EVALUATION OF DIFFERENT HYDRAULIC MODELS IN SUPPORT OF NATIONAL WEATHER SERVICE OPERATIONS

FINAL REPORT

Project Title: Evaluation of Hydraulic Models in Support of NWS Operations

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL WEATHER SERVICE
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The National Weather Service Office of Hydrologic Development would like to thank the dedicated individuals who conducted this evaluation of the current state of the art with respect to hydraulic models relevant to the agency's water forecasting mission. In addition, we are particularly grateful for the cooperation we received from the model developers/vendors for HEC-RAS, Mike-11, Sobek, and FLDWAV. Without their contributions this evaluation would have not been possible. This evaluation was not a source selection activity.

Gary Carter
Director
Office of Hydrologic Development

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1. INTRODUCTION

1.1. Background

The National Weather Service (NWS) is responsible for issuing weather and water related forecasts and warnings to the citizens of the United States. To accomplish this mission the NWS relies extensively on computer resources and scientific procedures. FLDWAV is a comprehensive hydraulic model within the National Weather Service River Forecast System (NWSRFS) designed to simulate unsteady flows in rivers controlled by a wide spectrum of hydraulic structures. It combines the capabilities of the following two NWS models: Dynamic Wave OPERational Model (DWOPER) and Dam-Break Flood Forecasting Model (DAMBRK).

An overall examination of the FLDWAV model implementation at the National Weather Service field offices showed that 10 out of 13 (77%) River Forecast Centers (RFCs) herein also referred to as field offices, had at some point attempted development of hydraulic models, however as of December 2006, 5 of them had halted their efforts (see Figure 1). The reasons for abandoning the development of FLDWAV models cited by the field offices were primarily inadequate training, user documentation and technical support. The level of technical support provided by the National Weather Service Office of Hydrologic Development (OHD) varied significantly between field offices. Frustration with model setup and calibration was also a factor. The complexity of the rivers being modeled, the data available, and the experience with unsteady flow models also varied significantly. Several River Forecast Centers who abandoned their operational FLDWAV development efforts were able to successfully execute historical datasets using the PC version of FLDWAV, but were unable to keep them running operationally in AWIPS without continual assistance from OHD. Some models were also abandoned after PC development when it was discovered that the AWIPS version of FLDWAV did not execute all the features available on the PC version. Currently, FLDWAV is being used operationally by 5 RFCs (39%) in various applications of real-time hydraulic routing.

Several RFCs that use, or planned to use FLDWAV, in their operations have indicated that FLDWAV modeling capabilities are not adequate for all complex conditions that exist in rivers, that the model lacks the tools for calibration, and that model calibration is a very time consuming, labor intensive and highly inefficient process. Other concerns were that FLDWAV is very difficult and cumbersome to use and lacks adequate user manuals. A few RFCs pointed out that on occasions the model’s instability presented problems for effective use for NWS operational purposes.

To address the limitations of the current FLDWAV model and to evaluate its capabilities relative to other widely used hydraulic models, a hydraulic model evaluation project was initiated. This project commenced on June 1, 2006 and ended on May 31, 2007.

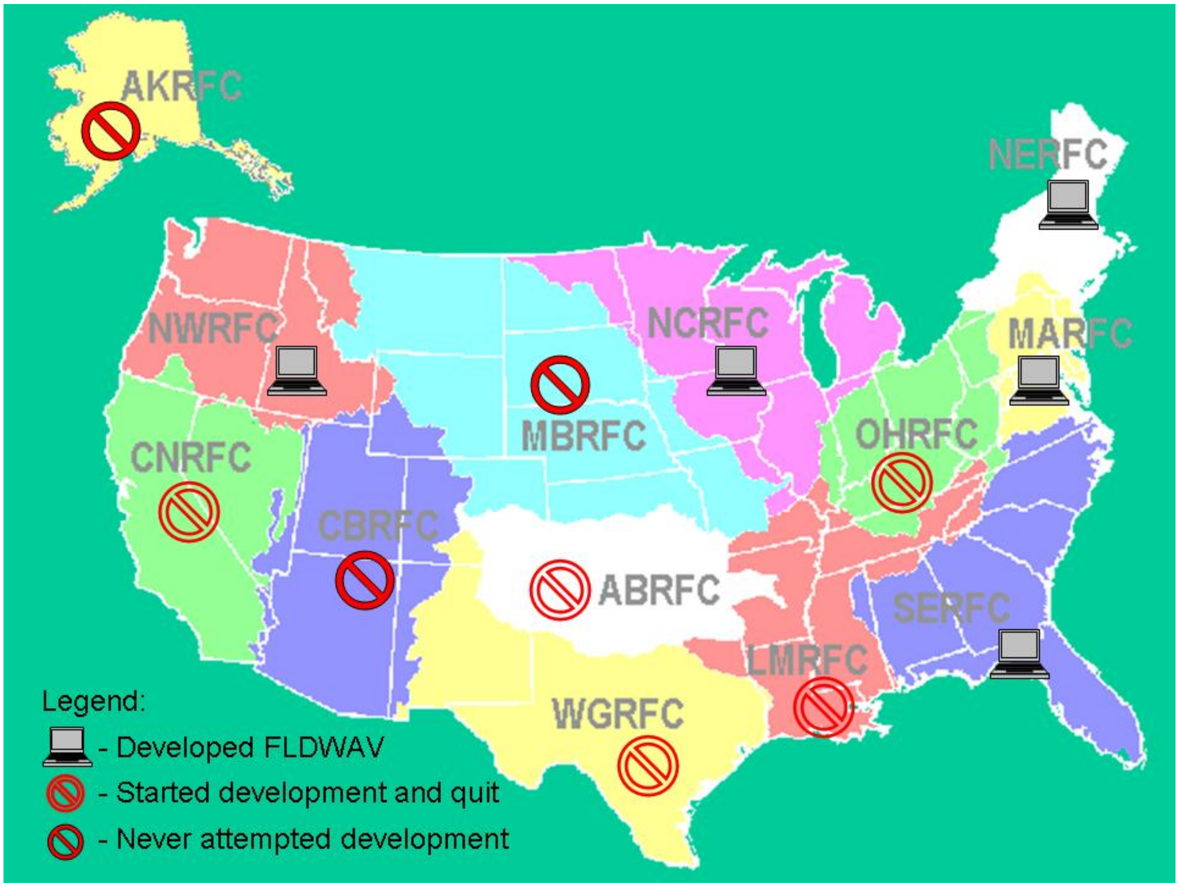

Figure 1 Map of all RFCs showing 5 RFCs that currently use FLDWAV in their operations, 3 RFCs that never developed a model and 5 RFCs that discontinued model development.

1.2. Team Members

A team for the hydraulic model evaluation was formed based on the directions from the Team Charter document given in Appendix 1. The team was made up of the three members of the Hydraulics group of the Hydrologic Science and Modeling Branch (HSMB) of the Office of Hydrologic Development; seven members representing various River Forecast Centers, including Arkansas-Red Basin (ABRFC), California-Nevada (CNRFC), North Central (NCRFC), North East (NERFC), North West (NWRFC), Ohio (OHRFC), West Gulf (WGRFC); and one member from the Cleveland Weather Forecast Office (WFO). The RFC participants for the evaluation team were selected with the intent of representing all the RFCs that either attempted FLDWAV development or currently utilize the FLDWAV model in operational NWSRFS forecasting. The team leader was Reggina Cabrera from OHD. A list of team members is shown below. Team meetings were held mainly remotely through numerous conference calls and three "face-to-face" meetings that occurred during the training sessions in the evaluation period.

OHD	Reggina Cabrera	Hydraulic Group Leader
OHD	Sanja Perica	Hydrologist
OHD	Cécile Aschwanden (**)	Hydrologist
ABRFC	Janet McCormick	Hydrologist
CNRFC	Thea Minsk	Hydrologist
OHRFC/MBRFC	Lori Schultz (*)	Hydrologist
NCRFC	John Halquist	DOH
NERFC	Edward Capone	Senior Hydrologist
NWRFC	Don Laurine	DOH
NWRFC	Joanne Salerno (**)	Senior Hydrologist
WGRFC	Michael Shultz	Hydrologist
WFO Cleveland	Brian Astifan	Service Hydrologist

(*) Started as a member of OHRFC and then transferred to MBRFC

(**) Associated members; joined the team in September 2006

2. OBJECTIVES

The main objectives of this hydraulic model evaluation project are to identify "state-of-the art" hydraulic models; to evaluate their capabilities and limitations in relevance to NWS operations; and to recommend the "best" model(s) that will be used instead of, or in addition to, the FLDWAV model. The ideal hydraulic model should be capable of simulating a range of complex water resources scenarios relevant to NWS operations using the most advanced methodologies through an easy to use interface.

By utilizing such a "state-of-the-art" hydraulic model the NWS will be able to produce reliable forecasts; consequently aiding in protecting life and property and carrying on the major objective of the National Oceanic and Atmospheric Administration (NOAA) "to Serve Society's need for Weather and Water Information."

Issues related to the implementation of the selected model(s) into the NWS operational framework were not part of this evaluation effort. They will be addressed after this evaluation is complete.

3. HYDRAULIC MODELS

3.1. Models Selected for Evaluation

Based on the broad criteria described in the Objectives, and after careful review of existing hydraulic models, the team decided to evaluate the following four models:

1. MIKE 11 software products developed by the Danish Hydraulic Institute (DHI), version MIKEZero 2005 SP4;
2. River Analysis System (RAS) developed by the U.S. Army Corps of Engineers (USACE), Hydrologic Engineering Center (HEC), version 4.0 Beta and 3.1.3;
3. SOBEK model developed by WL | Delft Hydraulics in the Netherlands, version 2.10;
4. FLDWAV model, developed by the National Weather Service, Hydrology Laboratory, Office of Hydrologic Development, several versions, as listed below

MIKE 11 is part of a family of software products developed at the DHI Water & Environment Institute. DHI is a non-profit research and consultancy foundation with more than 500 employees based in offices around the world including the United States. The model has a powerful numerical engine and a user friendly interface that allows users to efficiently set up and run complex one-dimensional applications. The model has been used in numerous situations around the world for real-time forecasting (e.g., Thailand, China, Italy, United Kingdom, United States, Bangladesh, Czech Republic, and Denmark). Although MIKE 11 itself is a one-dimensional (1D) model, it can be dynamically linked to other DHI software to perform two-dimensional (2D) flood modeling, water quality modeling, ground water modeling, etc.

RAS (or HEC-RAS) is a 1D model developed by the Hydrologic Engineering Center of the U.S. Army Corps of Engineers (USACE) designed to perform various types of hydraulic calculations for a full network of natural and constructed channels. The model has been used by numerous federal agencies, and has been adopted by the U.S. Geological Survey (USGS), Federal Highway Administration (FHWA), and Natural Resources Conservation Service (NRCS) as their 1D river hydraulic model over their own hydraulic models (WSPRO and WPS). HEC-RAS is also used by most state and local governments that perform open channel river hydraulics work, and is used extensively in the private industry all around the world. RAS is an integral part of the Corps Water Management System (CWMS) which is being applied by all of the Corps of Engineers offices that perform real-time operations. While HEC-RAS is a 1D model, work is currently underway to dynamically link HEC-RAS with the Adaptive Hydraulics (ADH) two- and three-dimensional (2D/3D) model developed by the Coastal and Hydraulics Laboratory of the Corps of Engineers.

SOBEK is a general software package developed by WL | Delft Hydraulics in the Netherlands jointly with Dutch public institutes and private consultants. It consists of different modules that are used to simulate particular aspects of the water system: flood forecasting, optimization of drainage systems, control of irrigation systems, sewer overflow design, ground-water level control, river morphology, salt intrusion and surface water quality. These modules can be operated separately or in combination. The data transfer between the modules is fully automatic and modules can be run in sequence or simultaneously to facilitate physical interaction. The module tested in this evaluation was SOBEK-Rural. SOBEK is an integral part of the WL | Delft Hydraulics' Flood Early Warning System (Delft-FEWS) that provides flood forecasting and warning systems customized to the specific requirements of an individual flood forecasting agency. Some of the current Delft-FEWS applications are in Germany, Taiwan, Vietnam, Thailand and Singapore.

FLDWAV is a comprehensive hydraulic model developed by the National Weather Service Hydrology Laboratory to simulate unsteady flows in rivers controlled by a wide spectrum of hydraulic structures. Currently, four versions of the FLDWAV model are available: 1) the latest PC-based version developed at OHD, 2) a LINUX AWIPS calibration version developed at OHD that incorporates FldAT, 3) an updated PC-based version under continued private development by Dr. Danny Fread, and 4) the LINUX-based version currently used operationally within the NWSRFS in AWIPS. Because of a number of issues encountered in setting up an input data set for Dr Fread's version during the evaluation process, it was decided to continue the evaluation with the other three FLDWAV versions in combination with the FLDWAV Analysis Tool (FldAT), a standalone software package developed by OHD to graphically display and analyze FLDWAV input data and results.

3.2. Training

To assist the team members in the evaluation process, training courses were arranged with all model developers. The training covered basic model capabilities, set-up, and specific topics of interest for NWS applications (e.g., dam break analysis). During the training sessions the team members installed the corresponding software on their laptops so they could take the models to their offices for future testing. During the training sessions team members and model developers established a relationship that expedited communications during the evaluation period.

To make the evaluation process as fair as possible, all training sessions were intended to happen at the same time with equal amount of time allocated to each session. However, it was not possible to arrange training with all model developers at the same time, so training sessions were arranged on three different occasions. The MIKE 11 and SOBEK models training sessions were held in Silver Spring, Maryland during the week of September 18, 2006. The training session on advanced FLDWAV modeling capabilities was held in Silver Spring, Maryland during the week of November 13, 2006. During the FLDWAV training week one of the team members familiar with the RAS model provided a two-hour training on basic model set-up since the RAS training could not be arranged with the Corps of Engineers until later in the evaluation process. This permitted the team members to start evaluating and comparing all four hydraulic models sooner. In the same week the team also visited the Corps of Engineers, Baltimore District, and saw a presentation on the suite of HEC models in operational mode. The final training session on HEC-RAS took place in Davis, California during the week of January 29, 2007. Training sessions for each model lasted between two and two and a half days.

4. EVALUATION PROCESS

The evaluation process follows the OHD-mandated operational software improvement process known as Hydrologic Operations and Service Improvement Process (HOSIP). The Statement of Need (SON) and HOSIP Research Project Plan appear in Appendices 2 and 3. These documents outline the Hydraulic Model Evaluation Team's mission to "Evaluate selected hydraulic models to determine their technical capabilities and limitations as well as their feasibility for implementation into NWS operations. The models will be tested for different data sets, providing a range of hydraulic conditions and different degrees of complexity."

The evaluation of the selected models was done in several stages. At the beginning of the evaluation process all field offices were asked to provide information on hydraulic modeling capabilities that are needed for their operations. Based on their responses a questionnaire for the model developers was formed. The questionnaire made inquiries on the model's ability to address different hydraulic functions relevant to current and potential future NWS operations. The developers were also asked about additional model characteristics such as calibration tools, output methods compatibility with NWSRFS, availability of documentation, technical support and related costs. All collected information was utilized by the team members during the evaluation process. In the meantime the selection of data sets started. For reasons that will be explained in Section 4.3, the data selection process ended up being the most challenging aspect of the whole evaluation process, and the one that restricted it significantly. The evaluation of general modeling capabilities of all four models was carried out by all of the team members. Detailed evaluations of advanced hydraulic functions for each model were done by at least two evaluators from the team who were the most familiar with the model. The criteria used for the evaluation were: quality of documentation, ease of data manipulation, quality of computational methods, model stability, ease of troubleshooting, availability and quality of tabular and graphical outputs. Those evaluations were used for the model comparison and they were used to make final recommendations.

4.1. Matrix of Needs

At the very beginning of the evaluation period feedback was requested from all 13 RFCs on the importance of different modeling capabilities for their operations. The intent was to determine modeling functionalities that are critical for the RFC's daily forecast operations. The feedback form included a number of common modeling features such as hydraulic modeling of river reaches (multiple rivers, braided rivers, split flows, river sinuosity, flow diversions, backwater effects, and effects of tail water conditions), modeling reservoirs, structures, dams and dam breaks, and levees and levee breeches. In addition, the feedback addressed the following "advanced" modeling capabilities: ice jam buildup/breakup hydraulics, wind effects, floodplain mapping, river and estuarine interface, water quality, interaction with ground water, flow in karst areas, sediment transport, habitat modeling and salt water intrusion. Feedback was also requested on the importance of 2D modeling capabilities. The RFCs were asked to grade the importance of a particular feature using grades on a scale of 0 to 3, with 0 - not needed at all, 1 - not important, 2 - relatively important, and 3 - crucial.

Responses were received from all field offices. They were grouped in categories and compiled in a document known as the Matrix of Needs (MON; Appendix 4). In addition to the grades provided by individual RFCs, the MON shows cumulative scores for each function. The maximum achievable score was 39. As a general rule, the higher the cumulative score of the particular feature, the higher priority should be given to the functionality in the model evaluation process. All functionalities with cumulative grades of 19 or more were considered vital for this evaluation and they were used to compare and to evaluate the hydraulic models. The lowest scores correspond to a few functionalities (shaded gray in the MOC) such as: modeling of flows in karst areas and interaction with groundwater, salt water intrusion, habitat modeling and fish passage, and sediment transport. For quick reference the MON also includes information regarding which models could handle each of the functions (each model's capabilities will be discussed in more detail in the following sections). Each model's capability to simulate a certain function was described as one of the following four categories: a) model has capability, b) model does not have capability; c) model has a capability with add-on module (usually requires purchase of additional license); or d) model does not have capability in a current version, but development is well on its way and can be expected to be included in an upcoming release.

