Yolo Bypass MIKE-21 Model Review: Strengths, Limitations and Recommendations for Refinement

By

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With

Yolo County and cbec eco engineering

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FREMONT WEIR AT HEAD OF YOLO BYPASS, MAY 2008 (LEFT) AND JANUARY 28 2010 (RIGHT) - NHC PHOTOS

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YOLO BYPASS MIKE-21 MODEL REVIEW: STRENGTHS, LIMITATIONS AND RECOMMENDATIONS FOR REFINEMENT

PURPOSE

This report summarizes the strengths and limitations of the MIKE-21 Yolo Bypass model prepared by cbec eco engineering (cbec), identifies areas requiring further model review, and identifies recommended model refinements.

BACKGROUND

The state and federal government are developing the Bay Delta Conservation Plan (BDCP) to improve water supply reliability and restore ecosystem functions within the Sacramento-San Joaquin Delta. A central BDCP component includes the implementation of various conservation measures that are intended to improve habitat for sensitive fish species. BDCP has identified Conservation Measure #2 within the Yolo Bypass, which includes the construction of a notch in the Fremont Weir and the installation of operable gates to lower the height at which Sacramento River water can flow into the Bypass. Conservation Measure #2 will increase the frequency and duration of flooding of the Yolo Bypass which is intended to improve fish habitat.

To estimate the “footprint” (i.e. location of inundated acreage) of additional flooding from an operable gate in the Fremont Weir, Metropolitan Water District of Southern California (MWD) and the Department of Water Resources (DWR) separately contracted with cbec to develop a two-dimensional, flexible mesh MIKE-21 hydrodynamic simulation model for the Yolo Bypass (cbec’s MIKE-21 Yolo Bypass Model). This model has been used to develop approximate extents and depths of inundation in the Bypass for several assumed steady state flow release scenarios and historical flood events at the Fremont Weir. Graphical displays of the MIKE-21 Model results provided to DWR and others visually display the inundation that might occur within the Yolo Bypass associated with different steady state and unsteady, historical flow release scenarios at the Fremont Weir. Given the importance of accurately estimating the approximate extents and depths of inundation because of the potential impact of flooding on existing land uses, Yolo County contracted with Northwest Hydraulic Consultants (NHC) to review the underlying assumptions in the MIKE-21 Model and to describe its current strengths, limitations and recommendations for refinement.

MIKE-21 is a modeling tool which uses numerical algorithms to approximate flow properties under user-specified conditions. The level of accuracy of the results provided by MIKE-21 is strongly dependent upon the level of accuracy of the user-specified information. Such information includes the bathymetric and topographic data used to create the computational grid, the refinement of the grid itself, channel and floodplain roughness values used within the model, and the correct flow boundary conditions located at the correct locations throughout the model. NHC’s review was founded on the understanding that the reliability of two-dimensional numerical models, such as MIKE-21, greatly depends on how well the user-specified information reflects the intended application of the model. The purpose of the model and the specific hydraulic questions the model is intended to address defines the necessary detail for various scalar and temporal components of a model's structure, its boundary conditions and key operational parameters. Determination of the flood conveyance capacity of the Yolo Bypass and water levels that may occur during a 100 or 200-year flood, for example, relies on data with significantly different levels of detail compared to much lower flow conditions associated with releases through an operable gate at the Fremont Weir. A numerical model is considered to be ready to produce reliable results only if the questions and problems to be addressed by the model are properly defined, all of the key input data have been thoroughly checked, and if model sensitivity, calibration and verification analyses have been carefully completed.

The following discussion provides a brief summary of NHC's findings regarding the cbec Yolo Bypass MIKE-21 Model. These findings are based on the information that has been received to date (see references). Further reporting regarding the ecological modeling analysis and results has been completed by cbec and is currently being reviewed by DWR. DWR has indicated that this additional reporting will become available this summer.

