REALM Description and Status

Delta Modeling Section, DWR

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Description

To understand and solve the Bay/Delta's complex problems, computer modeling tools are needed that are accurate, fast, and capable of producing results within a sophisticated study framework—more than simple trial and error model simulations.

Current models meet some of these requirements but not all. 1-D models are fast but too simple for many questions. 2- or 3-D models offer more detailed results but may be too slow. Current models make little use of systems analysis techniques such as optimal control, data assimilation and model steering. These are tools which allow questions to be posed in a sophisticated way and facilitate understanding complex tradeoffs. Finally, few models have been effectively connected to Geographical Information Systems (GIS). This capability is important in order to study flow, water quality, and particle tracking results together with more general environmental data such as habitat areas.

Delta Modeling Section members Ralph Finch and Eli Ateljevich, under the direction of the Section Chief, Tara Smith, have initiated a project to develop the River, Estuary, and Land Model (REALM). The goal is to create a public model that offers performance and decision-making support that is not available in models now. The Section believes that the technologies brought to the project by key partners will allow development of a model with capabilities that would otherwise be difficult to achieve.

Features

REALM will have features typical of current models, including 1-, 2-, and eventually 3-D hydrodynamics and water quality transport, and particle tracking. The model will also include features necessary to solve important Bay/Delta questions, such as the tidal or seasonal wetting and drying of areas, non-conservative constituents, wind effects, and particle tracking behavior.

To improve numerical accuracy and speed, REALM will use the computational infrastructure developed by Lawrence Berkeley National Laboratory (LBL), one of our two key collaborators. REALM will use parallel processing, Adaptive Mesh Refinement (AMR), and embedded boundaries to greatly improve speed and to concentrate computational effort in regions that are particularly difficult or of interest in a study.

REALM will also include systems analysis to make decision support, policy analysis, and real-time Delta management easier. REALM will provide:

- Model Steering: operating rules for boundary conditions and hydraulic devices that are managed adaptively (e.g. gates or pumps that are opened or closed depending on the state of the Delta such as water quality or stage values).
- Optimal control and data assimilation methods to make real-time control for O&M more accurate.
- Multi-objective analysis and visualization to let users see the tradeoffs between competing objectives, such as stage, exports, and water quality.
- Geographical Information System (GIS) for data storage and visualization.

REALM will not be initially released with all features in place. Instead, the first release will have only a subset of all features it is expected to eventually have. Feature priority should be driven by real-world problems and computational issues. For more information, see Appendix A.

Current Status

In December 2003 a contract programming expert was signed, Xiao Wang. A GIS contract was awarded in January 2004 to the Michael Thomas Group and started in March 2004. The LBL contract is expected to be finalized for next Fiscal Year (2004-05).

Project meetings are held weekly to move the project from concept to design and address technical issues as they arise. Management meetings are held monthly with the Modeling Support Branch Chief, Francis Chung, to discuss and resolve administrative issues and review progress.

For the past several months, Eli has been working on REALM in consultation with Lawrence Berkeley Laboratory (LBL). Prototype 2D flow and transport solvers have been developed and applied by Eli to simplified test problems but the solver has yet to be applied to Delta geometry. Results from the mass transport solver is shown in Figure 1.