4.2. Matrix of Capabilities

In order to learn more about the models tested a feedback form was sent to all four model developers. The form inquired not only questions on model capabilities relevant to current and potential future NWS operations but also on other topics that could have a major impact on the effectiveness of a hydraulic program within the NWS such as current uses of the model in operational settings, implementation and integration in NWSRFS, availability of documentation and support, and related costs. The following is the list of questions that was sent to the model developers:

4.2.1. Matrix of Capabilities Table

Model Developer Questions

a. Modeling capabilities needed for current NWS operations

- River reaches. Does the software have the ability to model:

  Multiple rivers

  Braided rivers

Model Developer Questions

Split flow

River sinuosity

Flow diversions

Lakes, ponds, etc.

Off-channel storage

Backwater due to tidal conditions, dams, bridges, large tributaries, etc.

Effects of tailwater conditions

- Reservoir and dam break modeling. Has the software the ability to model:

  Multiple reservoirs in series

  Dynamic routing through reservoirs and the ability of a reverse flow option

  Dam overtopping

  Erosion based breach

  Dam break initiated as a breach of the crest

  Dam break initiated as a piping failure

  Cascading dam failures

  Can the model be set up in a configuration that will allow the forecaster to generate a dam failure forecast in a relatively short period of time (~ 15 min)?

  Dam break impact downstream

- Levees. Has the software the ability to model the following:

  In-river levees

  Off-reach levees

  Is there a capability to add/remove temporary levees or fail permanent levees in real-time operations? How are levee breaches handled? Can the model differentiate between overtopping and a local breach? Can the user easily specify a breach location and timing? Can this information be easily saved for all future operational runs for a given event?

- Bridges and culverts. Has the software the ability to model the following:

  Multiple bridge/culvert openings

  Closely placed objects

  Bridge scour

  Has it the ability to import RAS bridge/ levee/ obstruction data?

Model Developer Questions

Has it the ability to import FLDWAV bridge/ levee/ obstruction data?

- Advanced modeling capabilities. Has the software the ability to model:

  Wind effects

  Ice jam buildup/breakup hydraulics

  Floodplain mapping

  River and estuarine systems interface

b. Additional modeling capabilities needed for future NWS operations

- Water quality modeling
- Interaction with ground water
- Flow in karst areas
- Sediment transport
- Debris flow
- Salt water intrusion or salt wedge simulation

c. Flood wave approximation

- Can the model be run in both, steady and unsteady state?
- Is fully dynamic flood wave approximation available?
- Is diffusive flood wave approximation available?
- Can model be run in 1-D and 2-D modes?

d. Cross sectional data manipulation

- How does the user create/modify model input?
- Can the software make use of USGS and HEC-DSS databases? Can it import HEC formatted cross sections directly?
- Can the software import FLDWAV formatted cross sections directly?
- What methods are available for creating cross sections? How does the user generate cross sections? Is GIS knowledge required to develop cross sections? How does the user add/delete cross sections or tributaries?
- Can cross sections be created via cross section interpolation? Can cross sections be irregularly spaced?
- When editing a cross section, can the user graphically view edited cross section information prior to model acceptance?

Model Developer Questions

- Can cross sections be graphically viewed during calibration and operations? How does the user accomplish cross section viewing? Does the scale change with each cross section or is the scaled fixed?
- Is it possible to change a gage location or datum, change geometry, or change an inflow location/time-series without a recalibration?
- How is Manning's n applied in the model? Can the model assign variable roughness to stage and discharge ranges at a cross section?

e. Boundary conditions. Does the software allow for the following boundary conditions?

- Upstream stage or discharge hydrograph
- Downstream stage or discharge hydrograph
- Downstream single-valued rating curve
- Downstream stage hydrograph – defined by tide hydrograph blended with a simulated tide hydrograph
- Can the model accept multiple boundary conditions (upstream and downstream)?
- How does the user define and modify boundary conditions?
- Does the model allow manual edits of lateral inflow (local and tributary flows)?
- Does it allow for internal boundaries: weirs, locks and dams, rating curves, low flow water crossings? How does the user manipulate/edit internal boundary conditions?
- Structure operations module. What operational rules are used to constrain lock/dam operations? Can gate settings be modeled or prescribed, or does the model use a specified pool internal boundary condition?

f. Model output

- Can model output time series be exported in different formats?
- Does the software output hydraulic information? Does the software provide tables and graphs of velocity, flow, stages, Froude number, rating curves, peak flow hydrograph, water surface profiles, and thalweg profile?
- How easily is the resulting water surface elevations exported for inundation mapping? What platform is used to produce the maps?
- Can graphical model outputs be extracted for web use?

g. Implementation and integration in NWSRFS

Model Developer Questions

- Is the model stable in a real-time situation for all flow regimes? Are there any known situations for which non-convergence typically occurs?
- Does it work with the local partial inertia technique?
- Is it easy to calibrate the proposed model? What support programs are available to aid in calibration? What type of statistics do you use to evaluate the calibration?
- Can the proposed model be reasonably used in operations? What are the model benchmarks for speed of operation on a system similar to the NWS AWIPS/LINUX environment? For example, how long does it take to run a 140mile stretch of river with 100 cross-sections?
- Is this model used for real-time forecasting? If yes, where? And by whom?
- Can a calibration model be easily implemented in operations (is there any conversion necessary from calibration to operational model)?
- How easy it is to utilize the model for those who are not experienced in hydraulics?
- Can the model be coupled with a hydrologic model or a 2-D model?
- Is the software source code available? If it is, is it customizable, i.e. can NWS make changes to the code?
- What software language(s) is the code written in?
- Can the model be integrated into NWSRFS on the LINUX AWIPS platform? Do additional utilities need to be developed to accomplish model integration into NWSRFS?
- On what platform can the model run (PC, LINUX, UNIX)?
- Can NWS customized user interfaces or scripts be used in conjunction with the model?

h. Documentation and support

- What documentation exists for the proposed model? Is the documentation adequate for debugging, calibration and operational troubles?
- What company or entity will provide calibration, and model setup support?
- Is technical support available beyond receipt of the model? Is operational support available (e.g., how would you get involved if the model does non-converge in real-time run)?
- If changes in the code are needed, can the NWS make a request for change? What is the request process for the NWS? What is the average time for changes to become effective?

Model Developer Questions

- Can you provide model set-up support within the NWS AWIPS/LINUX environment?

Can you provide support for model inclusion into the RFS environment?

i. Other

- Tell us items about your model that you want us to know.

j. Related costs

- Software license(s) costs:
- Technical support services costs:
- Training costs:
- Software updates costs:
- Are there any other cost charges related to your services?

All developers' responses were collected in a document called Matrix of Capabilities (MOC) that is given in Appendix 5. The same categorization that was used in the MON in Appendix 4 was used in this table. For quick reference and for easy model comparison all responses from the MOC document were summarized in a table given in Appendix 6. Since it was not always straightforward to classify the responses in yes/no form, the table in Appendix 6 contains comments if additional clarification was needed and if the response was considered relevant for the evaluation process. Also, occasionally the developers failed to answer a question from the feedback form. In order to have complete information about all models, those questions were answered by team members; they are highlighted. As can be seen in Appendices 5 and 6, when add-on software modules and/or forthcoming model upgrades are considered, all four models are capable of handling a vast majority of functions needed for current and future NWS operations. They can handle unsteady flows in complex river systems controlled by a wide spectrum of hydraulic structures; they are capable of modeling dam breaks and levee breeches and could at least export information needed for floodplain mapping. The models by–and-large could model numerous advanced functionalities including water quality, sediment transport, river and estuarine systems interface, etc., although with different levels of complexity. The differences among the models relevant to the current NWS operations were in modeling wind effects and ice hydraulics. MIKE and SOBEK could handle wind effects, RAS could not (although according to the model developers "this could easily be added") and FLDWAV only handles uni-directional winds with constant velocity. HEC-RAS is on the other hand the only model that currently is capable of simulating ice cover and ice jam breakup hydraulics (ice jam breakup hydraulics can run only in a steady-state mode).

The 2008 version of MIKE 11 is also projected to have the ability to simulate ice jams in a quasi-steady state mode. Regarding the implementation and integration in the NWS and technical support, the developers' responses were also similar. With the exception of AWIPS version of FLDWAV, all tested models will require development of additional utilities for integration in the operational environment on the LINUX platform, technical support might be available for a fee, and software code will not be available to the NWS.

4.3. Selection of Data Sets

The selection of data for the model evaluation proved to be by far the most challenging part of the whole evaluation process. The initial plan was to examine FLDWAV data sets that are currently being used by different RFCs in forecast operations and to select 3 or 4 reliable data sets that include a wide range of hydraulic functions relevant for the evaluation. The considered data sets included FLDWAV datasets for the Lower Columbia River, the Sacramento River, the Upper Red River of the North, the Upper Ohio River, the Tar River and the St. Johns River. The Tar River and the St. Johns River were selected because their flows were affected by tides. Other rivers had several tributaries, and a variety of structures and it was planned to use them to test levees, weirs, gates, and bridges. The FLDWAV geometric data, however, could not be converted into the other three model formats primarily because geometric data is handled differently in FLDWAV than in the other models. FLDWAV defines cross-sectional information as top widths with associated elevations; the number of elevations is kept constant for each cross-section. The other three programs represent cross sections in station-elevation (x-y) format. Because of the cross-sectional definition difference, Manning's n coefficients calibrated for FLDWAV model can not be applied directly to the other models. Also, Manning's n coefficients in FLDWAV are often calibrated based on flows, and that option is not available in some of the other tested models. It was also found that structures (e.g., bridges) were not always modeled explicitly in FLDWAV, but structure's geometry was reflected in the cross sectional data; therefore, no structure details were available.

Another suggestion that the team builds up one or more relatively complex data sets from scratch to be used to test gates, bridges, tides, dam break, ice jam, etc. was abandoned. It was assessed that the time allocated for this project was not nearly sufficient to produce new data sets, to convert and calibrate the data for all four model formats and to perform evaluations.

Since the transformation of data set set-ups for other programs to FLDWAV format was feasible, it was finally decided to use data sets from either MIKE 11, RAS or SOBEK projects and convert them to other formats. There was quite a bit of cross-section information available to us in HEC-RAS format: Upper Ohio River, Upper Mississippi River, Red River, Susquehanna River, etc. Unfortunately, for some there were no flow/stage measurements at desired locations available to be used in calibration, some did not have information on Manning's n coefficients and in some of them structures were missing. An additional difficulty was a tedious conversion to MIKE or SOBEK formats, in part because some cross-sections were geo-registered and some were not. The model developers provided team members great support with data conversions.

Finally, in March, the team selected two data sets to be used in the evaluation project: the HEC-RAS data set for the Red River, North Dakota (ND)/Minnesota (MN) and the FLDWAV data set for the St. Johns River, Florida (FL). The conversion of the HEC-RAS data set to MIKE and SOBEK formats was done by the model developers and conversion to FLDWAV was done among team members. The team decided to keep the FLDWAV file for the St. Johns River to test tidal effects because none of the available data files had a tidal boundary.

4.3.1. Red River Model

The Red River model was for an approximate 130 mile reach of the Red River plus a 20 mile reach of the Wild Rice River, ND. The upstream boundaries were at Hickson, ND on the Red and Abercrombie, ND on the Wild Rice. Lateral inflows were included for the Fargo Local, Sheyenne River at Harwood, and the Buffalo River, MN. The forecast point, Fargo, ND was located about midway in the reach. The model was constructed by combining 4 HEC-RAS Flood Insurance Study models and converting them from steady flow to unsteady flow. Combined there were 178 cross-sections, 25 bridges, 3 inline structures, 6 lateral structures, and 1 culvert. Unsteady flow data sets were provided for 1997 and 2001 flood events. The flow data for the 1997 flood event covered the time period from April 1st to May 2nd; and for the 2001 flood event from March 31st to April 10th. The schematic of the Red River model is given in Figure 2.

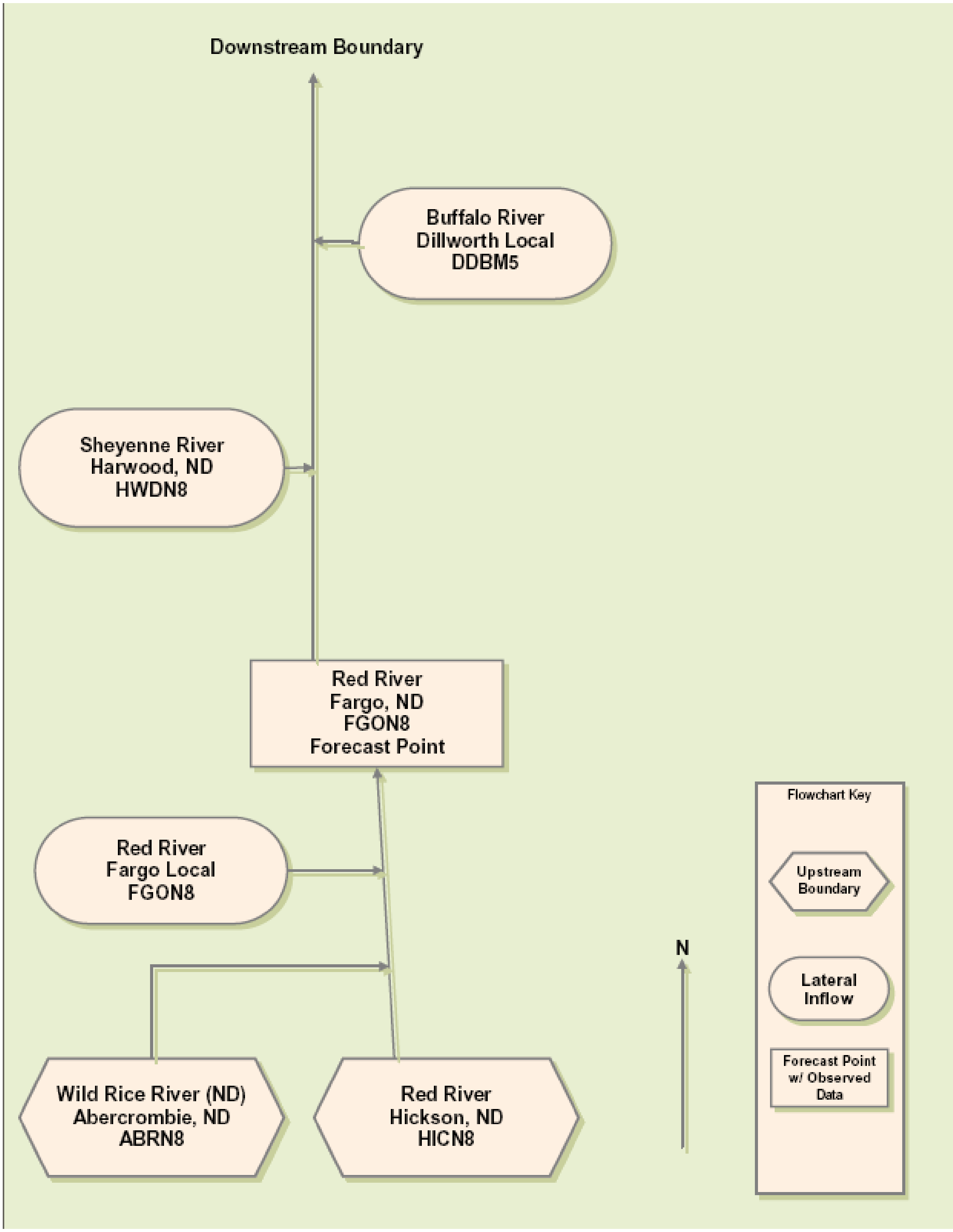

Figure 2 Schematic for the Red River model.

4.3.2. St. Johns River Model

The FLDWAV deck for the St. Johns River covered a total of 216.9 miles. The total number of cross sections was 52, and each cross section was represented with 9 top width - elevation pairs. There were no structures such as bridges or levees explicitly modeled. The total number of values in the Manning's n table was 19 and set as a function of flow. The flow data covered the time from December 19th 2004 to March 5th 2005. There were 11 lateral inflows, but none of them were modeled dynamically. The upstream boundary was set at Christmas (CHRF1) with a gage elevation of 1.62 feet and the downstream boundary was located at Mayport (MYPF1) with a gage elevation of 0 feet. Observed hydrographs were available for calibration at Christmas (CHRF1), Geneva (GENF1), Sanford (SNFF1), Deland (DLAF1), and Buffalo Bluff (PALF1). Data for the Jacksonville (SJLF1) stream gage was unavailable for the given time period. The schematic of the St. Johns River is shown in Figure 3.