STRENGTHS OF CBEC'S YOLO BYPASS MIKE-21 MODEL

MIKE-21 is a depth-averaged two-dimensional (2-D) numerical modeling tool designed to simulate water levels and flows in rivers, estuaries, bays and coastal areas. It can simulate both steady-state (constant) flow conditions or unsteady (time varying) flow conditions in the two horizontal dimensions. This proprietary modeling tool was developed by and can be obtained from DHI Water & Environment (DHI) in Denmark.

Unlike one-dimensional models, two-dimensional models are intended to simulate more complex flow conditions (flow direction, depth and average velocity), which may vary laterally across the width of flow or include flows with variable directions. These models require the user to input a network of ground elevation points throughout the entire area to be modeled, not just at widely spaced cross sections. A network of computational cells (triangles or quadrilaterals) containing this information is then used by the model to determine the water surface elevation, average flow velocity, flow depth and flow direction at each computational point in the network of cells. There can be hundreds of thousands of computational points in a detailed 2-D model, depending on the level of detail required to address a particular flow scenario.

The cbec MIKE-21 Model uses a "flexible mesh" version, which allows the user to specify small, closely spaced computational cells in areas where greater detail is needed to capture complex flow conditions. A typical application of a two-dimensional model would be to resolve complex flow conditions at a confluence of two rivers where pockets of high velocities may form with large recirculating eddies across the channel. Another application includes flows that occur in river and floodplain areas where a single-channel or multiple-channel river spreads laterally out onto a complex floodplain with variable flow directions, depths and velocities (e.g., similar to how the toe drain and Yolo Bypass fill and empty during floods). To help accomplish this for the Yolo Bypass, cbec used available LiDAR data (DWR, 2005) for Yolo Bypass floodplains and collected additional bathymetric data along the Tule canal/toe drain in 2009-2010 and measurements of the I-80 and I-5 causeway abutments and railroad trestle features in the Bypass. Cbec subsequently informed us that some of these data were reviewed, checked and summarized through the following methods and documents:

- 2009 Toe Drain surveys by Environmental Data Solutions (EDS) were undertaken to USACE approved QA/QC protocols.
- 2010 Toe Drain/Tule Canal surveys by cbec included reporting of QA/QC performed (cbec 2012).

These documents were not available or reviewed by NHC during the preparation of this report.

MIKE-21 is a highly respected modeling tool that comes with all of the standard hydrodynamic modeling capabilities needed to assess frequency and duration of flooding questions in the Yolo Bypass. It is well documented and comes with detailed users manuals. DHI provides limited technical support to licensed users of the model. However, as with all numerical models MIKE-21 is strongly dependant on user specified information including: inflow boundary conditions, tides, channel and floodplain roughness (including ground surface conditions, vegetation, cropping, cultivation patterns), floodplain topographic details, channel bathymetry, characteristics of flow obstructions and other required model parameters such as eddy viscosity and bed friction.

LIMITATIONS OF CBEC'S YOLO BYPASS MIKE-21 MODEL

Beginning in 2008, several different numerical models (one-dimensional and two-dimensional models) were developed by different groups for different purposes, using different assumptions and data to assess a variety of BDCP questions and issues. Currently available reports describing the development, application and results from cbec's MIKE-21 model of the Yolo Bypass do not provide sufficient details regarding the MIKE-21 model's purpose, its development and testing, sources and reliability of input data used to define key boundary conditions, modeling parameters and modeling assumptions. This lack of reporting detail regarding cbec's Yolo Bypass MIKE-21 model, and similarly several of the other models, makes review and comparison of current modeling results difficult for Yolo County resource managers. Based on a review of readily available reporting and discussions with DWR and cbec modelers, the following is a list of limitations associated with the current version of cbec's Yolo Bypass MIKE-21 model. The review included information provided in a recent memo from cbec dated June 18, 2012 entitled *MIKE 21 2D Yolo Bypass Model Strengths and Limitations* (cbec 2012b).