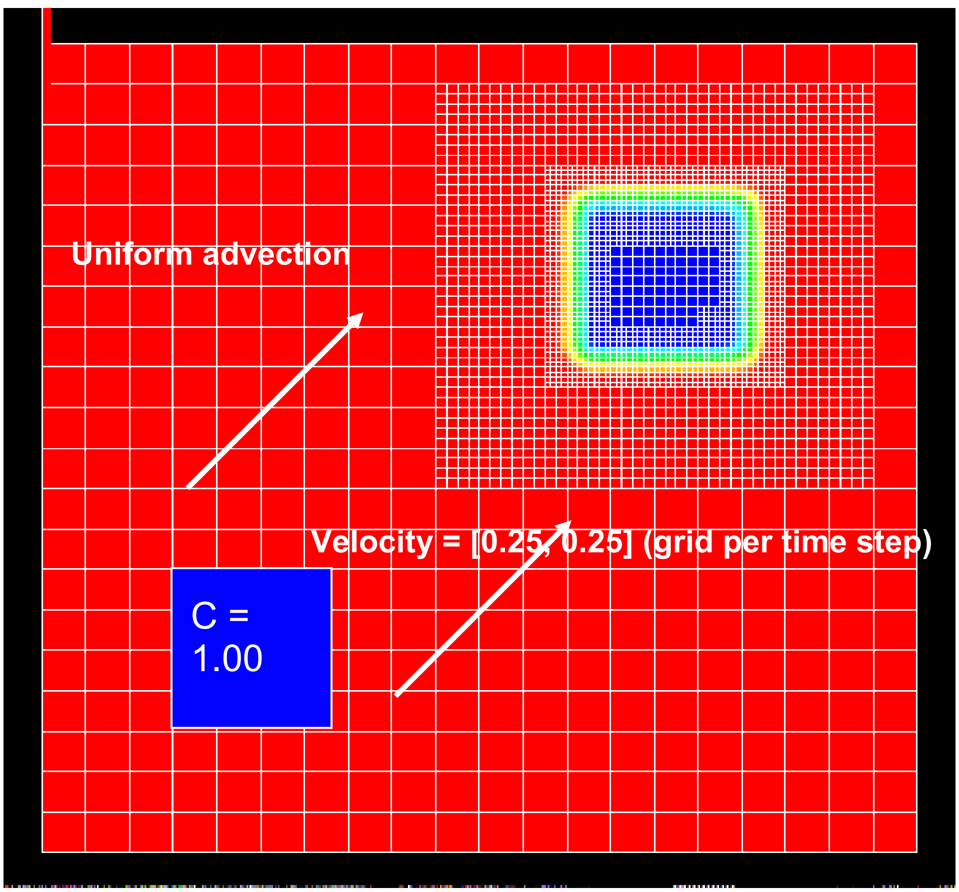

Figure 1. Advection in a uniform velocity field, showing Adaptive Mesh Refinement

Figure 1 illustrates the use of one of the LNBL computational techniques, Adaptive Mesh Refinement (AMR). This feature calculates the required grid density on-the-fly throughout the problem area, increasing the density where more grid points are needed to maintain accuracy, and decreasing the density where possible to lessen computational demand. Other LBNL features available are embedded boundaries (allowing accurate boundaries in rectangular grids), and parallelization libraries.

Some features planned for REALM have been tried using a new version of DSM2 as a test platform. This improves the functionality of our current Delta model and allows us to experiment and learn about proposed REALM features in a simpler environment. Features implemented in this manner in DSM2 include connection to a relational database for all non-time-varying data; a Graphical User Interface (GUI) to allow users to access and edit information in the database; new ways of implementing gates; and partial use of operating rules, limited to hydrodynamic parameters such as stage and flow, and gate operations only.

Funding Scenarios

We developed three scenarios with different financial resources. All scenarios lead to a fully functional 1D-2D hydrodynamics and water quality model with GIS graphical support and particle tracking by the end of 2006. The model will include support for adaptive mesh refinement (AMR), embedded boundaries and parallelization, and wetting and drying.

The scenarios differ in the timing and number of features offered. In the low and medium budget scenarios, it is possible to complete some advanced computational features such as 3D modeling and adjoint optimization capabilities, but not to package these features in a turnkey application within the 2006 planning horizon. Dollar amounts are totals over 3 years.

Comparison of Deliverables Near the End of 2006

Features/Funding Levels	**Low**	**Med**	**High**
Calibrated model 1D-2D	Jul 2006	Mar 2006	Jan 2006
3D solver (no GUI)	Dec 2006	Aug 2006	May 2006
3D full application			Jul 2006
Optimization capability (adjoint)	Mar 2006	Dec 2005	Dec 2005
Multi-objective optimization with GUI	> 2 years	> 2 years	May 2006
Real-time data assimilation, no GUI (Kalman filter)	> 2 years	Jun 2006	Feb 2006
Real-time data assimilation application	> 2 years	> 2 years	Apr 2006
Automated calibration	> 2 years	> 2 years	Sep 2006
1D-2D technical docs	Minimal (usage only)	Minimal (usage only)	Full with tutorial (Jan 2006)
3D, particle, graphics documentation	> 2 years	> 2 years	Sep 2006

Appendix A

Feature Priority and Interview Responses

- *Relevance*
  Features should solve problems of high benefit to the Department, SWP, Delta operations, and State water in general. The problems should be important enough that solving them is compelling.