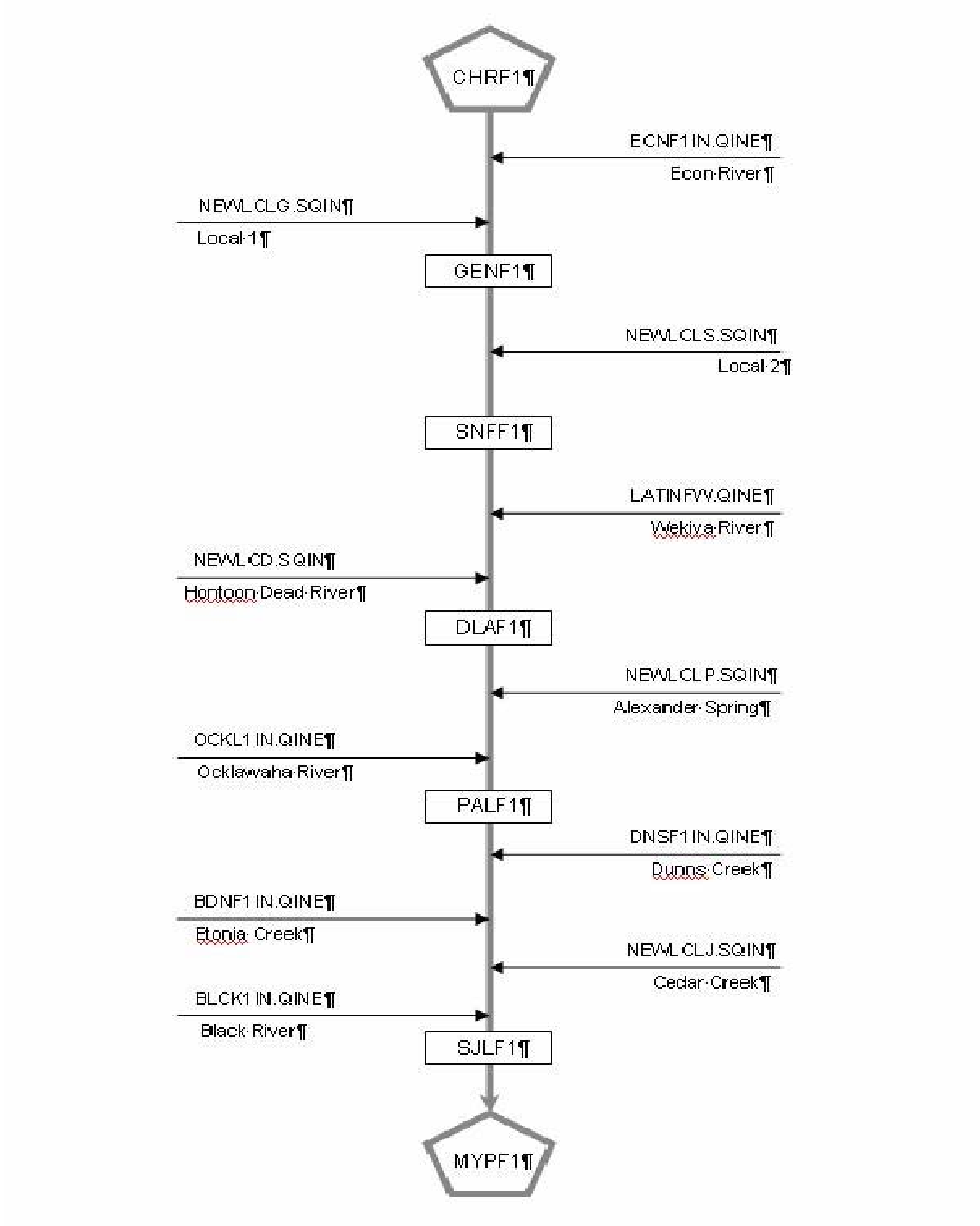

Figure 3. Schematic for the St. Johns River model.

4.4. Team Evaluations

The team evaluation was performed in two phases. In the first phase all team members evaluated general model set-up and manipulation for all selected hydraulic models. The topics evaluated in the first phase were the following:

Team Evaluation Table
a. Ease of use - Availability and quality of documentation - Model is understandable / user friendly - Other comments **b. Model run** - Quality of computational methods - Model stability - Model convergence - Simplicity of troubleshooting - Ability to simultaneously run several scenarios - Other comments **c. Input information** - Option of importing data from other programs - Straightforwardness of data entry - Cross section edits - Quality of cross section interpolation - Description of variable roughness - Handling of lateral inflows - Using different types of boundary conditions - Other comments **d. Output information** - Level of detail in output tables

Team Evaluation Table
- Output detail for individual cross sections - Can output time series be exported - Availability and quality of graphical output and animation **e.** Could graphical model outputs be extracted for web use

There were no restrictions on how the team members should do the evaluation in the first evaluation phase. The team members were expected to become skilled at using all of the four models based on training and available documentation and to perform evaluation using data of their choice: data sets provided by the model developers, data sets recommended for the evaluation project, or data sets they developed from scratch. Team members from field offices commented on each of the topics, and graded each models' performance on a scale from 1 to 5 (1 for poor performance or lack of ability and 5 for excellent performance). Additional comments on general model set-up were also encouraged; however additional comments were not graded. Several team members for example commented on SOBEK's inability to accept data in English units. All comments were taken verbatim so they reflect the opinions of the commenter and may be incorrect in some cases. The comments were organized per topic and per model, and are shown in Appendix 7. As can be seen from the Appendix, there was a consensus among the team members that all four hydraulic models are technically sound, high quality models. Most of the evaluators thought that no adequate information was available for comparison of the models' stability and convergence. Major differences among the models were found in "subjective" parameters such as ease of use, clarity of documentation and availability of sample solutions. The team members felt that extensive documentation for HEC-RAS that included a user's manual, hydraulic references and applications guide (with numerous examples complete with written explanations and electronic datasets) and its comprehensive error/warning messages were far superior over any of the other programs. ' The team members also found HEC-RAS' graphical user interface to be more intuitive than the graphical user interfaces for MIKE or SOBEK, and especially FLDWAV.

In the second evaluation phase each model was assigned for detailed evaluation to two team members who had acquired the most experience with the model during the first evaluation phase. Team members were encouraged to participate in evaluation of other models that were not assigned to them, as well. The following model capabilities were evaluated:

- tributaries, junctions and split flow;
- bridges and culverts;
- gates, weirs and lateral structures;
- levees and levee breach;
- dams and dam break analysis;

- tides;
- ice jam;
- floodplain modeling.

The criteria team members used for evaluation were quality of documentation, ease of data manipulation, quality of computational methods, model stability, straightforwardness of troubleshooting, availability and quality of tabular and graphical outputs. Similar to the evaluation procedure in the first phase, the evaluators commented on each of the topics, and graded the models' performance on a scale from 1 to 5 (1 for poor performance or lack of ability and 5 for excellent performance). All comments were organized per topic and per model, and are shown in Appendix 8. The evaluation showed that in nearly all evaluated technical categories all four models are robust software packages capable of handling most of the modeling problems encountered at different NWS forecast offices. Of course, there are some features unique to each model. For example, none of the four models approaches the regulation of gated structures (or actually any structure) in quite the same way. However, team members felt that none of these technical differences would prevent successful calibration, and that all models could provide accurate results. What the team felt could prevent successful calibration and use was inadequate documentation for some of the models

Average grades were calculated for each model and for each evaluated topic. Appendix 9 does not show grades but rather indicates the model(s) with the highest rank. The highest ranks presented in Appendix 9 should be taken with caution, as the scores are subjective. That is especially true for scores involving topics evaluated during the second evaluation phase which are often based on grades provided by only one or two team members.

5. SUMMARY AND RECOMMENDATIONS

5.1. Summary

The mission of the Hydraulic Model Evaluation Team was to: "Evaluate selected hydraulic software packages to determine their technical capabilities and limitations as well as their feasibility for implementation into NWS operations. The models will be tested for different data sets, providing a range of hydraulic conditions and different degrees of complexity." (Team Charter, Appendix 1)

It should be noted that during the first session the newly formed evaluation team decided to exclude the technical aspects of implementation into NWS operations from the evaluation. It was agreed that an implementation of a new model into operations should be treated as a separate project altogether once the technical evaluation was completed. This change was reflected in the HOSIP documentation (Statement of Need) included in Appendix 2. There was insufficient time for the team to evaluate the feasibility of models' implementation in operational environment. besides, the team members were specifically selected based on their knowledge of hydraulic modeling and they felt the technical issues and concerns related to incorporation of a new model into the operational architecture at the River Forecast Centers was beyond their expertise.

Another modeling aspect discussed among team members at the beginning of this evaluation was whether to include 2D models in the testing. The team decided to primarily focus on 1D modeling capability during this evaluation, as it was deemed unrealistic in the time frame allocated to the evaluation to perform an adequate assessment of 2D models. However, the team took into consideration the fact that 2D modeling capabilities are desirable for future development (e.g. hydraulic modeling in coastal areas, floodplain mapping).

This evaluation was envisioned to consider as many modeling aspects as possible in the given one-year time frame. Due to the time constraints and the complexity of the task the team was facing, each of the models raised various challenges for the team members, some of which probably could have been overcome with additional training and/or familiarization with the models.

5.2. Recommendations

The consensus among the team members was that all of the four evaluated models are of high quality and technically sound. Each one is a viable option for NWS hydraulic modeling. None of the four models is guaranteed to be stable and to converge for all flow regimes and structure operations without being thoroughly tested, but it is likely that all of them could be made to work under the most complex circumstances, if developed with someone with sufficient experience and knowledge. The main differences among the evaluated models are in the availability of calibration tools, documentation, technical support and licensing and development costs. Thus, to some extent, subjective parameters had an important role in differentiating among the models.

Finding #1

FLDWAV hydraulic model is native to the National Weather Service and it is currently operational at several River Forecast Centers. In those offices significant amount of in-house knowledge on hydraulic modeling using FLDWAV exists. Forecasters in those offices feel that the hydraulic schemes in this software are sound and capable of producing satisfactory results under the setting they have tested.

Recommendation #1

The team recommends that the AWIPS version of FLDWAV continues to be available to NWS hydrologists at the River Forecast Centers and that it should be included into the new operational architecture.

Discussion #1

Although several field offices have abandoned FLDWAV development, there are still some River Forecast Centers that have successfully implemented FLDWAV and these wish to continue using the software. Besides, the implementation of any new hydraulic model can not occur immediately; thus, FLDWAV models will continue to be used in operational settings for years to come.

Finding #2

The HEC-RAS hydraulic model could meet almost all the high priority requirements of the River Forecast Centers. In addition, it was found that the best overall training opportunities, documentation, and forecaster knowledge base exist for the HEC-RAS model of all models tested.

Recommendation #2

It is the consensus of the evaluation team that HEC-RAS be considered for inclusion into the suite of NWS hydraulic models.

Discussion #2

Even though the team felt that HEC-RAS model has the greatest potential for enhancing NWS hydraulic modeling capabilities, the team has some concerns that could not be resolved during this evaluation. The major concern is that there was no assessment of HEC-RAS performance in real-time operations. In addition, not having access to the software source code might hinder its maintenance in the operational architecture and implementation phase.

Finding #3

During the evaluation it was also found that calibrated FLDWAV data sets used by RFCs for hydraulic modeling could not be converted for use by other hydraulic models primarily because geometric data (including roughness coefficients) is handled differently in FLDWAV than in other hydraulic models.

Recommendation #3

The team recommends performing a test focusing on comparing development of FLDWAV and HEC-RAS models using identical data sets, assessing difficulties in converting data sets from one program to another and differences in results.

Discussion #3

To properly assess the elements involved in development of FLDWAV and HEC-RAS models, a more detailed test is needed. To get the most out of this comparison, the models should be first built independently in a selected river reach using identical data sets. Then, transformation from the built FLDWAV model to HEC-RAS model should also be tested. The evaluation should include calibration of models, comparison of results, and the discussion about lessons learned for transition from FLDWAV to HEC-RAS.

Finding #4

None of the evaluated models has all modeling functionalities needed the RFC's forecast operations (Matrix of Needs, Appendix 4). From the high priority items listed in Matrix of Needs, wind effect and the capability of importing FLDWAV structures are the only critical functionalities not met by HEC-RAS. In the case of FLDWAV, there are several critical RFCs' needs not currently met

Recommendation #4

Critical modeling functionalities not available in either HEC-RAS or FLDWAV models should be documented and resolved.

Discussion #4

From the RFCs' needs not met by the HEC-RAS model, the most immediate one would be the inclusion of wind effect. HEC was approached regarding this issue and the feasibility of adding wind component in HEC-RAS was discussed.

Any FLDWAV enhancements will depend on availability of resources for the task and should be discussed with the management at the Office of Hydrologic Development.

APPENDICES

Appendix A. Table of Acronyms

Acronym	Acrostic or definition
ABRFC	Arkansas-Red River Forecast Center
AWIPS	Advanced Weather Interactive Processor Service
CNRFC	California Nevada River Forecast Center
COE	Core Of Engineers
CONOPS	Concept of Operations
DAMBRK	Dam-Break Flood Forecasting Model
DELFT	Delft Hydraulics, Inc., Rotterdam The Netherlands
DWOPER	Dynamic Wave OPERational Model
FEMA	Federal Energy Management Agency
FHWA	Federal Highway Administration
FLDWAV	Flood Wave Dynamic Model
GUI	Graphical User Interface
HEC-RAS	Hydrologic Engineering Center-River Analysis System
HL	Hydrology Laboratory
HOSIP	Hydrologic Operations and Service Improvement Process
HSEB	Hydrologic Software Engineering Branch
HSMB	Hydrologic Science and Modeling Branch
MBRFC	Mississippi Basin River Forecast Center
MCP	Manual Calibration Program
MN	Minnesota
MOC	Matrix of Capabilities
MIKE 11	Hydrology model developed by the Danish Hydraulic Institute
MON	Matrix of Needs
MS	Microsoft
NCEP	National Centers for Environmental Prediction
NCRFC	North Central River Forecast Center
NERFC	North East River Forecast Center
NEXRAD	Next Generation Weather Radar system (NEXRAD)
NRCS	Natural Resources Conservation Service
NOAA	National Oceanic and Atmospheric Administration
NWRFC	North West River Forecast Center
NWS	National Weather Service
NWSRFS	National Weather Service River Forecast System
NWS	National Weather Service
NWSRFS	National Weather Service River Forecast System
OCWWS	Office of Climate, Weather, and Water Services
OHD	Office of Hydrologic Development
PC	Personal Computer
QA	Quality Assurance
RFC (s)	River Forecast Center(s)
SOBEK	Hydrology Model developed by Delft
SON	Statement of Need

Acronym	Acrostic or definition
USACE	United States Army Corps of Engineers
USGS	United StatesGeological Survey (USGS)
WFO (s)	Weather Forecast Offices
WGRFC	West Gulf River Forecast
WL/Delft	Formal Name of Delft Hydraulics, Netherlands
XML	Extensible Markup Language

Appendix 1. The Team Charter Document

(see attached)

Appendix 2. Statement of Need Document

(see attached)

Appendix 3. Project Plan

(see attached)

Appendix 4. Matrix of Needs (MON) Document with grades provided by al RFCs, cumulative grades and summary of each model's capabilities.

(see attached)

Appendix 5. Matrix of Capabilities (MOC). Responses from Model Developers

(see attached)

Appendix 6. Summary of the Matrix of Capabilities document

(see attached)

Appendix 7. Team members' comments on general model setup and manipulation.

(see attached)

Appendix 8. Team members' comments on specific model capabilities

(see attached)

Appendix 9. Highest ranks overall based on team members' evaluations

(see attached)

__Appendix 1.__ The Team Charter document.

TEAM CHARTER

Team for Hydraulic Model Evaluation

Vision: Provide software options for modeling hydraulic conditions in a forecasting environment.

Mission: Evaluate selected hydraulic models to determine their capabilities and limitations in the technical area as well as their feasibility for implementation into NWSRFS operations. The models will be tested for different data sets, providing a range of hydraulic conditions and different degrees of complexity. They will be reviewed against criteria to determine scientific suitability.

Scope of Authority/Limitations

- ❖ Basis for decisions will be decided on by the team (majority, consensus, other).
- ❖ Team will evaluate the following hydraulic models: FLDWAV, HEC-RAS, DELFT, MIKE-11 and/or MIKE-21.
- ❖ Team will generate HOSIP documents for SON and CONOPS
- ❖ Team will select the sets of data to be tested.
- ❖ Team will develop the evaluation criteria.
- ❖ Team will evaluate the technical and operational suitability of the models
- ❖ Access to test software will be provided to the team
- ❖ Team will determine the meeting requirements during the evaluation
- ❖ Pending approval of OHD Director, travel expenses will be covered with AHPS funds
- ❖ Team will present a preliminary draft of the time frame for the different activities.
- ❖ Team will provide a report summarizing the findings and recommendations about the software(s) for hydraulic modeling the RFCs could use in their operations.

Termination Date: The team will be formed and commence activities by June 1, 2006 and complete their work no later than June 1, 2007.

Success Criteria/Deliverables
Deliver a report summarizing the findings and recommendations that includes a list of hydraulic models suitable for forecasting stages and/or flows to be used as possible addition to or instead of FLDWAV. Documentation will be developed for stages 1, 2, and 3 of the HOSIP process.

Team membership: The team will be made up of at least four regional representatives two from the OHD, and one from the OCWWS/HSD. The team leader will be Reggina Cabrera. Additional personnel from the Regions or Headquarters may participate as resources without being official members of the team.

Team members:

NERFC	Ed Capone	Senior Hydrologist
CNRFC	Thea Minsk	Hydrologist
WFO	Brian Astifan	Service Hydrologist, Cleveland, Ohio
ABRFC	Janet McCormick	Hydrologist
NCRFC	John Halquist	DOH
NWRFC	Don Laurine	DOH
OHRFC	Lori Schultz	Hydrologist
WGRFC	Michael Shultz	Hydrologist
OHD	Sanja Perica	Hydrologist
OHD	Reggina Cabrera	Hydraulic Group Leader

Appendix 2. *Statement of Need document.*

<table>
<tr><th colspan="3">Statement of Need</th></tr>
<tr><td>Submitter:
Reggina Cabrera</td><td>Organization or Field Office:
Hydrology Science Modeling Branch</td><td>Date Submitted:
10/05/06</td></tr>
<tr><td colspan="2">Number: HOSIP Supplied:
H06-014 SON-06-001</td><td>HOSIP Date:
10/06/06</td></tr>
</table>

1. Title:

Project Title: Evaluation of Different Hydraulic Models in Support of NWS Operations

2. Description:

FLDWAV is a comprehensive hydraulic model within the National Weather Service River Forecast System (NWSRFS) that is used to simulate unsteady flows in rivers controlled by a wide spectrum of hydraulic conditions. FLDWAV has been used operationally by several River Forecast Centers (RFCs) in various applications of both real-time routing of runoff-generated floods, and in non-real-time dam-break flood forecasting. Many RFCs have indicated that the current capabilities of FLDWAV do not meet all of their requirements, and that either significant enhancements or alternatives to FLDWAV are needed in order to provide accurate and timely river forecasts.