1. Limitations related to Topography and Bathymetry

cbec (June 2012) state that "the accuracy of the Bypass model results are controlled by the accuracy of the topography and bathymetric data sources; the mesh size and resolution; the accuracy and reliability of the boundary conditions (inflow hydrographs); the spatial, temporal and depth-dependent hydraulic roughness conditions; and the stability of the numerical (computational) scheme and its ability to handle wetting and drying." The reviewers agree that these model development considerations control the accuracy of the MIKE-21 model and other models being applied to the Yolo Bypass. Based on this understanding, the following are specific MIKE-21 modeling limitations and concerns.

A. **Some topographic data are inaccurate.** cbec describes inherent topographic inaccuracies due to LiDAR information affected by returns off ponded water, floating vegetation and dense riparian corridors, LiDAR flight timing, and because there are missing portions of the West Side LiDAR coverage in the non-leveed portion of the Bypass. The steps necessary to check and correct these potential inaccuracies need to be identified, but they will generally include additional detailed surveys. Similarly, low profile topographic features such as agricultural roads, berms, swales, graded break lines, rice checks, rice check gates and culverts, and irrigation and drainage ditches may not be discernable in the current LiDAR data (see discussion below), which is equally important when modeling field-to-field flooding and draining processes during low to medium flow conditions in the Bypass.

B. **Some topographic detail is insufficient.** The topographic detail may be insufficient in low areas adjacent to the Toe Drain and Tule Canal to accurately depict where and when lateral breakout flows leave the canal and spread out onto the floodplain. Inaccuracies in these areas could also affect how return flows drain back into the Toe Drain (draining and drying of the floodplain). cbec further identified large areas where insufficient topographic detail is available to accurately describe how flows discharging from west side tributaries (i.e., Knights Landing Ridge Cut, portions of Willow Slough outlet, and Putah Creek) spread out and eventually discharge into the Toe Drain or Tule Canal. An accurate depiction of shallow flooding processes in the tributary inflow areas is very important to determine the existing impact of flooding on agricultural land uses. The lack of topographic detail on a field-by-field basis is a significant limitation of the current model. However, it should be noted that modeling on a field-by-field basis will be challenging due to the numerous rice checks/culverts that change on a yearly basis. Additional ground surveys, as discussed in 1C below, will be needed to refine the MIKE-21 model in order to address this issue.

C. **Need additional ground surveys.** cbec identified areas where additional ground surveys were conducted to provide greater detail near water control features and grade breaks. Additional detail is still needed in other areas, especially where agricultural impacts need to be assessed at an individual field level. This may require collecting additional information to better understand the effects of rice check culverts on the shallow flooding characteristics of individual fields. These checks may be opened or closed, depending on the water management needs of individual field managers. Field-by-field berms with holes in them may be less of a concern.

2. Limitations related to Hydrology and Flow Boundary Conditions

A. **Reliability of west side tributary flows is questionable.** The reliability of the currently prescribed west side tributary flows from the Knights Land Ridge Cut, Cache Creek, Willow Slough and Putah Creek is questionable. Hydrologic information included in the MIKE-21 model for the west side tributary flows originated from preliminary estimates produced during an initial planning-level study completed in 2001 by Jones and Stokes (Yates, 2012). Based on the documents reviewed by NHC for the MIKE-21model review, the preliminary hydrologic estimates have not been checked, verified or updated since 2001. Cbec has indicated that the preliminary estimates have been updated as part of their work for DWR (cbec March 2012), which has not yet been released or peer reviewed. In addition, the inflow locations of some of the west side tributary inflows are not accurately specified in the model at this time. The model needs to have sufficient detail to accurately define inflow locations of all west side tributary inflows and how those flows will spread out onto the Bypass. It is very important to evaluate and, if necessary, update the west side tributary hydrologic data prior to continuing further modeling assessments.