- *Not solvable by other means*
  Problems should not be solved yet, and be largely or entirely unsolvable with other means or tools. Or, other tools will only give approximate or qualitative solutions, when a REALM feature could provide a precise, quantitative solution which makes a substantial difference in benefit.

- *Ease of implementation*
  Features easy to implement, even though marginally useful, might be preferred over difficult implementations.

It was important to identify real-world problems that a REALM feature could solve. We felt the best way to do this was to talk with workers with a history of direct involvement in solving Delta issues. The interview question and responses are given below.

We posed a general question to engineers, environmental scientists, and managers:

"What problems or questions in the Delta would you like to resolve, that you cannot because of limitations in current tools? What problems would you solve if tool limitations were not an issue?"

The following is some of the replies we received. Some interviewees preferred their answers not be included.

1. *Pat Brandes*
   US Fish and Wildlife Service
   pbrandes@delta.dfg.ca.gov
   Conversation February 26, 2003

   - When juvenile salmon (3-6 months) enter the Central Delta, their survival rate is 3 to 20 times worse than if they do not enter the Central Delta. Why is this?
   - There exists much old coded-wire tag data (time and place of release and capture of fish). Would like to incorporate with models to get new insight (model calculates water flow, make inferences about fish movement). See if it could help us better understand how the fish move from one area of the Delta to another.
   - If young fish swim near the surface as it moves seaward it would help them migrate to sea, once they reach that section of the Estuary. If spawning fish tend to migrate near the bottom as it moves landward it would also help them in their migration upstream to spawn. It would be great to model this type of behavior better.

2. *Bruce Herbold*
   US Environmental Protection Agency
   Herbold.Bruce@epamail.epa.gov
   Email March 7, 2003

   - Use to compare and optimize alternative delta ops; this could be short term like the operators, but also planning to see how different proposed tools or rule relaxation would allow changes in exports, WQ.
   - Use to refine permit and regulatory conditions to achieve desired results
   - Use to improve particle tracking so that 2- and 3-D velocity patterns at breaks more accurately reflect conditions facing fish, salmon, striped bass eggs and larvae, smelt larvae, etc. in effect a physical transport model, This could then also start to realistically incorporate our understanding of fish behavior as we acquire it -- i.e. day/night, shallow seeking, staying within a certain amount of light penetration, etc.
   - Put in different BOD, transparencies, contaminant discharges to better mimic O2 depletions, phytoplankton growth, bacterial growth, WQ impacts. I.e. an ecosystem oriented flow model.

3. *Ted Sommer*
   DWR, Div. Of Environmental Services
   tsommer@water.ca.gov
   Conversation March 7 and 10, 2003

- Particle Tracking
  - More complex hydrodynamics need around e.g. 3 Mile Sl, Sherman Island, to correctly model particle movement.
  - Must add behavior, otherwise not worth doing; behavior such as moving up and down in the water column to catch differential flows; "surfing" the tides (Delta Smelt).
- Temperature Distribution, interest here is in geographical range and number of days of correct temperature range for a species.
- Wetting/Drying on a seasonal (flood plains and flooded islands) and tidal basis
  - Velocity distribution, depth, aerial extent e.g. Yolo Bypass
  - Duration of tidal flooding
  - Not interested in transient response of particles during a levee break (only for water quality interests)
  - Wind effects in shallow areas (< 6 feet) of much interest
- Better GUI
- 3D movement of particles (horiz as well as vertical); inshore/offshore behavior (e.g. Delta smelt move between channels and shoals, e.g. ship channel to Grizzly Bay).
- Ag diversions, model locations individually rather than lumping. May need very detailed model of very local area (Sherman Is) (Matt Nobriga).
- Run model by biologists
  - change behavior of particles
  - input distribution of particles, run on given hydrodynamics
  - realtime hydro, place particles in realtime run