Technical support for FLDWAV users within the NWS is provided by the Hydraulics group of the Office of Hydrologic Development (OHD), Hydrologic Science and Modeling Branch (HSMB). To address the limitations of the current FLDWAV model and to evaluate its capabilities relative to other widely used hydraulic models, a hydraulic model evaluation project is being proposed.

The goal of this evaluation is to recommend a hydraulic model that is capable of analyzing and solving a range of complex water resources problems using the most advanced methodologies through an easy to use interface. The project team will examine four proposed models to identify and evaluate the differences in the models and make recommendations based on their technical capabilities and ease of use. Although there will be no direct testing of a 2-dimensional simulation, the applications that require a 2-D approach will be noted in the final report.

The project will be headed by a team that will consist of staff members from the HSMB, Hydraulics Group and most of the current RFCs that utilize FLDWAV models in operational NWSRFS forecasting.

This group will be tasked with surveying the River Forecast Centers to develop a comprehensive list of requirements for the NWS operational program. The team will evaluate the following hydraulic models: 1) NWS FLDWAV model; 2) US Army Corps of Engineers (COE) HEC-RAS model; 3) MIKE 11 software products developed by the Danish Hydraulic Institute; and 4) SOBEK model developed by the WL | Delft Hydraulics in the Netherlands. Although the numerical algorithms for the solution of unsteady flow equations are similar in all models, substantial differences exist with respect to available model features, model approximations and assumptions, data handling, and graphical interface.

If an alternative model in addition to FLDWAV is recommended, the report will document how this additional hydraulic model will enhance the mission of the River Forecast Centers due to improved technical capabilities and ease of use.

3 Justification:

3.1 Linkages:

The evaluation results will address the National Oceanic and Atmospheric Administration (NOAA) Goal 3, to "Serve Society's Needs for Weather and Water Information." Enhanced hydraulic modeling capability will enable NWS forecasters to produce reliable forecasts for events that cannot be accurately forecasted using the current NWS hydraulic model. It may additionally provide integrated applications for dam break analysis and inundation mapping in flood prone areas, consequentially aiding in the protection of life and property.

3.2 Need Originator, Sponsor & Stakeholders

Originator:	Hydrologic Science and Modeling Branch, Hydraulics Group
Sponsors:	North Central RFC, California-Nevada RFC, and North West RFC
Stakeholders:	All River Forecast Centers Users of the RFC forecasts and informational services

4. Existing capabilities and limitations related to the need:

The existing NWSRFS hydraulic model FLDWAV has several limitations relevant to NWS operations. Primarily the FLDWAV modeling capabilities are not adequate to model all the conditions present at different rivers; model implementation procedures are not easy to use; converting the model from stand-alone calibration to operational mode is somewhat cumbersome; the graphical user interface is not adequate; and current user documentation is limited.

One of the main concerns in the operational use of FLDWAV is the intensive support needed by field offices. Common inquiries from the RFCs include requests for explanation, instructions and assistance with implementing a model using the software and maintenance of the models. Although some offices were able to successfully implement a model using this code, if any problems were encountered with running the model, no debugging tools would be available to assist them in resolving the problem.

The lack of user knowledge and understanding of the model make it difficult to overcome these limitations. This has caused many field offices to abandon their projects before they were completed.

5. Benefits and Performance Impact:

The primary benefits to the NWS river forecasting and water resources program will be enhanced capabilities to model complex river systems. Improved user interfaces and tools will allow the NWS to more effectively and efficiently develop, configure, and calibrate these complex hydraulic systems. By utilizing external hydraulic model(s), the NWS will be able to capitalize on advancements in hydraulic development tools and expertise from other entities such as the Federal Emergency Management Administration's (FEMA) Flood Insurance Studies (FIS), and the COE (hydraulic engineering studies). This will make the implementation of hydraulic models into NWS River and flood forecasting mission much more efficient. Finally, the interagency coordination between the NWS and the other entities will also be enhanced.

6. Constraints

The costs of licenses, training, and on-call support will also have to be factored into the decision of which model should be chosen for integration in the operational hydrological forecast system. However, this evaluation exceeds the scope of this hydraulic evaluation team. The final decision on implementation of any model in the NWS operations will ultimately depend on the technical evaluation and recommendations from the OHD Hydrologic Software Engineering Branch (HSEB).

7. Attachments:

None.

8. Resource Proposal for Stage 2

Two members from the HSMB Hydraulic Mechanics group will together draft the research proposal and a plan of action for carrying out the evaluation. During this stage, the two members will confer with various RFCs to determine their level of expertise with using the different hydraulics models and software; and solicit their participation in the evaluation. This work will require 80 hours to complete and two HSMB Scientists; and an additional 20 hours of the HOSIP Administrator for document review and project support. It is anticipated that the following RFC's and Weather Forecast Office will participate in the evaluation.

- Arkansas-Red Basin (ABRFC);
- California-Nevada (CNRFC);
- Missouri-Basin (MBRFC);
- North Central (NCRFC);
- North East (NERFC);
- North West (NWRFC);

- West Gulf (WGRFC); and
- Cleveland Weather Forecast Office (WFO).

The evaluation will be conducted remotely and through a series of conference calls, training sessions and group meetings with project participants, starting on June1, 2006 and terminating with a report one year later. Three training sessions are anticipated during this time and team members will receive background information for each of the models in preparation for the evaluation. Team members will also discuss goals, the evaluation structure, and the general mechanics of how the team will operate during the entire evaluation process.

9. Review and Analyses Statement

The team will select a committee to write the final report and recommendations. The whole team will review the draft versions throughout the writing process. Starting in February, 2007, the committee will submit draft versions to the team leader on a bi-weekly basis with a copy sent to all team members.

10. Expected Start Date

Starting date for this project is June 1, 2006. Project will end on May 31, 2007.

11. Appendices

Appendix A - Table of Acronyms

ABRFC	Arkansas-Red River Forecast Center
CNRFC	California Nevada River Forecast Center
COE	United States Army Corps of Engineers
FLDWAV	Flood Wave Dynamic Model
FEMA	Federal Emergency Management Administration
HEC-RAS	Hydrologic Engineering Center-River Analysis System
HSMB	Hydrologic Science and Modeling Branch
MBRFC	Missouri Basin River Forecast Center
NOAA	National Oceanic and Atmospheric Administration
NCRFC	North Central River Forecast Center
NERFC	North East River Forecast Center
NWRFC	North West River Forecast Center
NWS	National Weather Service
NWSRFS	National Weather Service River Forecast System
OHD	Office of Hydrologic Development
RFC	River Forecast Center
WFO	Weather Forecast Office
WGRFC	West Gulf River Forecast Center

Appendix 2. *Statement of Need document.*

12. Approval Section

<table>
<tr><td colspan="3">Proposed Service Theme Area</td><td colspan="5">“Innovation Team”</td></tr>
<tr><td colspan="2">Project Leader:</td><td colspan="2">Reggina Cabrera</td><td colspan="2">HOSIP Admin Analyst:</td><td colspan="2">Marylin Andre</td></tr>
<tr><td colspan="5">Gate 1 Approval</td><td>Date:</td><td colspan="2"></td></tr>
<tr><td>Office Name</td><td>Group Leader</td><td>Project Area Lead</td><td>Branch Chief</td><td colspan="2">OHD Architecture</td><td colspan="2">OCWWS</td></tr>
<tr><td>HSMB</td><td>Reggina Cabrera</td><td></td><td></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td colspan="4">Dependencies: No dependencies</td><td colspan="4"></td></tr>
<tr><td colspan="4">Funding Secured for Stage 2: (Yes/No). Yes. This is funded by AHPS Innovation Team</td><td colspan="4"></td></tr>
<tr><td colspan="2">Stage 2 Expected Start Date:</td><td colspan="2"></td><td colspan="2">Stage 2 Expected End Date:</td><td colspan="2"></td></tr>
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HOSIP RESEARCH PROJECT PLAN

Evaluation of Different Hydraulic Models in Support of National Weather Service Operations

Version 2-2

Revision History

Date	Version	Description	Author
11/01/2006	1.0	Initial draft document	M. Andre
5/3/2007	2-0-1	Draft Put into Science Project Format	C. Holte
6/8/2007	2-2	Review	R.Cabrera

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1. Identification

Project Title: Evaluation of Different Hydraulic Models in Support of National Weather Service (NWS) Operations

Project ID: H06-014 SON-06-001

2. Abstract

[The abstract is a short summary of the project and includes the key highlights of the research project: purpose, procedure and schedule. This summary should be no more than 2 to 3 sentences to set the context for the reader.]

The purpose of the Evaluation of Different Hydraulics Models is to examine four different hydraulic models in order to determine how these models and their features can be used to improve hydraulic modeling operations at the National Weather Service. The end goal of the evaluation is to recommend a hydraulic model that is capable of analyzing and solving a range of complex river systems using advanced technology through an easy to use interface. The evaluation will be conducted remotely and through a series of conference calls, training sessions and group meetings, starting on June1, 2006 and terminating with a report one year later.

3. Introduction

The existing National Weather Service River Forecast System (NWSRFS) Flood Wave Dynamic Model (FLDWAV) has limitations relevant to NWS operations while at the same time there are a number of hydraulic models which have features whose examination might reveal means to improve current forecast capabilities and a way forward towards implementing hydraulic modeling with additional capabilities than the ones currently available through FLDWAV.

This project will evaluate four existing hydraulic software products. These models were selected based on their capabilities of modeling hydraulic conditions. The end product of this effort will be a report evaluating these four models and recommendations for further action. The software models being evaluated are:

1) NWS FLDWAV;
2) US Army Corps of Engineers Hydrologic Engineering Center-River Analysis System (HEC-RAS);
3) MIKE 11 **products** developed by the Danish Hydraulic Institute; and
4) SOBEK developed by the Company WL | Delft Hydraulics in the Netherlands.

It is hoped that by evaluating other hydraulic software and selecting one of these models, additional tools and capabilities will be available to the NWS. In addition, NWS can capitalize on the expertise from those other entities and improve NWS hydraulic modeling in order to properly forecast complex river systems. This will make the implementation of hydraulic models into the NWS river and flood forecasting system much more efficient. Finally, the interagency coordination between the NWS and the other entities will also be enhanced.

4. Problem Description

The existing NWSRFS hydraulic model FLDWAV has limitations relevant to NWS operations. There is an inconsistency between the version of the model as developed originally by Dr. Fread for the Personal Computer (PC) environment and the operational AWIPS version. Attempts to develop models using FLDWAV at different field offices have been abandoned due to implementation difficulties experienced by staff. Forecasters have voiced concerns regarding the lack of adequate user documentation, difficulty in troubleshooting, and the lack of graphical user interface and tools for viewing results. Also the model lacks the tools for calibration and is difficult to convert from stand-alone calibration to operational mode. Lastly, FLDWAV modeling capabilities are not adequate to model all the conditions present at different rivers.

No model can do it all, so it is hoped that by evaluating other existing state-of-the-art hydraulic models alternative hydraulic models with additional modeling capabilities will be identified and that as a result improved modeling capabilities will be made available to forecasters.

5. Literature Review

HEC-RAS model, U.S. Army Corps of Engineers, Hydrologic Engineering Center, USA
Sobek model, WL/ Delft Hydraulics, The Netherlands.
Mike-11, Danish Hydraulic Institute
FLDWAV model, National Weather Service, USA

6. Approach

Stage 2 - Validation
The participants for the evaluation team were selected with the intent of representing all the River Forecast Centers that have on-going, past, or future projects using hydraulic models. The main criterion used in the selection of team members was their knowledge of FLDWAV. The RFCs represented are: • North West River Forecast Center (NWRFC), • California-Nevada River Forecast Center (CNRFC) • Missouri-Basin River Forecast Center (MBRFC) • North-Central River Forecast Center (NCRFC) • Arkansas-Basin River Forecast Center (ABRFC) • West-Gulf River Forecast Center (WGRFC) • North-East River Forecast Center (NERFC)

One member is representing the Weather Forecast Office at Cleveland, OHIO, who brings the expertise in modeling; and two members are representing the Office of Hydrologic Development.

Stage 3 - Research & Analysis

The examination of these models by the project team will focus on their technical capabilities, ease of use and calibration tools. Special emphasis will be placed on the examination of similarities in the numerical algorithms for the solution of unsteady flow equations within the models and potential differences that may exist with regards to available model features, model approximations and assumptions, data handling, and graphical interface.

In order to perform this evaluation, all the team members will need to have knowledge on how to set and execute the models selected for the evaluation. This knowledge will be imparted by the software developers of the selected hydraulic models through the team-members training. It will be expected that during and after the training periods, team members will request information and/or clarification about the use of the different software. In order to assist evaluation participants with additional information on the capabilities of the software, a questionnaire will be prepared by the team members and submitted to the developers to enable them to perform a pre-comparison of capabilities provided by the different software. For each model, team members will highlight specific items that they deem important and request detailed information and clarification on that model. The questionnaire, referenced as the Matrix of Capabilities (MOC) by the team members will be compared to the Matrix of Needs (MON) which will reflect the feedback from all the RFCs. The latter will be sent to the 13 River Forecast Centers (RFCs) with a request for feedback on the importance of each items had for the corresponding RFC.

The hydraulic models were selected by the team based on their frequency of use and whose owners were willing to participate in the evaluation and provide licenses that could be used during the evaluation, at no cost.

Selected data sets will be sent to the vendors prior to start of the first training so the different issues such as setting up data input could be discussed during the training.

At least two data sets will be used by the team for testing of the models. These are the Red River in Minnesota (MN) and the St. Johns River, Florida (FL). If time permits a third data set will be selected.

The evaluation team will be subdivided into groups in order to execute pre-set evaluation tasks and to get the data sets prepared prior to executing the models. All the team members will participate in the execution of the data sets using all the models. The pre-tasks are identified in the Timetables and Milestones section **8** below.

These pre-tasks are integral part of the evaluation, so the comments received from tasks i. and ii. will be included in the final report. In particular the benefits and disadvantages from each of the software evaluated will be documented. Additional tasks have been assigned to help the main ones identified above.

Work will be done remotely and through a series of conference calls starting on June 1, 2006 and terminating with a report one year later. Team testing will start fully in November, once the final data sets are delivered to all the team members. The testing for all four models should finish by April, 2007 by which time all test results will be due for incorporation in the final report. The three on-site training sessions that are being planned will provide team members background information for each of the models being evaluated.

The first training session will be held in Silver Spring, Maryland during the week of September 18,

2006. Specific information pertaining to the SOBEK and MIKE 11 models will be presented. Team members will also discuss goals, the evaluation structure, and the general mechanics of how the team will operate during the entire evaluation process.

Between the first and second training sessions, team members will begin to evaluate the SOBEK and MIKE 11 hydraulic models which were presented during the first session. Data sets which will be used to test these models will also be selected. These data sets will be provided to all the team with the following requirements: a) the data sets will allow testing of most of the model capabilities needed for NWS river forecast operations, and b) the data sets are already implemented into NWS operations at one of the RFCs.

The second training session will also be held in Silver Spring, Maryland during the week of November 13, 2006. Advanced FLDWAV and basic HEC-RAS GUI familiarization training will be presented. In addition to the training, the team will visit the Corps of Engineers, Baltimore District, and receive a "hands-on" demonstration concerning the suite of HEC models, in operational mode. This would aid in the assessment of the HEC operational capability.

Between the second and third training sessions, selected data sets will be tested and evaluated using each of the four hydraulic models selected.

The third training session will be held in Davis, California and will occur at the end of January 2007, for two and a half days. Detailed information about the HEC-RAS model will be presented. During the year several training classes take place or are planned by HEC for a broad range of participants interested on the topic. However, this particular training will be offered for the evaluation of evaluation team members only. The sessions will include discussions of interest for the evaluation effort itself.