B. **Fremont Weir inflow boundary conditions have not been verified.** Preliminary inflow boundary conditions at the Fremont Weir (for weir overtopping spills and for an assumed gated slot in the weir) were developed in 2009 by DWR and may not have been fully tested or verified. A letter from DWR also refers to errors in a logic statement and a datum associated error that resulted in overestimation of the notch flow period and underestimation of historical periods of Fremont

Weir overflows (DWR, June 2011). Therefore, important flow boundary conditions being used in the MIKE-21 model may need to be carefully checked or verified. DWR also explains that there are three different ways inflows into the Yolo Bypass over the Fremont Weir have been computed for the BDCP. cbec used constant steady flows over the Fremont Weir without inflows from the West Side tributaries for their work for MWD. For DWR, cbec used constant notch flows at the Fremont Weir with assumed steady (constant) flows entering the bypass from each of the west side tributaries. The notch flows were derived from the Draft Technical Memorandum for Technical Study #2: Evaluation of North Delta Migration Corridors: Yolo Bypass (BDCP April, 2009). Their estimated West Side tributary flows were derived in collaboration with DWR based on average conditions assumed to be coincident with notch flow activation as described in cbec November, 2010.

C. **Need to further assess and document effects of system-wide filling and draining processes.** DWR mentioned (Kirkland, 2011a, 2011b) that ". . . flooding and draining in the Yolo Bypass varies with system-wide conditions as well as with Fremont (Weir) inflows." Therefore, results from previous studies of the Yolo Bypass could be quite different depending on how explicitly the system-wide filling and draining processes are specified in the MIKE-21 model or other models used to assess Conservation Measure #2. We agree that understanding how these processes work and how they are currently being depicted in Yolo Bypass models is very important and warrants further assessment and documentation.

D. **Need to complete additional model sensitivity and calibration analyses.** Floodplain storage and drainage, and the effects of bi-directional flows caused by diurnal tides greatly complicate the hydraulics and water levels in the southern portion of the Yolo Bypass and 2-D model during frequent floods and pulse flows. Additional model sensitivity testing and calibration analyses should be completed to ensure that the daily influences of changing tide levels are being modeled properly for Conservation Measure # 2 flow conditions and that the current downstream model boundary is in a reliable location.

E. **Need to check simplifying assumptions.** Simplifying assumptions necessary to develop and run the MIKE-21 model such as floodplain roughness have not been checked or verified. The model currently includes the primary control structures within the Toe Drain, such as the Lisbon Weir; however, tide gates and checks located away from the Toe Drain within the Bypass (e.g., Los Rios dam) are not included in the model. Inclusion of these types of floodplain water control features would require additional surveys to be conducted. The effects of these features could affect modeled Conservation Measure #2 flow results.

F. **Need to clarify inclusion of waterfowl habitat in model assumptions.** The model assumptions do not clarify whether areas within the Bypass that are currently managed to provide waterfowl habitat through the winter and early spring are included in the current models or how those managed wildlife areas affect flooding on adjacent agriculture lands. It is unclear whether flooded fields are included or not. Based on discussions with cbec, details regarding management of water fowl areas are not included in the model. Collection of data needed to assess such areas could be somewhat cumbersome due to year-to-year changes in management practices. However, the effects associated with the wetland areas being full or empty during modeled flood events should be accounted for at a reasonable level due to their associated effects on Conservation Measure #2's flow results.

3. Limitations related to Model Structure and Computational Assumptions

A. **Need to validate wetting and drying assumptions.** Accurate simulation of wetting and drying processes on individual agricultural fields is one of most sensitive, yet important physical processes to be tested and verified within the MIKE-21 model. Accurate information regarding timing, depth, spatial extent and duration of inundation within the Bypass is required for the agricultural impact assessments. It is important to test and document how the currently prescribed internal boundary conditions are being used for wetting and drying in individual cells.

The importance and sensitivity of these internal floodplain wetting and drying assumptions are amplified by the cell size (dimensions) and ground slope within the cell. How the model simulates these processes needs to be tested and better understood and documented to determine how sensitive and reliable model results are to those assumptions.