4. *Marianne Kirkland*
   DWR, Div. Of Environmental Services, Aquatic Restoration, Planning and Implementation
   marianne@water.ca.gov
   Conversation March 19, 2003 and follow-up email

I'd like to model the Sacramento River system, focusing in particular on the Sutter Bypass and Yolo Bypass under flows ranging from 200 year events to conditions when only ponds and low flow channels contain water. At this point I've only been working in Yolo Bypass, but I think Sutter Bypass has great potential for improved native habitat, too. The rest of the Sacramento River system is of interest to investigate flood control benefits/impacts, but I don't think it would need to be modeled in the same detail as described below.

The first problem I'd like to solve is to model the filling and draining of the Yolo Bypass at a field-by-field scale (~2000 fields, ~1/16 mile scale, 2-3 ft berms). The Yolo Bypass partially or completely floods from incoming water from one or more of six locations along its 40 mile length. The southern portion of the bypass is in the Delta, and is tidally influenced. Much of the gradually south-easterly sloping Yolo Bypass is separated into agricultural fields (rice ponds, duck ponds, etc.) by low berms and ditches.

At high flows, these surface elements don't appear to be influential. There appears to be little mixing due to the shallowness of the flooded water relative to the horizontal extent of it. At lower flows, fields flood sequentially after neighboring fields do (imagine the dimples of a waffle being filled with syrup). As the bypass drains, water flows off from east to west and from north to south. After water that can drain off does, some fields may still retain water due to perimeter berms. These fields may not be available to agricultural use until they finish drying out by percolation.

Given incoming hydrographs, I'd be interested in predicting the time to wet and fill discrete fields, and duration of inundation. This would help describe current conditions, and the effects of any proposed changes to the Bypass on individual landowners. I imagine this problem to be a common one along rivers that border agricultural land. Not sure about specific rivers.

GUI: show results, gradual filling and draining; animation. Some other phenomena that it would be interesting to model include:

Levee overtopping from Feather River into Sutter Bypass - this may already be possible.

The collision of East-flowing Sacramento River water with South-flowing Sutter Bypass water just north of Yolo Bypass (streamlines, turbulence, and velocity distribution). This would be informative from an erosion/sediment accretion standpoint, which has application to flood management maintenance costs, river geomorphology analysis, etc.

Mixing of sediment and other WQ constituents at the above site and within the Bypass (portray water from different sources as different colors?) This would be informative for potential habitat restoration and water treatment projects because it could identify where contaminants were being stored in the system, and where contaminants and sediments continue on to the Delta.

5. *Paul Marshall*
   DWR, Bay-Delta Office, Delta Planning Branch
   marshall@water.ca.gov
   Conversation March 21, 2003

   - Fish effects (particle behavior); in addition to particles moving up and down in water column, need to add **swimming behavior** e.g. swimming against flood tide, and with an ebb tide, to move out of the Delta faster.
   - Need more accurate fingerprinting with 2D model for e.g. EPA Source Water Quality Standards.
   - Non-conservative constituents.
   - Need sediment transport of bed loads, i.e. movement of bottom sediment ('dunes"), not so interested in modeling suspended sediments. This is to deliberately engineer channel dredging so they will "self-dredge" if possible, for better water conveyance.

6. *Art Hinojosa*
   DWR, Operations and Maintenance, Operations Compliance & Studies Section
   hinojosa@water.ca.gov
   Conversation March 26, 2003

Art basically needs a tool that can predict the future. In his case the future depends on accurate data and an accurate model; REALM can help with the model and some with the data (data assimilation using adjoint operators).

Current use of DSM2:

- Run once a week and look at results 2-3 weeks forward.
- Can't input weather:
  - Low pressure
  - Wind; in particular strong winds from the west

Both affect stage, which in turn affects salinity. Salinity (WQ) is target parameter.
Even though weather can't be accurately forecast, bookending in the model would be useful.
DSM2 can't accept wind or baro effects (could we provide a separate translation to stage effect?)