Stage 4 - Design & Development

Not applicable to this project

7. Critical Success Factors

No.	Activity Stages:	2	3	4	All
1	Creation of a non-centralized core group of people with training, familiarity and experience with these hydrological models and their issues. This will allow having a larger group available for support when needed for dealing with operational issues as they arise in the future.				x
2	Compile enough information and testing results to be able to recommend implementation of the selected software solution				x
3	Compile feedback from the field offices to determine their needs and how to satisfy them so they can provide a better service to their user's community				x
4	Learn capabilities and limitations of the different software available at NWS and outside				x

8. Timetable/Milestones

Stage	Dates
Stage 2 -Validation	**Dates**
Develop Evaluation Approach	5/1/06-5/31/06
Select Evaluation Participants	5/1/06-5/31/06
Complete CONOPS	11/15/06
Complete Project Plan	11/15/06
Branch Review & Approval	11/21/06
HOSIP Gate 2	12/06/06
Stage 3 - Research & Analysis	**Dates**
For each test session: Divide evaluation team into groups. Prepare data sets for evaluation. Execute Models. Evaluate minimum two datasets (up to three). Execute additional runs so that all team members can evaluate all the models using all the datasets	6/1/06 – 5/30/07
i. Transformation of data sets to be used with the different models	6/06 – 7/06
ii. Summary of the responses from the MOC with emphasis in the differences among the software considered.	7/06-8/06
iii. Develop Strategy to follow during the evaluation	8/06-9/06
iv. First Training – Silver Spring, Maryland • DHI • Delft	09/18/06 – 09-22-06
v. Team member Evaluation of SOBEK and Mike 11 Models	9/22/06-10/22/06
vi. Selection of data sets	10/22/06-11/06
vii. Second Training – Silver Spring Maryland • FLDWAV • HEC-RAS overview in steady state • Visit to Army Core of Engineers	11/13/06 – 11/16/06
viii. Pre-selections of data sets to be tested and evaluated in each hydraulic model	11/06-12/06
ix. Third Training in Davies, California (HEC-RAS)	01/07
x. Solving problems with structures and conversions in data sets	02/07
xi. Testing of models begins	03/07
xii. Continue testing and sending results for report to OHD	04/07
xiii. Write the final report	05/07
xiv. Update Project Documents	05/07
Gate 3 Review	July 18, 2007
Stage 4 - Design & Development	**Dates**
Not applicable to this project	

9. Budget/Roles and Responsibilities

Role/Name	Responsibility	Hours	Dollars ($)
Stage 2 - Validation			
HSMB, Hydraulics Group Leader, Reggina Cabrera	Provides overall guidance for the evaluation and coordinates activities among the different participants	200	
	Total		
Stage 3 - Research & Analysis			
HSMB, Hydraulics Group Leader, Reggina Cabrer*a*	Provides overall guidance for the evaluation and coordinates activities among the different participants	500	.
HSMB Hydraulic Team Research Scientist, Sanja Perica	Research team member	700	
Arkansas-Red Basin RFC	Research and Evaluation participants	250	
California-Nevada RFC	Research and Evaluation participants	250	
Missouri Basin-RFC	Research and Evaluation participants	250	
North-Central RFC	Research and Evaluation participants	250	
North-East RFC	Research and Evaluation participants	250	
North-West RFC	Research and Evaluation participants	250	
West-Gulf RFC	Research and Evaluation participants	250	
Cleveland Weather Forecast Office	Research and Evaluation participants	250	
HOSIP Analyst	HOSIP Administration, document review and Q/A	40	
Geoffrey Bonnin, HSMB Chief	Project Oversight	8	
Pedro Restrepo, Senior Scientist	Reviews Evaluation documentation	8	
1st Training Session	Review and Evaluation Conference Conference hours Hotel Fees Flight	40 5 nights	
2nd Training Session	Review and Evaluation Conference Conference hours Hotel Fees Flight	40 4 nights?	
3rd Training Session	Review and Evaluation Conference Conference hours Hotel Fees Flight	40 3 nights?	
3 Sessions	Instructor Fees	25	
	Total	***2956***	
	Not applicable		
	Total		

10. Assumptions and Constraints

Assumptions and Constraints	
1	All resources needed to begin the analysis and research will be made available
2	NCEP Data needed for research will be provided
3	Participants will be available
4	Costs of Licenses, training and on-call support will be factored into final report

11. Risk Assessment and Mitigation

No.	Risk	Mitigation Plan
1	Team Members communication issues	Communicate regularly and using a variety of methods including emails, phone calls, and conference calls so that all are in communication nearly all the time.
2	Team Members not being able to attend the training	Provide alternative resources including meeting summaries and model user training material, outside the training sessions
3	Team members operational forecasting duties may limit time for participation and testing of models	Provide resources so that Team Members may proceed with the testing on own schedule if necessary
4	Not enough time to test all the features during the time allotted to the project	Continue testing after the project is completed if needed. Request extension for the preparation of the final report if necessary.

APPENDICES

Appendix A – Table of Acronyms

Acronym	***Acrostic or definition***
ABRFC	*Arkansas-Red River Forecast Center*
AWIPS	*Advanced Weather Interactive Processor Service*
CNRFC	*California Nevada River Forecast Center*
COE	*Core Of Engineers*
CONOPS	*Concept of Operations*
DELFT	*Delft Hydraulics, Inc., Rotterdam The Netherlands*
FEMA	*Federal Energy Management Agency*
FLDWAV	*Flood Wave Dynamic Model*
GUI	*Graphical User Interface*
HEC-RAS	*Hydrologic Engineering Center-River Analysis System*
HL	*Hydrology Laboratory*
HOSIP	*Hydrologic Operations and Service Improvement Process*
HSEB	*Hydrologic Software Engineering Branch*

Acronym	***Acrostic or definition***
HSMB	*Hydrologic Science and Modeling Branch*
MBRFC	*Mississippi Basin River Forecast Center*
MCP	*Manual Calibration Program*
MN	*Minnesota*
MOC	*Matrix of Capabilities*
MIKE 11	*Hydrology model developed by the Danish Hydraulic Institute*
MON	*Matrix of Needs*
MS	*Microsoft*
NCEP	*National Centers for Environmental Prediction*
NCRFC	*North Central River Forecast Center*
NERFC	*North East River Forecast Center*
NEXRAD	*Next Generation Weather Radar system (NEXRAD)*
NOAA	*National Oceanic and Atmospheric Administration*
NWRFC	*North West River Forecast Center*
NWS	*National Weather Service*
NWSRFS	*National Weather Service River Forecast System*
NWS	*National Weather Service*
NWSRFS	*National Weather Service River Forecast System*
OCWWS	*Office of Climate, Weather, and Water Services*
OHD	*Office of Hydrologic Development*
PC	*Personal Computer*
QA	*Quality Assurance*
RFC (s)	*River Forecast Center(s)*
SOBEK	*Hydrology Model developed by Delft*
SON	*Statement of Need*
WFO (s)	*Weather Forecast Offices*
WGRFC	*West Gulf River Forecast*
WL/Delft	*Formal Name of Delft Hydraulics, Netherlands*
XML	*Extensible Markup Language*

Appendix B – References

[Make sure your references follow general standards]

1. HEC-RAS model, U.S. Army Corps of Engineers, Hydrologic Engineering Center, USA
2. Sobek model, WL/ Delft Hydraulics, The Netherlands.
3. Mike-11, Danish Hydraulic Institute, Denmark
4. FLDWAV model, National Weather Service, USA
5. http://www.weather.gov/oh/rfcdev/projects/rfcHMET_chart.htm

Appendix C – Attachments

Appendix 4. *Matrix of Needs (MON) document with grades provided by all RFCs, cumulative grades and summary of each model's capabilities. Shaded areas indicate low priority functions.*

Functionality		RFC: ABRFC	APRFC	CBRFC	CNRFC	LMRFC	MARFC	MBRFC	NCRFC	NERFC	NWRFC	OHRFC	SERFC	WGRFC	**TOTAL**	MODEL: F	M	R	S
River reaches	Multiple rivers	2	2	1	3	3	0	0	3	3	3	3	2	3	**28**	√	√	√	√
	Braided rivers	1	3	0	0	2	0	3	2	2	3	3	2	2	**23**	√	√	√	√
	Split flow	2	2	0	3	3	0	0	3	3	3	3	2	2	**26**	√	√	√	√
	River sinuosity	2	2	0	0	3	0	0	2	3	3	3	2	3	**23**	√	√	√	√
	Flow diversions	3	2	2	3	3	0	3	3	3	3	3	1	3	**32**	√	√	√	√
	Backwater effect	3	2	1	2	3	0	3	3	3	3	3	3	3	**32**	√	√	√	√
	Effects of tailwater conditions	3	2	1	2	3	0	3	2	3	2	3	2	3	**29**	√	√	√	√
Reservoirs	Multiple reservoirs in series	3	1	2	2	3	2	3	2	3	3	3	3	2	**32**	√	√	√	√
Dams and dam break	Dam overtopping	3	2	2	2	3	3	3	3	3	3	3	3	3	**36**	√	√	√	√
	Erosion based breach	3	2	3	2	3	3	3	2	3	3	0	3	3	**33**	√	√	□	$
	Crest breach	3	2	3	2	3	3	3	2	3	3	0	3	3	**33**	√	√	√	$
	Piping failure	3	2	3	2	3	3	3	2	3	3	0	3	3	**33**	√	√	√	$
	Cascading dam failures	3	2	3	2	3	3	3	2	3	3	3	2	3	**35**	√	√	√	$
	Flood mapping after dam break	3	2	1	2	3	3	3	3	3	2	3	3	3	**34**	$	√	$	$
Levees	In river	3	2	2	3	3	2	3	3	3	3	3	2	3	**35**	√	√	√	$
	Off-reach	3	2	2	2	3	2	0	2	3	2	0	1	3	**25**	√	√	√	$
	Levee breaching	3	2	2	3	3	2	3	2	3	3	3	2	3	**34**	√	√	√	$
Bridges and/or culverts	Multiple openings	3	2	1	2	3	0	3	2	3	3	0	3	3	**28**	√	√	√	√
	Closely placed objects	3	1	1	2	3	0	3	2	3	3	0	2	3	**26**	√	√	√	√
	Bridge scour	2	2	1	0	2	0	1	1	2	2	0	2	2	**17**	X	X	√	X
	Can import RAS structures	3	3	1	3	3	0	3	3	3	3	3	3	3	**34**	X	X	√	√
	Can import FLDWAV structures	3	3	1	3	3	0	3	3	3	3	3	3	3	**34**	√	X	X	X
Advanced modeling capability	Wind effects	1	1	2	2	3	2	1	2	3	0	0	3	0	**20**	√	√	X	√
	Ice jam buildup/breakup hydraulics	1	3	0	0	2	1	2	2	3	2	3	0	0	**19**	X	□	√	X
	Floodplain mapping	1	2	1	3	2	3	2	3	2	2	3	3	2	**29**	$	√	$	$
	River and estuarine systems interface	0	2	0	0	3	3	0	1	0	3	0	2	0	**14**	√	√	√	□
	Water quality	2	2	0	0	0	0	1	2	0	2	0	1	0	**10**	X	$	□	$
	Interaction with ground water; karst flow	1	1	1	0	2	0	2	1	0	0	0	2	0	**10**	X	$	□	√
	Sediment transport	0	2	0	2	2	0	2	2	0	0	0	0	0	**10**	X	√	√	√
	Salt water intrusion, salt wedge	0	1	0	0	2	0	0	0	0	1	0	0	0	**4**	X	√	□	$
	Habitat modeling, fish passage	0	1	0	0	0	0	1	1	0	0	0	0	0	**3**	X	√	X	√
Floodwave approx.	Fully dynamic flow description	3	2	3	3	3	2	3	3	3	3	3	3	3	**37**	√	√	√	√
	Diffusive wave approximation	3	2	3	3	3	2	3	3	3	3	3	3	3	**37**	√	√	√	√
	2-dimensional simulation	1	2	0	0	3	0	2	1	2	2	0	2	2	**17**	X	$	□	√
Manning's n	Variable roughness (by HG and Q)	3	2	0	3	3	0	3	3	3	3	3	3	3	**32**	√	√	√	√
Boundary conditions	Multiple upstream boundaries	2	1	1	3	3	3	3	2	3	3	3	2	2	**31**	√	√	√	√
	Multiple downstream boundaries	2	1	1	3	3	0	2	2	3	3	3	2	2	**27**	√	√	√	√
	Tidal fluctuations/surge	0	2	0	3	3	3	0	0	3	3	0	3	3	**23**	√	√	√	√
	Dam boundary	3	2	2	3	2	0	3	3	3	3	3	3	3	**33**	√	√	√	√
	Internal boundaries	2	1	0	0	3	0	3	2	3	3	3	3	3	**26**	√	√	√	√
	Structures operations module	3	2	1	3	3	0	1	3	3	3	3	0	0	**25**	√	√	√	√

Model: F – *FLDWAV,* M – *MIKE 11,* R – *RAS,* S – *SOBEK*
Model capabilities: √ - yes/has capability; X– no/ no capability; $ – has capability with licensed add-on module; □ – current version has no capability, but well under development

Appendix 5. *Matrix of Capabilities document.*

1. MODELING CAPABILITIES NEEDED FOR CURRENT NWS OPERATIONS

1.1. MODELING RIVER REACHES

⇒ **Multiple rivers**

F: It can model multiple rivers of either dendritic (tree-type) composition and/or bifurcated (island/bypasses) configurations.

M: MIKE 11 has a looped network where branch ends can be connected to any location in the network.

R: No limits on the number of river reaches.

S: Yes

⇒ **Braided rivers**

F: It can model braided rivers.

M: Yes

R: Any kind of braided or looped networks is ok.

S: Yes

⇒ **Split flow**

F: It can model split flow such as multiple outlets to lakes or bays.

M: Split flows are naturally handled in a looped network.

R: We have an optimization routine when run in steady flow mode. When run in Unsteady flow mode, this is automatically taken care of on a time step by time step basis.

S: Yes

⇒ **River sinuosity**

F: It has special non-linear sinuosity coefficients.

M: Yes

R: We do not have an automated river sinuosity factor, but the forces/energy losses from river sinuosity can be incorporated into Manning's n values and reach lengths of the overbanks.

S: Yes

⇒ **Flow diversions**

F: It can model flow diversions over levees or special diversion outflows.

M: Yes

R: Many methods for handling flow diversions. The user can enter a hydrograph, the user can model the flow diversion with a lateral hydraulic structure option in RAS, or they can put in rating curves to represent the diversion.

S: Yes

⇒ **Lakes, ponds, etc**

F: It can model lakes and ponds by treating them as level-pool or by fully dynamic with dead-storage and/or dendritic-type branching channels.

M: Yes

R: Can be modeled with storage areas, or can be modeled with cross sections for dynamic routing through lake/ponds.

S: Yes

⇒ **Off-channel storage**

F: It can model off-channel storage including the treatment of floodplain storage below the levee crest elevation with simultaneous treatment of active flow area above the levee crest elevation.

M: Storage can be represented as regular storage in the cross sections (always applies), and additional storage, which can be added to any cross section in the form of a stage-area curve.

R: Off channel storage can be handled in two ways with RAS: first the user has the option to partition parts of the cross sections to be modeled as storage. Second, the user can use “Storage Areas” to model separate off channel storage. Storage areas can be connected to river reaches with Lateral Structures, and they also can be connected to other storage areas. Storage areas can also be the upstream or downstream boundary of a river reach.

S: Yes

⇒ **Backwater due to tidal conditions, dams, bridges, large tributaries, etc.**

F: Yes

M: Yes

R: Backwater is inherent in the use of the full unsteady flow equations.

S: Yes

⇒ **Effects of tailwater conditions**

F: The FLDWAV can treat submerged bridge flows and dam spillway flows.

M: Yes.

R: The effects of tailwater conditions are included in all of these computations.

S: Yes.

1.2. RESERVOIR AND DAM BREAK MODELING. Does the software have the ability to model:

⇒ **Multiple reservoirs in series**

F: It can model multiple reservoirs in series, as well as, multiple reservoirs on multiple rivers (dendritic or bifurcated).

M: Yes

R: No limits to how many.

S: Yes

__Appendix 5.__ Matrix of Capabilities document.

⇒ **Dynamic routing through reservoirs and the ability of a reverse flow option**

F: Downstream reservoirs are modeled in the FLDWAV Model using fully dynamic flood wave routing. The most upstream reservoir on each river with dams can be modeled by either dynamic routing algorithm or a level-pool routing algorithm. Reverse flows can be modeled in the FLDWAV Model. These flows may occur in reservoirs, upstream of river junctions, or even through a dam.

M: A reservoir can be represented with a stage-area curve, by a series of cross sections or any combination of these. The user decides whether to resolve the hydraulics of the reservoir.

R: User's can perform complete dynamic routing through the reservoir, which will inherently allow for reverse flow if it exists.

S: In case the reservoir is incorporated in the model schematization.

⇒ **Dam overtopping**

F: Dam overtopping flow over level dam crest or an uneven dam crest.

M: A dambreak structure in MIKE 11 is defined with a structure representing the crest and a structure representing the breach. Additional structures can be added to the same location, e.g. additional gates.

R: Complete level and non-level dam profiles for overtopping analysis.

S: Yes

⇒ **Erosion based breach**

F: Erosion or collapse formed breach using time dependent formation and shapes of either rectangular, triangular or trapezoidal with specified breach initiation by water surface elevation or elapsed time from start of simulation; and breach formation can be linear or nonlinear with tailwater submergence correction included.

M: A breach can be prescribed with a time-series or with an erosion based model.

R: RAS currently does not have an erosion based breach capability. The user must enter the breach dimensions and development time. HEC-RAS has options for growing the breach either linearly, with a sinusoidal growth function, or the user can specify a breach growth curve. We are currently working with the ARS and other federal agencies looking at erosion based breach algorithms, the results of this work will be put into HEC-RAS as an erosion based algorithm

S: Yes. 1D and 2D Breaking Dams.

⇒ **Dam break initiated as a breach of the crest**

F: Erosion or collapse formed breach using time dependent formation and shapes of either rectangular, triangular or trapezoidal with specified breach initiation by water surface elevation or elapsed time from start of simulation; and breach formation can be linear or nonlinear with tailwater submergence correction included. Breach can be by overtopping using broad crested weir flow with tailwater submergence correction.

M: Two models are available for piping failure, MIKE 11 and NWS dambreak equations.

R: Yes, we have overtopping breaching capabilities

S: Using the Real-time control module, you can define any kind of failure mechanism. The evolution of these failure mechanisms can be done in a Matlab computation.

Appendix 5. *Matrix of Capabilities document.*

⇒ **Dam break initiated as a piping failure**

F: Breach can be by piping with orifice flow changing to broad crested weir flow when head water elevation recedes to near the top of pipe breach (tailwater submergence correction for both orifice flow and broad-crested weir flow).

M: For both models the breach can be initiated as a piping or breach failure.

R: Yes, we have piping failure capabilities

S: Yes

⇒ **Cascading dam failures**

F: Multiple dams in sequence can be breached according to either overtopping or piping initiated breaches.

M: Dambreak structures are generic, and can be added as a series of structures. The only constraint is that there must be a cross section between each dambreak in a series of dambreaks.

R: There is no limit to the number of dams in series or in parallel.

S: Yes

⇒ **Can the model be set up in a configuration that will allow forecaster to generate a dam failure forecast in a relatively short period of time (~ 15 min)?**

F: Not answered.

M: This is a little bit broad in the formulation. In principle yes, but of course there are limits, e.g. the model run time may be longer than the 15 minutes if the model is too detailed.

R: Yes. HEC-RAS allows the users to set up a model with dambreak parameters for each dam, test dambreak simulations, and refine the results. Once this is done, a single switch can be set to turn off/on the Dambreak option for any individual dam. If the model is setup this way, then it only requires one parameter to be changed and rerunning the model to have the model perform a dambreak during a forecast. The model was setup this way to facilitate its use in a forecasting environment

S: Forecasts within a relatively short period of time are possible with a 1D schematization. For 1D-2D more time might be needed, depending on the 2D grid size and the total simulation time.

