot. A common modeling and data development plan and framework would encompass hydrodynamics, water quality, ecosystem, economics, and operations. During the second year, the Collaboratory physical venue will be established along with the development of integration efforts and cooperation mechanisms.

An initial form of a Collaboratory might be established with seed funding from agencies using existing infrastructure from the University of California. Venues for meetings, visualization of data and modeling results, and an operation agreement could begin the business model and evolve into a fuller Collaboratory framework.

Conclusions

Complexity in estuarine systems calls for integrated and community-based approaches for using and developing models and data. Environmental and hydrodynamic models have helped organize and extend knowledge and predictions for physical, biological and chemical aspects. However, specialization has often steered science and management to fragmentation among models, data, and management of estuarine systems. Integration of models and data in platforms that increase collaboration, interdisciplinary work, organization, and transparency have been successful in other systems. The Sacramento-San Joaquin Delta can benefit from a Collaboratory approach where a physical venue would provide a hub for a network of agencies, academia, non-governmental organizations, and industry to better address major modeling, data, and management issues. This Collaboratory would arrange for basic information technology, visualization, meeting, and communication infrastructure for more coordinated and broadly credible modeling results for use by the broader policy-making community. Limited staff would support and facilitate basic infrastructure and interactions among various organizations. A Collaboratory framework would help advance the usefulness and broad credibility of science, data, and models to face the future environmental management challenges of the Delta and could be easily applied in similar systems elsewhere.

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