There may be new WQ parameters of interest in the future besides salinity, such as temperature and DO in the SJR, which O&M will have to deal with on a day-to-day operational basis. He was aware that DSM2 did these, but not aware of the extent of Hari's work with those parameters.

- Carriage Water estimates. They run DSM2, trial & error, to estimate CW costs of transfers. A fast estimator based on ANNs would be helpful here. They also have an immediate need for a monthly-to-daily data converter which we already have.
- Land use. WQ in Rock Slough is not always an ag problem, they believe that sometimes the Ironhouse Sanitation District floods fields adjacent to the CC Canal with treated effluent, which seeps back into the Canal. They would like to model this.
- Need an accurate groundwater model to estimate seepage from river/aqueduct into the underlying groundwater table, which water right holders (farmers) pump as in-lieu supply. O&M wants to know if the "groundwater" is in fact coming from the Project.
- Middle River water levels and Consumptive Use; need accurate CU estimates. Need good estimates of ET (Western Water).

- DCC gate operation is based on WQ—they have some "leading indicator" stations to help with this.
- Clifton Court Forebay Operation.
  - Try to pump an average of 6680 cfs, but it's done in gulps of up to 9000 cfs for a few hours—this is motivated by energy and reliability of water supply (get the water pumped today when you know you can).
  - Can try to pump on a flatter schedule.
  - Gates are driven by stage in CCFB, not WQ.
  - Field Div operates gates. They are given closed periods each day by HQ, the closed periods being when to protect S. Delta stages.
  - WQ not a factor as to when to open gates, fairly constant over tide cycle.
  - Power dominates day-to-day SWP operation.
  - Ability to transfer water dominates Delta operation.
  - WQ is only a constraint, not a variable. Water Volume much more important to contractors.

7. *Tara Smith*
   DWR, Bay-Delta Office, Delta Modeling Section
   tara@water.ca.gov
   Conversation April 7, 2003

- Improved accuracy
- 1-, 2-, & 3-D capability
- Triggers to allow changes in operation
- Robust, that is, model different hydrologies well
- Implement at least DSM2 Hydro, Qual, PTM and non-conservative constituents
- Easily expanded beyond Delta (both upstream and downstream into aqueduct)
- Reservoir modeling—mainly temperature desired
- Easy to calibrate, including different versions of computational detail (1, 2 3D; different grid densities)
- Easy to port to new computers
- Easy to modify quickly
- Can change model dimension depending on needed accuracy
- Model levee breaks (dynamic)
- Model wetting and drying
- Ease of entering observed data into system [or, using observed data]; no explicit importation of data
- Better interface with statewide planning models such as CALSIM
- Water quality mass calculations—what is WQ at treatment plants?
- Particle behavior—triggered by age, WQ, flow, etc.
- PTM—screens to block out particles but pass water
- Precipitation & evaporation
- Easily generated graphics for reports & web page
- Easy to use
- Well documented
- QA/QC process to check inputs & model outputs
- Forecasting
- Hindcasting—streamlined process
  - Validating model
  - Kalman filter
- Animation—1-, 2-, 3-D

    - Water Quality
    - PTM—movement, bar charts
    - Flow/stage—whole Delta & time series
    - Source water—different colors?
- Fast computational time
- Graphics—tidal volume, pumping
- If extended upstream—graphics of reservoir releases & temperature
- In-Delta Storage
    - Two operating rules, one for pumping in, the other for pumping out
    - Pumping in, two factors:
        - Normal WQ standards
        - DOC of pumped water, tends to increase in island
    - Pumping out, one factor—DOC at export pumps. Therefore DOC of pumped water months before important—**optimization problem**
- PTM—instead of asking "how many more fish are entrained with 50cfs increase at Banks", ask, "how much can we pump to increase entrainment to X value"—**control problem**

8. *Curt Schmutte*
   DWR, Bay-Delta Office, Levees and North Delta
   schmutte@water.ca.gov
   Conversation April 24, 2003; Tara Smith attending

Curt's emphasis was on a vision of Delta restoration he is pursuing called "landscape gradient". This is a large swath through the Delta beginning from Martinez, through Suisun and Grizzly Bays and the Suisun Marsh, then along the Sacramento and San Joaquin Rivers and the islands between them. The gradient refers to the physical elevation gradient there, and also hydraulic, salinity, and ecological gradients.