⇒ **Dam break impact downstream**

F: Flooding information is output from FLDWAV to enable assessing dam break flooding impact downstream. The information includes maximum flood elevations ,maximum depths, maximum velocities (in channel and/or in left floodplain and right floodplain portions of the downstream channel/valle); and times at which maximum elevations, velocities, and depths occur.

M: A dambreak structure is part of the network, and the user can add downstream whatever he/she feels like.

R: Downstream routing can be performed, as well as multiple plan analysis to evaluate the impacts of various dam break analysis on downstream locations.

S: Yes

__Appendix 5.__ Matrix of Capabilities document.

1.3. LEVEES. Does the software have the ability to model the following:

⇒ **In-river levees**

Yes: F, M, R, S

F: The levees can be specified as one or both sides of a river and its tributaries or bifurcation reaches, the levee can have a specified crest elevation slope along the river; the levee can be next to the river or set back a specified distance from the river, the levee can be breached with a time-dependent breach of specified length initiated by a specified water surface elevation being flooded, the levee can breach to an specified arbitrary elevation that can be lower than the floodpain, the tailwater effects on submergence correction to the levee breach flow or levee overtopping flow can be simulated, the water elevations in the floodplain can be modeled by either dynamic routing or level-pool routing in the floodplain receiving the levee overtopping and/or breach flows.

M: Yes

R: Levee options exist as part of the base cross section options in HEC-RAS

S: In case this concerns a structure located in the model schematization.

⇒ **Off-reach levees**

F: Yes

M: Yes

R: Off reach levees can be modeled with Lateral Structures in RAS. The inside area of the levee can be modeled as a ponding area with an HEC-RAS storage area, or it can be modeled as another routing reach with cross sections.

S: In case this concerns a structure discharging water out of the model schematization.

⇒ **Is there a capability to add/remove temporary levees or fail permanent levees in real-time operations? How are levee breaches handled? Can the model differentiate between overtopping and a local breach? Can the user easily specify a breach location and timing? Can this information be easily saved for all future operational runs for a given event?**

F: The levees are specified at beginning of each simulation; levee properties can be changed with each simulation; the effort to change levee properties is considered minimal. Different levee simulation scenarios can be saved through multiple carry-over files.

M: Levee failure can be described with the dambreak module, which allows a prescribed failure of the levee. In addition the MIKE 11 Control Structure module allows a generalized time-varying structure description, which can be used for adding/removing levees dynamically during a simulation. Levee breaches can be simulated by using the dambreak module. Yes, the model can differentiate between overtopping and a local breach. Dambreaks can be prescribed so the detailed time development of the breach in known in advance, i.e. when and how the breach develops. The dambreak specifications are part of the model input, and can easily be reused in other, future, simulations.

R: HEC-RAS has the ability to perform levee failures in the same manner than Dam failures can be performed (overtopping or piping failures). This can be done both in real time operations or in planning/calibration type studies. HEC-RAS can handle overtopping and levee failure analysis. Locations and parameters to control levee breaches can be set up, and then easily turned on and off with a single switch for each location. This can be done in both real-time modeling as well as planning/calibration types of studies.

S: Levee breaches can be modeled 1D or 2D. The answers to all questions is yes.

Appendix 5. Matrix of Capabilities document.

1.4. BRIDGES AND CULVERTS. Does the software have the ability to model the following:

⇒ **Multiple bridge/culvert openings**

F: The bridges are modeled by contracted weir flow which considers the head differential across the bridge, as well as, friction losses through the bridge, and the effect of bridge piers, bridge alignment, abutments, etc, using a specified coefficient of bridge flow. Bridge overtopping flow and orifice flow are automatically treated. The bridge option used as an internal boundary condition, properly accounts for its upstream backwater effects. Scour is not directly considered, however the bridge opening may be specified so as to approximate bridge scour. The bridge may be modeled within FLDWAV to approximate debris blockage with subsequent debris/bridge collapse and flow outburst.

M: Yes

R: HEC-RAS has an extensive set of bridge and culvert routines, that have been extensively tested with real data. Users can have multiple bridge/culvert and open channel flow openings at the same river crossing.

S: For bridge number of pillars can be defined. For culverts a number of culverts are to be placed in parallel branches, which can be edited easily, using the Multiple Data Editor. SOBEK offers also the functionality to specify a compound structure, meaning that all compound members lie on the same branch. Hence the user does not need to define a parallel branch for each compound member.

⇒ **Closely placed objects**

F: See above.

M: Yes

R: There is no limitation on how closely spaced the objects are from each other.

S: In the graphical interface, object may lie exactly on each other. By toggling the object of interest can be selected.

⇒ **Bridge scour**

F: Not answered.

M: No

R: HEC-RAS can perform bridge scour analysis from either steady or unsteady flow hydraulics.

S: No

⇒ **Does it have ability to import RAS bridge/ levee/ obstruction data?**

F: Cannot import RAS data

M: No, not directly. MIKE 11 has the FHWA bridge module included, which has been tested and compared to HEC-RAS in connection with the FEMA approval of MIKE 11.

R: Yes.

S: Yes, SOBEK offers the functionality to import a HEC-RAS network.

⇒ **Does it have ability to import FLDWAV bridge/ levee/ obstruction data?**

F: Yes.

M: No, not directly.

R: We currently do not have an option for importing FLDWAV data, but would be willing to add this option.

S: No.

Appendix 5. *Matrix of Capabilities document.*

1.5. ADVANCED MODELING CAPABILITIES

⇒ **Wind effects**

F: It can model wind effects; however, the wind is uni-directional and constant velocity (these limitations can be eliminated with only limited software programming).

M: Yes.

R: HEC-RAS does not currently have a wind affects option. This could easily be added.

S: Yes.

⇒ **Ice jam buildup/breakup hydraulics**

F: Not answered.

M: Over the last couple of years we have worked on implementing ice modelling capabilities in MIKE 11. The development project is funded by Hydro-Quebec (one of the main hydro-power producers in Canada) and carried out by DHI and LaSalle which is a Canadian consultant specified in ice in rivers. The project is still ongoing but we expect to release it as a commercially available module later this year. I've attached a power point presentation providing you with some details on what ice processes are included. Ice jam module "runs in parallel with quasi-steady hydrodynamic module." It means that when simulating ice jam the hydraulics is at each time step calculated using a steady state approach. I.e. at each time step the change in ice jam will be calculated and sub-sequently a back water profile will be calculated based on the updated ice jam, downstream water level and upstream inflows.

R: HEC-RAS has the capability to simulate the presence of river ice covers of known thickness and roughness and estimate the thickness and hydraulic roughness of wide-river ice jams under steady flow conditions.

S: At this moment SOBEK does not have a provision for including the effect of ice cover and jams. Ice cover could be modelled if an adaptation in the description of the hydraulic radius is made. There is no perfect work-around with the current implementation of conveyance in SOBEK. An extension of SOBEK would require further discussions with your modelling specialists. Ice jams would require consensus on the physics behind the formation of ice jams. The track to follow would be the extension and use of one of the hydraulic structure formulations in SOBEK.

⇒ **Floodplain mapping**

F: It does not provide direct floodplain mapping; however, it can provide output to drive flood mapping software.

M: A GIS extension is available for flood mapping. Generating inundation maps is a standard feature of MIKE 11, i.e. there are no additional licenses or costs associated to generating inundation maps. Prior to running a MIKE 11 simulation you simply request one or more maps to be generated. Maps can be generated based on cross section information only (in which case MIKE 11 will interpolate ground elevations between cross section) or you can supply a DEM as additional information to be used as ground elevation between cross sections. The maps are generated as .dfs2 files which is the DHI standard file format for 2D grid data. These files can off course be visualized and animated using standard features within MIKE Zero, but plug-in tool are also available for ArcMAP, Google Earth and World Wind. These plug-in tools are free of charge and allow for visualising the generated flood maps. Installing the plug-in simply adds a button by which you can select the generated flood maps file and it will automatically appear correctly geo-referenced in the map view of the software package in question. No file or data conversion is required.

R: We have extensive flood mapping capabilities with our HEC-GeoRAS companion product that runs in ArcGIS. There is no license requirement for HEC-GeoRAS, it is free to anyone. However, it requires ArcGIS version 9.x as well as Spatial analyst and the 3D Analyst.

S: Inundation maps can be generated using the SOBEK Overland Flow (2D) module. It is also very easy to make animations of the inundation in time within SOBEK. The National Weather Services purchased one license of the SOBEK Overland Flow (2D) module. Thus, no extra costs if this license fulfils your needs. For extra licenses of a module, we offer multiple license discounts up to 75% discount. Many clients use GIS systems for post processing the SOBEK inundation results for further analysis, such as damage analysis. Many of our clients use ArcGIS (ESRI) and you may need additional licenses for ArcGIS or another GIS system, depending on the capacity required.

⇒ **River and estuarine systems interface**

F: It can model the interface between river and estuarine systems; however, it does not account density variations.

M: MIKE 11 can be dynamically linked to a 2D model of an estuarine system.

R: This can be handled with boundary conditions passed between HEC-RAS and an Estuarine model.

S: To simulate the combined river and estuarine system Delft Hydraulics Software offers the highly innovative combination of 1D-3D: a 1D model covering the complex branched river network, on-line coupled to a 3D model covering the wider estuary branches with salt intrusion and the coastal zone. This combination is in research phase and is now being tested on several water systems such as the Pearl River Delta.

2. ADDITIONAL MODELING CAPABILITIES NEEDED FOR FUTURE NWS OPERATIONS

⇒ **Water quality modeling**

F: Not answered.

M: MIKE 11 and MIKE 21 (and thus MIKE Flood) offers water quality modelling capabilities through Ecolab which is DHI's generic model component for water quality modelling. With ECO Lab you can combine the power of a differential equation solver with DHI's powerful flow models. You get access to the best of both worlds - you can define the ecosystem exactly to the degree of complexity required and still be able to transport and disperse material and substances in a highly accurate manner. Ecolab thus provides the basis for accurate spatial predictions of any aquatic ecosystem response - regardless of the size and structure. Physical, chemical and biological processes relevant to environmental problems and water pollution are thus integrated and can be simulated with Ecolab when combined with one of DHI's flow models. For more details: www.dhigroup.com/Software/Marine/ECOLab.aspx

R: We currently have the ability to perform sediment and temperature modeling in HEC-RAS. Right now we are working on the ability to transport other water quality constituents.

S: Delft Hydraulics Software offers with SOBEK a very powerful water quality modelling software tool. Especially when you are interested in modelling the environmental impacts of floodings. The capability is based on the integrated 1D and 2D approach to water quality modelling. This is unique in the world. Concisely we can offer the 1DWAQ module and the 2DWAQ module (pre-release available): 1DWAQ module: a) Based on more than 30 years of experience world-wide; b) Uses a library of 600 processes and substances; c) Includes pre-defined subsets of variables and processes; d) Includes the fraction option to analyse the origin of pollutants. 2DWAQ module: a) Fully integrated with 1DWAQ; the same water quality engine; b) In combination with the Overland Flow module extremely powerful; c) Especially for modelling environmental impacts of floodings. The wide range of modules within the SOBEK framework makes it possible to model almost any aspect of a water system. However, for those who prefer to add new processes to proven knowledge, SOBEK offer the Open Process Library approach. Using this tool you can define easily your own processes and you can add easily the new processes to proven knowledge. This approach is available in the 2007 release. Note that the National Weather Services purchased 1 license of the 1DWAQ module.

⇒ **Interaction with ground water**

F: No.

M: MIKE 11 has some groundwater components, and the model can be dynamically linked to a saturated and unsaturated groundwater flow model (MIKE SHE) to simulate the natural exchanges.

R: HEC-RAS has a simple groundwater interaction routine that allows the user to either loose ort gain water based on groundwater stages and Darcy's law. The user must enter Darcy K coefficients and groundwater stages for each reach modeled. We are also currently working on linking HEC-RAS with the USGS MODFLOW model for a more comprehensive way at evaluating groundwater/surface water interaction.

S: The interaction with ground water can be modeled: a) in a simple way by running the RR (Rainfall-Runoff) module (including ground water and unsaturated zone) with the 1DFLOW module simultaneously; b) in a more complex way by running the 1DFLOW and/or RR modules with 3D ground water models such as MODFLOW (only research releases available now, using the OpenMI standard to link models).

⇒ **Flow in karst areas**

F: No.

M: MIKE 11 does not have this functionality. It is available in MIKE SHE.

R: We do not have this capability in HEC-RAS. However, once we have a successful link with the USGS MODFLOW program, interaction with the river/floodplain and Karst flow areas could be handled.

S: The flow in karst areas can be modeled by using a 3D ground water model and the 1DFLOW module.

⇒ **Sediment transport**

F: No. (Note: Versions of the NWS DWOPER Model (a progenitor of FLDWAV) did have capabilities for sediment transport and ground water interaction)

M: MIKE 11 has a comprehensive sediment transport module that can handle cohesive and non-cohesive sediment with either a single or several fractions, and a two-layer substrate model.

R: With the release of HEC-RAS 4.0 we now have the ability to do sediment transport routing/erosion/deposition.

S: Now only available in SOBEK-RE 2.52. Soon available in the new SOBEK-River product line.

⇒ **Debris flow**

F: No. However, some debris flows behaves as mud flow and FLDWAV can model this type of flow.

M: It depends on what it meant by "debris flow". If it is the hydraulics of the water and debris mixture, the answer is no. MIKE 11 has been used for simulation of debris flow formulated as time-varying structures or with the sediment transport module.

R: We do not have an option to modify the fluid properties for a debris flow. We know how this is done and could easily add this to HEC-RAS if needed. We do have the option for adding debris and/or ice pilling up at bridge crossings. User's can try different amounts of debris hanging up on piers.

S: To be discussed in more detail during training.

⇒ **Salt water intrusion or salt wedge simulation**

F: No.

M: MIKE 11 has two sub-models for the description of the vertical variation: a) a two-layer model (MIKE 12) with a Lagrangian description of the interface, and b) a model with several layers (MIKE 11 XZ) with an Eulerian description.

R: To model salt water intrusion correctly requires a multi-dimensional model. The Corps has a new multidimensional model called ADH (Adaptive Hydraulics) which can be run in 2D or 3D and can handle saltwater intrusion. We are currently working on linking HEC-RAS and ADH on a time step by time step basis.

S: Now only available in SOBEK-RE 2.52. Soon available in the new SOBEK-River product line.

3. FLOOD WAVE APPROXIMATION

⇒ **Can the model be run in both, steady and unsteady state?**

F: The FLDWAV Model (herein refers to the PC version included in the FLDWAV Training Seminar by D.L. Fread) can be run in both the steady and unsteady mode.

M: Yes.

R: RAS has an extensive steady flow engine as well as an unsteady flow engine.

S: SOBEK is especially designed to run in unsteady state. The hydrodynamic simulation engine is equipped with a very robust scheme for numerical computation. It also guarantees mass conservation, even in case of transitions through suddenly varying cross section shapes. The engine combines computations of sub critical and supercritical flow, at scales selected by the user. It handles flooding and drying of channels without the user of artificial methods such as the Preissmann slot.

⇒ **Fully dynamic flood wave approximation:**

F: In the unsteady mode, the flood wave approximation is fully dynamic using either implicit or explicit solution schemes.

M: Yes.

R: RAS solves the full unsteady flow equations.

S: The hydrodynamic simulation engine is based upon the complete de Saint Venant Equations.

⇒ **Diffusive flood wave approximation:**

F: diffusion and/or Musingum-Cunge, as well as, level-pool flood wave approximations can be selected at any specified Δx reaches within the river system during the simulation.

M: Yes.

R: RAS has a mixed flow regime option that limits the inertial terms of the momentum equation. The user can set these terms to zero, thus having a diffusion wave routing technique.

S: The dU/dt term can be eliminated in the momentum equation.

Appendix 5. *Matrix of Capabilities document.*

⇒ **Can model be run in 1-D and 2-D modes?**

F: The FLDWAV Model can run in only the 1-D mode; however, with judicious use of off-channel storage and branched and/or braided river/valley reaches a powerful pseudo 2-D representation can be achieved.

M: MIKE 11 in itself cannot run in real 2-D, though MIKE 11 is a 1-D model with a looped network that can be set up in quasi 2-D mode. MIKE 11 can also be coupled to a 2-D model (MIKE 21) via MIKE FLOOD. MIKE 11 can also be coupled to MIKE SHE, which has a simpler and less demanding 2-D model (kinematic wave approximation) that MIKE 21.

R: RAS is a 1D model, but we are currently working on being able to link HEC-RAS on a time step by time step basis to a 2D/3D model called ADH (Adaptive Hydraulics). ADH was developed by the Corps and is non-proprietary.

S: Furthermore combined 1D-2D mode is also possible. SOBEK offers one powerful hydrodynamic simulation engine for 1D, 2D and 1D-2D mode. This engine is used in all 1DFLOW modules and Overland Flow modules (2DFLOW) within the SOBEK framework. Thus allowing the combined simulation of channel-, pipe- and overland flow through an implicit coupling of 1D and 2D flow equations. SOBEK is the ideal tool for studying the effects of river floods, dike breaches, dam breaks, urban flooding etc.

4. CROSS SECTIONAL DATA MANIPULATION

⇒ **How does the user create/modify model input?**

F: The input can be easily modified using either a new very simple data input template or a GUI Software Package.

M: MIKE 11 has a graphical user interface (GUI) integrated under MIKE Zero. All model editing is done in this interface, and both graphical editing and tabular editing is available.

R: Creating and modifying input data is developed in a Windows based User Interface. This interface has been designed and programmed by Hydraulic engineers that use the software. The interface has been developed and modified based on input from thousands of engineers around the world.

S: Through the user interface manually by typing input data, importing tables (e.g. boundary conditions), importing GIS files containing input for model schematization.