B. **Need to refine model to address questions related to impacts of flooding.** Current cell sizes used to represent major portions of the floodplain west of the toe drain are much larger than those along the toe drain. Therefore, cbec (June 2012) recently stated that, "While it is possible to use the model to predict floodplain inundation extents over discrete sub-reaches of the Bypass, the model is not currently appropriate for predicting floodplain inundation on a field-by-field basis. There is no model currently available that can do this type of analysis in the Bypass." Significantly smaller mesh sizes, but more importantly, increased spatial details to facilitate the use of smaller mesh sizes are needed in order to assess field-by-field depth, duration, lateral extent of flooding and hydraulic wetting and drying processes required for agricultural impact assessments. Such model refinements would require careful assessment of current LiDAR data, reconstruction of portions of the floodplain model and the inclusion of local land form details such as roads, ditches, berms, rice checks, swales, drainage control structures, etc. Additional ground surveys may be required to provide these details. Model sensitivity analyses need to be conducted to determine where and to what levels of precision new topographic data are required. If new topographic and bathymetric data were collected the model would need to be updated, tested and recalibrated. Results from a future refined model may be measurably different from the present coarse-grid model. Model refinements and their effects on prior results need to be thoroughly reported.

4. *Model Testing, Calibration and Verification*

A. **Need additional sensitivity analyses.** Further model testing is essential given that there is only limited model calibration data available. Therefore, additional model sensitivity analyses should be conducted as stated in the sections above, including detailed model sensitivity analyses to test the effects that small changes in topographic detail, or assumed floodplain roughness (Manning's "n"), or computational mesh size (and spatial details), or the effects that a time varying tide may have on computed results. The current Yolo Bypass MIKE-21 model was calibrated to flow conditions measured in the Tule Canal and Toe Drain during an approximately bank-full flow period in February and March of 2010. No floodplain data are available for calibrating or verifying water levels or shallow flooding processes in the floodplain areas. Therefore, the accuracy of computed wetting and drying and shallow overland flow processes (depths and velocities) in floodplain areas has not yet been determined, which would first require additional ground surveys and further model testing and refinements to rectify known inadequacies in the topographic source data. Additional analyses should be conducted to determine which modeling parameters and data requirements the model is most sensitive to.

Test results will likely indicate which types of model input data may require improved precision and refinement.

B. **Need to validate model.** cbec recently stated (June 2012) that the Bypass Model has not been validated. cbec has informed us that they collected additional data during the April 2011 flood that could be used for validation but they have not been contracted to use these data. In addition, DWR should check with their monitoring and modeling groups as well as the Corps of Engineers to determine if model validation data are available. Perhaps implementation of simplified winter flow and water level monitoring activities should be considered in order to provide needed calibration and validation data?

5. MIKE-21 Model Availability

A. **MIKE-21 is a proprietary model.** MIKE-21 is a proprietary model and a model license must be purchased from DHI Water & Environment along with annual user support fees if one elects to receive annual technical support and model updates. Interested users can perform limited reviews (view only) of results files produced by cbec without a model license; however, a model license is required for users to develop input files and to open and work with output files to prepare graphics or perform additional model simulations. Therefore, independent evaluation of MIKE-21 modeling results by stakeholders may be difficult without owning a licensing agreement with DHI. Costs to purchase a license and pay for annual support fees can be significant.

RECOMMENDED NEXT STEPS

The following is a list of recommended next steps:

1. **Clearly define Yolo Bypass modeling questions.** Beginning in 2008, several different numerical models (one-dimensional and two-dimensional models) were developed by different agencies and groups for different purposes, using different assumptions and data to assess a variety of BDCP questions and issues. It is likely that many of the models evolved without the benefits of having a mutually-agreed-upon Model Development Program to provide stakeholders such as Yolo County the opportunity to define their most important key questions and physical processes to be modeled prior to model development. Therefore, key Yolo Bypass questions to be addressed by the MIKE-21 model need to be clearly defined along with specification of all the essential information needed to develop a reliable MIKE-21 model of the Yolo Bypass (i.e., geometry, hydraulic boundary conditions, hydraulic parameters, key modeling assumptions, and water control features). This is also true for any of the Yolo Bypass models (e.g., HEC-RAS, RMA-2).