He sees almost all issues--hydraulics, salt, subsidence, biology, carbon, seismic--as interconnected.

One of Curt's ideas is that exotic species could be reduced, and native species helped, by reproducing at least somewhat the historically variable salinity regime. That is, change pumping and allow Delta salinities to increase for a brief period, on the order of weeks, by manipulation of upstream releases and flooded island operations. Then bring down the salinity so pumping can continue. The increase in salinity should drive out non-native species, assuming they are not adapted to varying salinity conditions like the natives are.

Curt also wants to make sure that the Suisun Marsh is not artificially separated from the Delta.

A couple of points were made with respect to future models. Curt thinks understanding the estuary hydrodynamics is absolutely critical for future operations. This implies REALM's optimal controller feature. Tara asked about the transient salt rise should a levee fail, and how would the Delta salinity be brought back down in an optimal manner? This again implies the need for optimal control.

9. *Gwen Knittweis and Monica Martin*
   DWR, Bay-Delta Office, Levees and North Delta
   gwenk@water.ca.gov
   Conversation May 8, 2003

Gwen is a Senior Engineer under Curt Schmutte. She acts as project manager for the North Delta Flood Control and Ecosystem Restoration Project, a CALFED implementation project.

She needs accurate modeling of climate change affects, in particular due to sea level rise and precipitation or hydrology pattern changes, and their impacts on the Delta and SWP operations.

Gwen's biggest concern in the interview was sediment: its transport and mercury content. Transport is important for both flood control and habitat restoration. They need to know and model (forecast) not only simply where it will go, but they need to control its movement, for instance, to create shallow water habitat, marshes, and wet/dry areas for native species.

Mercury in sediment is a very significant problem. Through a process called methylation—influenced by DO (anaerobic conditions), temperature, and organic carbon—the mercury moves out of the sediment and into the food chain. Unfortunately conditions or habitat good for native species seem conducive to create methylation. This must be modeled throughout the vertical water column.

Exotic species invasions are a problem. By controlling water depth, wetting/drying, temperature, DO, and water "stagnation", i.e. velocity, natives can be encouraged and exotics discouraged. Organic carbon and THMs also need to be modeled.

Subsidence reversal is another key task. This can be encouraged with deliberate control of sedimentation, but also involves encouraging specific plant growth which will build up organic layers. They also need to understand, model, and control the underlying causes of subsidence.

The seismic response of levees is important. Transient parameters in the Delta during a levee break are not so important, but the long-term effects are (e.g. Franks Tract).

Finally, for flood modeling, they need something that can do everything HEC-RAS can do. Gwen mentioned the importance of the momentum term and accounting for backwater and "jet" effects that create more erosion.

10. *Bob Suits*
DWR, Delta Modeling Section
suits@water.ca.gov
Conversation May 8, 2003; Eli and Tawnly attending

Bob is very familiar with South Delta issues and the interview was largely about that.

The main concerns in the S. Delta are circulation and stage levels. Lack of circulation (water movement between the San Joaquin east side and the seaward west) causes salinity and DO problems. Dischargers (e.g. City of Tracy treated sewage) are causing more problems.

Velocities are berm islands, scouring potential habitat, is a problem, along with siltation of intakes, thus sediment transport modeling is needed. More detail in general is needed in the S. Delta.

Realtime management in the S. Delta is becoming more important. This includes forecasting 1-2 weeks such parameters as stage, flows, DO, salinity, and fish movement. Then actions to possibly take would be gate operations to control parameters within max/min limits: min particles (fish) that should reach the Forebay; min salinity in S. Delta and export water; min DO in S. Delta; stage levels; and velocities.

Reducing salinity and increasing water levels often conflict, that is, circulation is poorer when stage is increased.

Realtime modeling could allow the DWR to take advantage of rather short term events.

A new model should also act as a learning tool for the Delta.