⇒ **Can the software make use of USGS and HEC-DSS databases? Can it import HEC formatted cross sections directly?**

F: The FLDWAV Model (stand-alone version does not directly use USGS or HEC-DSS databases or import HEC cross sections.

M: Yes, there are tools available for importing cross sections from HEC. MIKE 11 cannot directly access a HEC-DSS database.

R: HEC-RAS has the ability to read data from HEC-DSS directly, as well as read any cross section data from previous versions of HEC-RAS. We also have automated utilities within our HEC-DSSVue software for reading from USGS and NWS data formats, which then can be read into HEC-RAS from the DSS file. HEC-RAS has the ability to read in geometric data (cross section data and other data) in many external formats, however, we do not currently support the reading in of FLDWAV cross section data. This option could easily be added.

S: Not answered.

Appendix 5. *Matrix of Capabilities document.*

⇒ **Can the software import FLDWAV formatted cross sections directly?**

F: Yes.

M: No.

R: HEC-RAS has the ability to read in geometric data (cross section data and other data) in many external formats, however, we do not currently support the reading in of FLDWAV cross section data. This option could easily be added.

S: Not answered.

⇒ **What methods are available for creating cross sections? How does the user generate cross sections? Is GIS knowledge required to develop cross sections? How does the user add/delete cross sections or tributaries?**

F: The cross sections can be best (most accurately and simply) developed using topographical maps and a scale.

M: Cross sections can be added and edited manually, imported from survey data or cut from a DEM. Basic GIS knowledge is required for extraction of cross sections from a DEM, but not for editing the cross sections in the MIKE 11 cross section editor (see figure below).

R: The user can enter cross sections by hand in the cross section editor, or they can import them in, or they can cut and paste them in, or they can import them from a GIS. HEC-GeoRAS is one option for getting cross sections from a GIS but many other commercial packages exist that also do this (There is software available that runs off of Intergraph, AutoCad, and others GIS/CAD systems). Our HEC-GeoRAS product is designed for the typical hydraulic engineer who does not have a lot of GIS experience. It is very easy to use in laying out cross sections, and other hydraulic structures to be passed to HEC-RAS. Cross sections can be deleted one at a time or the user has the option to select multiple cross sections, then have them all deleted simultaneously. Entire reaches can also be deleted in HEC-RAS.

S: GIS knowledge is not required for developing cross-sections. Cross-section are entered in Tables, either by typing or importing tables.

⇒ **Can cross sections be created via cross section interpolation? Can cross sections be irregularly spaced?**

F: Cross sections can be created between input cross section by linear interpolation which is controlled by a single parameter for each reach between adjacent input sections. The input cross sections can be unevenly spaced; however, the interpolated sections are evenly spaced so that extremely small reaches are not created through truncation (this avoidance promotes numerical stability). Further numerical stability of irregular cross sections (expansion/contraction) along the river by use of automatic insertion of interpolated sections according to critical stability criteria and by automatic use of the conveyance option a very irregular cross section in the vertical (incised channel with a very wide, flat overbank or floodplain).

M: Yes, cross sections can be interpolated in the MIKE 11 cross section editor, a single cross section can be interpolated to a specified location, or a series of cross sections can be interpolated along a reach. Cross sections can be irregularly spaced; there are no constraints on the locations of cross sections, and additional interpolated cross sections can be forced in the network by a parameter ("Maximum dx") that determines the maximum distance between calculation cross sections in the network. Such additional cross sections are generated automatically in the engine, and are not in the cross section database.

R: HEC-RAS has an extensive set of cross section interpolation routines which have been tested thoroughly. Users can have cross sections evenly spaced, or they can specify specific distances, or maximum distances.

S: SOBEK interpolates between user defined cross-sections.

⇒ **When editing a cross section, can the user graphically view edited cross section information prior to model acceptance?**

F: Not answered.

M: Yes, the cross section editor is both graphical and tabular (see figure below) and shows the cross section shape, resistance distribution and markers, as well as the processed data for the cross section (flow area, width, radius, additional storage, resistance factor, conveyance).

R: HEC-RAS has an extensive graphical cross section editor in which the user can view and edit any cross section. The editor allows for moving, entering, and deleting points. It also allows the user to enter/modify optional cross section properties such as Manning's n values, levees, ineffective flow areas, blocked obstructions, ice, debris etc…

S: The user can view cross-section graphically.

⇒ **Can cross sections be graphically viewed during calibration and operations? How does the user accomplish cross section viewing? Does the scale change with each cross section or is the scaled fixed?**

F: Not answered.

M: The cross sections can be viewed in the MIKE 11 cross section editor for the model setup (see figure below) and in result presentation where the cross sections can be viewed together with the calculated water level. When plotting multiple cross sections the users controls if the scale changes with each cross section or of the scale is fixed.

R: Cross sections and water surfaces can be viewed in either calibration or an operational mode. Cross sections are automatically scaled to the data by default, but the user can set a persistent scale to use for viewing the cross section data.

S: Results data can not be graphically viewed in cross sections yet.

⇒ **Is it possible to change a gage location or datum, change geometry, or change an inflow location/time-series without a recalibration?**

F: Gage datum are easily changed, as well as, other input such as time series, cross section properties.

M: Yes, MIKE 11 does not demand that your model is calibrated. Recalibration can be done manually or by using the auto-calibration tool.

R: Yes. In a real time forecasting mode the user can make changes to flow and boundary conditions, as well as a limited set of geometric data (i.e. roughness coefficients, flow versus roughness factors, flow versus seasonal factors for real time calibration). HEC-RAS does allow for datum corrections at either single locations or a range of user selected locations. However, this is not typically done in real time operations.

S: It is possible to change all data without recalibration.

⇒ **How is Manning's n applied in the model? Can the model assign variable roughness to stage and discharge ranges at a cross-section?**

F: The FLDWAV Model uses either constant roughness or variable roughness with stage or discharge. The roughness relation is specified for each reach between input cross sections or multiple reaches of input cross sections

M: Yes, the Manning n can be specified both as function of the location along the cross section (e.g.

different river and floodplain resistance) and as a function of stage, which is often used to reflect that rivers are rougher at low stage. The Manning n can also be varied longitudinally, either in the cross sections or through other input files (HD parameters).

R: Manning's n values can be applied in many ways in HEC-RAS. Users can input n values varying horizontally across any cross section. Manning's n values can be varied vertically with stage or flow. In a real time mode the user can set a range of cross sections and apply either flow versus roughness factors or seasonal roughness factors.

S: Yes, it is possible to assign variable roughness as function of h and Q (i.e. n=f(x,Q) or f(x,h). These functions are available on the so-called River Profiles

5. BOUNDARY CONDITIONS. Does the software allow for the following boundary conditions?

⇒ **Upstream stage or discharge hydrograph**

F: Upstream boundary can be a discharge or stage time series or a combined discharge time series with a level-pool flood routing algorithm.

M: Yes.

R: Can be hand entered or read from our DSS (Data storage system).

S: Yes.

⇒ **Downstream stage or discharge hydrograph**

F: Yes.

M: Yes.

R: Can be hand entered or read from our DSS (Data storage system).

S: Yes.

⇒ **Downstream single-valued rating curve**

F: Downstream boundary can be a specified rating of discharge and stage

M: Yes.

R: Can be hand entered or read from our DSS (Data storage system).

S: Yes.

⇒ **Downstream stage hydrograph – defined by tide hydrograph blended with a simulated tide hydrograph**

F: Downstream boundary can be a discharge or stage (lake level or tide) time series; … The FLDWAV Model can have a tide (stage time series) boundary and include storm surge elevations. Versions of FLDWAV used for Slidell RFC can use NWS Storm Models output files and a version used for NWRFC can perform some tide adjustments for barometric variations.

M: Yes.

R: Users can have a stage hydrograph or they can have a stage hydrograph that then transitions to a simulated flow hydrograph. Can be hand entered or read from our DSS (Data storage system)

S: You can define h(t) as a periodic function with a specific duration.

__Appendix 5.__ Matrix of Capabilities document.

⇒ **Can the model accept multiple boundary conditions (upstream and downstream)?**

F: The FLDWAV Model can accept multiple boundary conditions, i.e., at the upstream boundary and at the downstream boundary.

M: For the mathematical problem to be well-posed, all open ends of branches in the MIKE 11 looped network must be assigned a boundary condition. There is no practical limit to the amount of boundary conditions that can be assigned, but only one boundary condition can be applied at an open branch end (e.g. only one discharge or water level time-series specified at an open end). Several point sources can be added to the same location (which does not have to be an open branch end), but only one e.g. inflow boundary condition can be specified at an open branch end. MIKE 11 handles this in a general way, which allows the user to e.g. specify several inflows in tributaries, which in the looped network join up with a mainstem that empties through several outlets, each outlet with a water level, Q-H or even discharge boundary condition.

R: Yes, there are no limits on the number of upstream and downstream boundary conditions for a single model.

S: Yes, the model can accept multiple boundary conditions.

⇒ **How does the user define and modify boundary conditions?**

F: Not answered.

M: MIKE 11 has a Boundary Conditions editor where the boundary conditions are listed and edited. The user selects the location for each boundary, and has access to automatically putting boundary conditions on all open ends (these are always boundary conditions), and select boundary conditions types, associate time-series etc. The boundary conditions are shown graphically in the network. Flow and level boundaries can be set as either a constant value or as time varying. For the latter the time series editor is used.

R: Within the HEC-RAS interface there is a separate editor for entering and editing unsteady or steady flow data and boundary conditions. These editors are fully windows based and have automated cut/copy/paste, as well as the ability to read data in an automated way from a DSS file.

S: SOBEK offers a user friendly user interface to define and modify boundary conditions. The data can easily be copied from EXCEL, imported from databases, such as HYMOS, and/or setup from scratch using a tool to generate boundary condition tables. All time series can be viewed in graphs.

⇒ **Does the model allow manual edits of lateral inflow (local and tributary flows)?**

F: The FLDWAV Model can accept lateral flow time series (+) inflows and (-) outflows. These time series can be changed prior to simulation.

M: Yes, the boundary conditions include inflows/outflows that can be prescribed in single points or distributed along a reach. Lateral inflow/outflow can be specified as point or distributed sources. Lateral inflow/outflow can also be passed to/from other models like MIKE 21 and MIKE SHE in a fully dynamic coupling.

R: Yes, either directly from HEC-RAS, or if data is being read from an HEC-DSS file, we have a program called HEC-DSSVue, which allows the user to view/edit any data in an HEC-DSS file. This is also a windows based program, but it can also be run on UNIX workstations, as it was developed in JAVA. We have both point and distributed lateral inflow capabilities.

S: Yes you can edit lateral inflows.

Appendix 5. *Matrix of Capabilities document.*

⇒ **Does it allow for internal boundaries: weirs, locks and dams, rating curves, low flow water crossings? How does the user manipulate/edit internal boundary conditions?**

F: The FLDWAV Model can have internal boundaries such as dams, weirs, locks and dams, rating curves, critical flow cross sections, and bridges. The dams can have fixed spillways, fixed gate, moveable gate settings, overtopping flow for level or variable dam crest elevations, combined rating tables, breached dams (each of these is automatically corrected for tailwater submergence effects).

M: Yes, all these are available in the structure module of MIKE 11. The internal boundary conditions are defined with structures, which replace the momentum equation in Q-points where they are defined. The user edits the structures in the MIKE 11 network editor.

R: All of the listed internal boundaries can be handled in HEC-RAS as well as many that are not listed. HEC-RAS has what we call an Inline Hydraulic Structure and a Lateral Hydraulic Structure, both of which are internal boundary conditions. These structures can be used to model bridges, culverts, weirs, gated structures, etc… The user can model combinations of these structure types at any location. Additionally the user can enter rating curves as an internal boundary condition. The rating curve option will also release the rating curve from being used if the stage would exceed the rating curve value, which could be used for handling low water crossings.

S: Yes, internal boundary conditions can be accommodated using control options. For instance the discharge over a weir can be prescribed as function of other parameters.

⇒ **Structure operations module. What operational rules are used to constrain lock/dam operations? Can gate settings be modeled or prescribed, or does the model use a specified pool internal boundary condition?**

F: The FLDWAV Model cannot have a dam as the upstream boundary; however, a dam boundary condition used as an internal boundary can be adjacent to the upstream boundary condition that is a combination of a discharge time series and a level-pool flood routing algorithm. The FLDWAV Model can use lock/dam operations as an internal boundary using target pool elevations controlled by the lock master's unknown manipulation of gate settings or by specified time-dependent gate or multiple gate settings, or by automatic switch to channel control when tailwater target elevation is reached.

M: MIKE 11 has a comprehensive Structure Operations module with generic rules that can be used for defining the operation of any structure.

R: HEC-RAS now has four options for controlling gated structures. The following is a short description of each: 1) The user can enter a time series of gate openings that are used directly. 2) We have an "elevation controlled gate" option that allows the user to monitor any location in the model for stage or flow, and then make gate opening and closing decisions from these stages or flows. The user also has the option to look at two locations and compare stages and flows, then operate gates based on the difference in values. 3) We have developed an extensive capability which we call our "Navigation Dam" boundary condition. This is an extensive set of routines that will automatically calculate gate openings/closings based on user entered target pool elevations, hinge point targets, and knowledge of upstream flows. This algorithm was developed to allow the Corps to model all of the locks and dams on the Mississippi, Ohio, and Missouri rivers. It has also been used to model smaller structures in which target stages and flows can be established for gate operations. This method is documented in our User's manual. 4) With the Release of HEC-RAS 4.0 we now have an extensive "Generic Rules" boundary that can be used to control any gated structure within a RAS model. The rules editor allows the user to develop there own set of comprehensive rules for how a structure can be operated. The rules editor allows the user to establish variables, get simulation values from the current HEC-RAS time step, write equations, perform table lookups, and set operational parameters for each time step in a simulation. This capability has been applied to the Tampa Bay Water Project for evaluation water releases from the Hillsborough River, based on a complex set of operational requirements.

S: SOBEK has a very powerful Real-time control module, allowing for any kind of operation, for instance making decision on basis of water balances or external (no SOBEK computed) data. To be discussed in more detail during the training.

6. MODEL OUTPUT

⇒ **Can model output time series be exported in different formats?**

F: The FLDWAV Model provides time series files of water surface elevation, discharge, velocities, Froude numbers, as well as, maximum water surface elevation and maximum discharges, and river thalweg bottom profiles (computed at each cross section and interpolated cross section. These are currently printed in output tables, and graphs within FLDWAV and/or are exported to external Flood Information Software Plotting Packages, (Flood Java Plot and FLDGRF).

M: Output can be written to the MIKE 11 result file format (.res11), to time-series (.dfs0 or ASCII) or to 2-D maps (.dfs2) based on the 1-D results. There are also tools available for exporting from a MIKE 11 result file to ASCII files.

R: Yes. HEC-RAS by default writes its model output to a binary file (we are willing to give this file format to anyone). We also can write are output to an HEC-DSS file. We have free libraries that can be used to incorporate the ability to read and write data to and from a DSS file in your code. We also can write some of our results to text files. And finally, we can export some results to a GIS exchange file format that we use for performing inundation mapping.

S: Yes, for example: MS Access Files (*.mdb), Comma separated values Files (*.csv), dBase Files (*.dbf).

⇒ **Does the software output the hydraulic information? Does the software provide tables and graphs of velocity, flow, stages, Froude number, rating curves, peak flow hydrograph, water surface profiles, and thalweg profile?**

F: The FLDWAV Model provides time series files of water surface elevation, discharge, velocities, Froude numbers, as well as, maximum water surface elevation and maximum discharges, and river thalweg bottom profiles (computed at each cross section and interpolated cross section.

M: MIKE 11 output water level and discharge to the standard MIKE 11 result file, while additional output can be written to a separate file, as well as to time-series files. The additional output ranges over a vast amount of variables like shear stress, flow area, Froude number, flow width, radius, velocity, Manning n etc.

R: HEC-RAS computes and outputs over 300 hydraulic variables at every cross section for every user selected time step. All of the outputs you have listed are available from HEC-RAS and many more. We have extensive plotting capability for cross section plots, profile plots, hydrographs, and 3D plots. We have generic plots in which the user can plot any variable in profile, or plot one variable versus others at a particular node (cross section, bridge, culvert, etc…) We have many predefined output tables, and we also allow the user to develop there own tables of the variables they want to see. User tables can be saved for recall from any model execution.

S: Yes, all listed output can be produced, except for the Froude numbers.

⇒ **How easily are the resulting water surface elevations exported for inundation mapping? What platform is used to produce the mapping?**

F: These are currently printed in output tables, and graphs within FLDWAV and/or are exported to external Flood Information Software Plotting Packages, (Flood Java Plot and FLDGRF).

M: There are two ways inundation mapping can be done in MIKE 11: 1) MIKE 11 has a GIS extension that can make flood maps based on the result files and a DEM. The water surface elevation (WSE) map is usually generated by using the simulated water levels and the locations of these, which can be combined with the cross section lines for a better representation. The mapping platform is GIS. 2) The inundation map is generated on the fly as the models computes. The map can be visualized in MIKE 11 or GIS.

R: HEC-RAS has an option to export results to a generic GIS exchange file format. The format is documented in the HEC-RAS User's Manual. We have developed a companion product called HEC-GeoRAS that works with the ArcGIS software for performing inundation mapping of results. This software is very easy to use for developing inundation maps. The HEC-GeoRAS product is PC based in that it is built in ArcMap and written in VBA within ArcGIS. However, because we write our results to a generic text GIS file format, anyone can read these results and perform the mapping. Other commercial vendors that already do this are MicroStation/Intergraph, BYU with WMS and SMS, Boss International with AutoCAD, and Haestad methods.

S: Delft-FEWS offers powerful Flood Mapping. Furthermore, in 2D computations the SOBEK output is written to ESRI compatible Ascii grid files.

⇒ **Can graphical model outputs be extracted for web use?**

F: Not answered.