2. **Clearly document MIKE-21 modeling information.** The current modeling information needs to be clearly documented and validated to ensure the model results accurately represent the expected inundation scenarios associated with Conservation Measure #2. Therefore, the model's purpose, procedures used for development and testing the model, sources and reliability of input data used to define key boundary conditions, modeling parameters and modeling assumptions need to be fully described and reported. Out-of-date, untested, or unverified data and inflow boundary condition assumptions need to be updated prior to refining and recalibrating the model.

3. **Collect missing data and perform sensitivity analysis.** Missing or inaccurate topographic data need to be collected and integrated into the model, as feasible. Also, sensitivity analyses need to be conducted on the model's base assumptions to identify and prioritize where and what additional model refinements and improvements are necessary. The preliminary West Side tributary flow information (Jones and Stokes, 2001), for example, needs to be extended to include recent flow records. More detailed information regarding the West Side tributary flow characteristics, inflow locations, and boundary condition assumptions needs to be developed and integrated into the model.

4. **Develop a public domain model.** Given the need to use the Yolo Bypass model in the future to address many different types of questions and flow scenarios, there should be a strategy for making the MIKE-21 model and/or its result files available to stakeholders or there should be consideration of possibly using a different "open source" model that is publicly available. For example, the Sacramento District of the USACE completed the development and testing of multi-dimensional hydrodynamic simulation models (ADH and EFDC). These models geographically cover the entire Sacramento-San Joaquin River Delta, the Yolo Bypass, Fremont Weir and the Sacramento, Sutter Bypass, Feather River confluence area adjacent to the Fremont Weir. These models have been under development and testing for the past 3-4 years primarily to assess high flow conditions in the Bypass in relation to the Delta. Therefore, the resolution of the Corps of Engineers models is not currently of sufficient detail to answer the agricultural impact questions being posed by Yolo County. Further investigations and discussions with the Corps should be conducted to identify whether these USACE models (ADH/EFDC) could be refined to address low flow hydrodynamic flooding and draining conditions in the Yolo Bypass or whether other publically available models should be developed.

   The MIKE-21 model software is not a public domain model, meaning that it is not freely available for download from the internet. A software license must be purchased from the developer, DHI, Inc to run simulations. However, a MIKE-21 model viewer can be used to view results files but not to make changes to the model input files. MIKE-21 is widely owned by consultants active in the field locally, and is approved by the USACE and FEMA.

   The US Army Corps of Engineers (USACE) developed a public domain RMA2 model of the Yolo Bypass in 2007 that is widely used by consultants and agencies and is mandated by the Central Valley Flood Protection Board (CVFPB) for addressing impacts to flood conveyance in the Yolo Bypass. However, this is a steady state 2-dimensional model and therefore can only be used to model impacts to peak flood events. It cannot be used to model hydrographs and unsteady flow conditions, such as the tidal boundary at the lower extents of the Yolo Bypass. This is one of the reasons the MIKE-21 model was developed.

   DWR has recently updated an historically available 1-dimensional, hydrodynamic HEC-RAS model for the Yolo Bypass. We understand that this model is being updated for the recently collected data provided by DWR and MWD, such as the toe drain bathymetry. While this model is appropriate for analyzing system-wide issues, it is not appropriate for analyzing detailed shallow floodplain inundation and interactions with distributary channels, such as the toe drain, in the Yolo Bypass

   The data used to develop the MIKE-21 model input files, such as LiDAR data, toe drain bathymetric surveys, and input boundary hydrology has been disseminated by DWR and MWD. These data can be used for development of other models for the Yolo Bypass for other objectives. The MIKE-21 model input files cannot be used in the development of other models.

5. **Develop a strategy to address recommendations in this report.** Yolo County proposes to work collaboratively with DWR and cbec to determine what modeling refinements are most essential for evaluation of the Bypass and the best approach for implementing the recommendations described above. Adopted next steps must ensure that any model refinements accurately reflect the model's purpose and clearly address Yolo County's questions regarding Conservation Measure #2's long-term effects on land uses within the Yolo Bypass. We recommend developing a strategy to implement the recommendations in this report before major decisions are made related to Conservation Measure #2.

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