M: Graphs can be exported from result presentation and MIKE Zero to common image formats like jpeg, bitmap, gif and meta files, or directly to the Windows clipboard by copying graphs. These can then be used on the web or in applications that support these formats.

R: Yes, all of the HEC-RAS graphics can be sent to the windows clipboard or written to a DXF file. They can then be put into a web page by simply pasting them in. We have examples of HEC-RAS outputs on our web page that can be viewed to see a demonstration of this.

S: Yes, Delft Hydraulics Software offers the combination of Delft-FEWS and SOBEK for graphical model outputs on the web.

7. IMPLEMENTATION AND INTEGRATION IN NWSRFS

⇒ **Is the model stable in a real time situation for all flow regimes? Are there any known situations for which non-convergence typically occur?**

F: The FLDWAV Model is stable for all flow regimes (subcritical, supercritical, and transcritical (flows that change in space or in time from subcritical to supercritical or vice versa). However, proper selection of time steps, distance steps, and certain modeling options such as the LPI (Local Partial Inertia) algorithm; conveyance representation of the friction slope, S_f; adherence to the cross section expansion/contraction constraint; and avoidance of the KD=4 looped downstream boundary option when the river bottom slope is too flat (about 2 ft/mi or less). Nonconvergences can occur when the conveyance option for Sf is not used and the incised channel with a wide, flat overbank is being simulated. This nonconvergeence occurs when the change in topwidth exceeds about 500 to 600 ft. per ft. of elevation. However, many times, the automatic time step reduction contained within FLDWAV when nonconvergence occurs can cause the model to converge with correct solutions; also, the convergence criteria EPSY can eliminate some of this type of nonconvergences by using a larger value or using a alternative type of EPSY (a percentage criteria activated by preceding EPSY with a (-) sign, e.g., -0.03 which means a 0.03 percent change in the depth or discharge is used as the tolerance in the Newton-Raphson Iteration within the solution algorithm). Also, nonconvergence can occur if the distance step is too large at locations where the water surface curvature is excessive, e.g., near critical flow locations or where pool elevation behind dams or flooded bridges approach an upstream steep sloping river bottom.

M: Stable, but not unconditionally. There is an upper limit on the time-step. Nonconvergence: steady state calculations in complex networks with many branches and structures.

R: The model is capable of being stable in a real time simulation for all flow regimes. However, this is highly dependent on cross section spacing, time step selection, as well as several other factors. HEC-RAS has a mixed flow regime option that is based on what FLDWAV does to handle mixed flow regimes. No model can claim to be 100 percent stable for all flow regimes and all possible operations without being thoroughly tested. Especially if the model input was developed by someone who does not understand what it takes to make an unsteady flow model stable. Anyone who claims their model can handle every possible situation that any user will come across, and remain stable, is not being realistic! HEC-RAS has been applied to situations that are simple to complex. It also has been applied to several Dambreak analyses with a range of channel slopes. All of which we have been able to develop stable models that produce reasonable engineering results. In my experience the toughest situations are working in very steep terrain, in which supercritical and or mixed flow regimes occur. The model can be made to work under these circumstances, however, it takes someone with a lot of experience and knowledge on how to space the cross sections, selecting the time step, and setting the mixed flow regime parameters.

S: Yes, the robustness is one of the most important advantages. Nonconvergence: Not known for SOBEK hydraulic computations.

⇒ **Does it work with the local partial inertia technique?**

Yes: F, M, R, S (not needed)

F: The FLDWAV Model has the local partial inertia techniques which can be used for each river, separately, or with selected reaches within each selected river.

M: Yes, MIKE 11 automatically reduces the convective terms as critical depth is approached, which allows the model to handle sub- and super-critical flow as well as transition.

R: Yes, this is the technique that we use to model mixed flow regimes. The technique in HEC-RAS is based on a paper by Dr. Fread and Dr. Janice Lewis.

S: No, SOBEK does not need this technique for stability.

⇒ **Is it easy to calibrate the proposed model? What support programs are available to aid in calibration? What type of statistics do you use to evaluate the calibration?**

F: The FLDWAV Model can be automatically calibrated for the roughness as a function of discharge or stage. However, sufficient stage time series must be available from a reasonable number of gaging stations throughout the river system being simulated. The calibration option is available within the FLDWAV Model by simply selecting the input variable (NP) to be -1 and providing the necessary stage time series. Mild to steep sloping rivrs with few gaging stations can be calibrated manually.

M: The difficulty in calibrating a model varies a lot. Models with detailed cross section data and a few accurate gages are easily calibrated, while models with poor data quality can be very challenging. Many gages also require more work in the calibration process. Result presentation is useful for adjustment of the Manning n value, and an auto-calibration tool that can make automatic adjustments to the Manning n is available. For manual calibration the result presentation have options for quantifying how well measured and simulated compares. Several approaches are available in the auto-calibration tool, e.g. emphasis on high-flow or low-flow etc.

R: The model is easy to calibrate. However, the level of complexity of calibrating the model depends on the level of complexity of the system being modeled. We have many options for incorporating observed data in plots and tables for visual inspection. The user has options to easily adjust Manning's n values or they can establish flow versus roughness factors for various ranges of cross sections. The program also allows for seasonal roughness corrections for long term simulations. For calibration statistics we compute peak stages, flows, and volumes, as well as differences between computed and observed values. Since HEC-RAS can write its results to the HEC-DSS system, other types of statistical analysis can be computed from our HEC-DSSVue program by comparing computed and observed data.

S: To calibrate models the current SOBEK release (2.10) provides tools to easily analyze results data of different cases in combination with monitoring data. As many users would like to use support programs for (semi) automatic calibration, SOBEK will offer Data Assimilation Tools in near future.

⇒ **Can the proposed model be reasonably used in operations? What are the model benchmarks for speed of operation on a system similar to the NWS AWIPS/LINUX environment? For example, how long does it take to run a 140mile stretch of river with 100 cross-sections?**

F: Not answered.

M: The computation time in MIKE 11 depends on the model setup, and obviously on the CPU speed. MIKE 11 speed is usually measured in points per second, and fast desktop computers (e.g. 3.4 GHz) can run about 300,000 points per second. For a model covering 140 mile stretch with 100 cross section which has to simulate a 7-day period (typical for real-time forecasting) the runtime would be a few seconds.

R: We have an operational version of HEC-RAS that is used for real time operations. This version works on SUN workstations. The HEC-RAS computational engines are written in Fortran and can be compiled on any UNIX workstation environment. The HEC-RAS User interface is written in Visual Basic and only runs on the PC with Windows. However, we have an operational interface that is written in JAVA that allows the user to change flows and boundary conditions, gate operations, and a limited set of geometric variables in a real time operations mode. With that said, it will take some effort to implement HEC-RAS into the NWS forecasting system. We do not see this as a monumental task, but it will be work, time, and money required to do so. As far as how fast it runs? We can not answer the question exactly. In order to answer this question we would need to know how long of a simulation period was run, what time step the model was to be run at, and the exact specs of the machine to be run on. All we can say is that the matrix solver used in HEC-RAS is very fast. We also pre-process the geometry data into a series of tables and curves to improve speed of the computations. So in a forecasting environment, the geometry preprocessing does not have to be re-run when applying new flows and boundary conditions. To venture a guess we would say that the computational time for a 140 cross section model running at a 15 minute time step for seven days would run in less than 10 seconds. We also can apply the flow and seasonal roughness factors without re-running the geometry preprocessor, this also speeds up real time computations. HEC-RAS is currently being used in the Corps real time system called CWMS (Corps Water Management System), which is primarily a UNIX based system with clients on PC's. HEC has a lot of experience in developing, applying and using real time systems for hydrologic computations.

S: Yes, the robustness, accuracy and the speed for operation make SOBEK the model.

⇒ **Is this model used for real-time forecasting? If yes, where? And by whom?**

F: Not answered.

M: The model has been used in numerous cases around the world for real-time forecasting. Selected references are shown in the table below (Thailand: Department of Local Administration, Royal Irrigation Department, Bangkok Metropolitan Administration; New Zealand: Environment Waikato; China: China Yangtze Three Gorges Project Development Corporation, Changjiang (Yangtze) Water Resources Commission; Italy: Consorzio Venezia Nuova, Regione Piedmonte; UK: The Environment

Agency - Anglian Region; USA: Lower Colorado River Authorities; Bangladesh: WMO; Czech Republic: Danish Environmental Protection Agency). For additional details refer to:

www.dhigroup.com/Software/WaterResources/MIKEFLOODWATCH/Details/Applications/SelectedReferences.aspx

R: Yes, HEC-RAS is used for real time operations. As mentioned previously it is an integral part of the Corps Water Management System (CWMS). This system is being applied by all of the Corps of Engineers offices that perform real time operations. Many real time systems have already been put together and are in operation. Others are currently under development. And some others are planned to be developed.

S: SOBEK is used in various Delft-FEWS (Flood Early Warning Systems). New Delft-FEWS applications are Taiwan, Vietnam, River Rhine-Europe, Songkla Lagoon-Thailand and Marina Reservoir-Singapore.

⇒ **Can a calibration model be easily implemented in operations (is there any conversion necessary from calibration to operational model)?**

F: Not answered.

M: Typically updating is not included in the model calibration, but real-time updating (or data assimilation) should always be included when applying the model for real-time forecasting as this will significantly improve the accuracy of the forecasts.

R: Calibration models can be directly input for use in operations. During real-time operations, flow and boundary conditions can be changed, as well as gate operations. Additionally a limited set of parameters can be adjusted in real time operations in order to refine a model to improve a specific forecast.

S: Yes, for example SOBEK can easily be implemented in the open shell forecasting system Delft-FEWS.

⇒ **How easy it is to utilize the model for those who are not experienced in hydraulics?**

F: The FLDWAV Model must be set-up and calibrated by one who has been trained for such a task. Once this has been done and the model has been checked for unusually low or high-flow situations, it can be run by one who is not as highly trained.

M: DHI’s philosophy is that it should never be difficult to use DHI’s models, but they are still complex model. Experience and knowledge in hydraulics are not required to operate the model, but would seem to DHI to be necessary for understanding how the model works, and understanding the model setup and results.

R: Any hydraulics model should be developed and calibrated by someone who does have experience in hydraulics. However, once the model has been developed and calibrated it is very easy for anyone to change parameters, rerun the model and view results. It is also very easy to do this in a real time context.

S: Our standard two day training course makes it possible for those who are not experienced in hydraulics to utilize SOBEK. However for the interpretation of model results, we think understanding of hydraulics is preferable.

⇒ **Can the model be coupled with a hydrologic model or a 2-D model?**

F: The FLDWAV Model could be coupled to a hydrologic model by proper output/input files. A 2-D dynamic modeling option could be added fairly easily as an additional routing option within the FLDWAV Model, itself. However. it has been shown for some estuaries in which only typical flood information (stage, hyrographs)is desired, the 2-D Model does not have any significant advantage over a well constructed 1-D Model.

M: Yes, MIKE 11 can be coupled to a the MIKE 11 Rainfall Runoff module for lumped parameter modeling of the hydrology, or it can be linked to a 2D overland flow model (MIKE 21) for simulation flood inundation, or it can be linked with a spatially-distributed hydrological (MIKE SHE) for integrated surface water and groundwater modeling with 2D overland flow, 1D unsaturated zone flow, 3D groundwater flow, and detailed evapotranspiration processes.

R: Yes. HEC-RAS has always had the ability to be coupled with hydrologic models by simply reading and writing flow and stage boundary conditions to common databases. We currently do this with our HMS (Hydrologic Modeling System) as well as other hydraulics models. We are currently working on methods to allow HEC-RAS to be tightly coupled to other models on a time step by time step basis. We will be trying this with the Corps 2D Hydraulics model ADH as well as the USGS MODFLOW model this coming year.

S: Yes, coupling with hydrologic models (f.i. Sacramento model) is possible. In effect any kind of rainfall-runoff model can be coupled, since it refers to a lateral discharge as function of time on a lateral boundary node. And yes, within SOBEK it is easy to setup a model for 1D2D simulations, as SOBEK contains only one hydrodynamic simulation engine in all 1DFLOW modules and Overland Flow modules.

⇒ **Is the software source code available? If it is, is it customizable, i.e. can NWS make changes in the code?**

F: The FLDWAV Model source code is available. It can be customized or changed fairly easily by one who has familiarity (gained by experience or by training) with the code.

M: The source code is not normally available, though specific user defined routines can be added. The code is customizable, and is continually updated and improved by DHI.

R: We do not distribute the source code of any of our newer software products including HEC-RAS. The software executables and documentation are made available for free to anyone with no licensing requirements. In the past we did distribute source code freely. From that experience we found it impossible to keep up with changes that other people were making, and still calling the software HEC's version. We have a responsibility and an obligation to maintain our software and answer questions on what are considered to be bugs and problems in our software. Distribution of source code would not allow us to do this in an effective manner. We are also not willing to accept the liability that goes along with allowing others to make changes to our code, and still call the product and HEC product. Because we do not distribute source code, only HEC can make changes to the code. We are more than willing to work with anyone on changes that are requested and needed. If a change is something very minor, then we would probably do that for free. If the changes will require some significant amount of time (more than 1 person day) then we would require a transfer of funds, scope of work, and time line for performing the changes. In the past, we have given out small pieces of the source code that are used for reading and writing to our data files and output. We are more than willing to continue to do that so anyone can easily interface with are input and output files. In the future we may be changing the format of are input files to and XML format and are output files to HDF5, which are both standard text and binary file formats in which there are generic readers that can be used to view and decipher the file formats.

S: SOBEK offers an Open Process Library for water related processes, including a powerful user interface to describe your own processes and coefficients and based on this description to generate a personalized software source code, which can be interlinked with the other SOBEK modules. The software source code of SOBEK is not available.

__Appendix 5.__ Matrix of Capabilities document.

⇒ **What language(s) is the code written in?**

F: The code is written in Fortran 77.

M: Delphi Pascal.

R: The computational engines are written in the Fortran 90 coding language. The main user interface is written in Visual Basic. We have a limited user interface that is written in JAVA for real time applications on UNIX systems.

S: The computational cores in Fortran, user-interfaces in .NET, Visual Basic.

⇒ **On what platform can the model run (PC, LINUX, UNIX)?**

F: The code can run on a PC and can be integrated into NWSRFC on the LINUS AWIP Platform.

M: Windows. Older versions existed in DOS and UNIX.

R: The model is mostly used on PC's. But we also have a version running on the SUN workstation in the SUN OS. The computational engines could be compiled for any platform as they are generic Fortran. Are limited HEC-RAS interface that is written in JAVA currently runs on PC's and the SUN OS. This interface could be adapted to run under Linux.

S: The User Interface and the computational cores can run on PC. The computational cores on Linux are still in research phase.

⇒ **Can NWS customized user interfaces or scripts be used in conjunction with the model?**

F: Not answered.

M: MIKE 11 has an in-built user defined structure that allows the user to link to a DLL in which the structure is defined.

R: Yes, many people have built custom interfaces around HEC-RAS. We have always made the code that reads and writes our file formats available for people to do this. We have also modified the HEC-RAS interface to expose most of the objects and functions, such that users can write code to control our user interface in an automated way. Some commercial examples of this are the WMS and SMS systems developed by BYU. Boss International has developed there own interface and system around HEC-RAS, as well as Haestad methods. There are several other smaller firms that have done the same thing for real time operations, such as David Ford Consultants.

S: To be discussed in more detail.

8. DOCUMENTATION AND SUPPORT

⇒ **What documentation exists for the proposed model? Is the documentation adequate for debugging calibration and operational troubles?**

F: The documentation of the theory and of many example runs is abundant via a users manual and several professional papers. Also, additional information is on two training CDs produced under the auspices of the Bureau of Reclamation and the Association of State Dam Safety Officials and available at minimal or no cost.

M: Detailed user and reference manuals are available in hardcopy and PDF format. The hardcopy manuals are supplied with a MIKE 11 installation, while the PDF manuals are installed with the MIKE Zero installation on the hard disk (usually under c:\program files\DHI\MIKEZero\Manuals). In addition there is an online help functionality that allows the user to quickly seek information regarding a specific portion of the model, e.g. when located in a specific dialog window. The manuals are comprehensive, and allow the user to solve most problems.

R: HEC-RAS has extensive documentation available. We currently have three manuals for HEC-RAS: a User's Manual; Hydraulic Reference Manual; and an Applications Guide. All are free and available to download from our website. Each document is updated for each major release of the software. The User's Manual is designed to explain how to use the software and all of its capabilities. The Hydraulic Reference Manual describes the equations and algorithms used in the solution schemes, as well as what data is required and guidance on how to get it or estimate parameters. The Applications Guide has 17 example data sets that walk the user through how to use the software for various applications. The manuals are very comprehensive and easy to read. The documentation has separate sections on calibrating a model as well as producing a stable and accurate model. Additionally, documentation exists on what to do when you run into problems.

S: The documentation contains Getting Started, Tutorials, Reference Manual, Technical Reference Manual, Frequently Asked Questions, SOBEK input file formats, Installing the software and Error messages. All available in the Online Help. The documentation should be adequate for learning the system, debugging calibration and operational troubles.

⇒ **What company or entity will provide calibration, and model setup support?**

F: Not answered.

M: If requested from DHI, it will be done by DHI experts, the majority holding Masters or Ph.D. degrees. DHI does not have any influence on what other contractors the user would involve in the process.

R: HEC can provide this support, but there are also many consulting firms that are currently providing such support for a fee. We have a list of venders on our web site that will provide this support for a fee. HEC is more than willing to provide this support for a fee also. We have an extensive set of classes that we provide on the use of HEC-RAS that can be made available specifically for the NWS. We can also assist in providing model setup and calibration serves for a fee. We also have IDIQ contractors that work directly with us that can provide this kind of support. Depending on the extent of services needed, many options are available for acquiring this type of support.

S: To be discussed.

⇒ **Is technical support available beyond receipt of the model? Is operational support available (e.g., how would you get involved if the model does non-converge in real-time run)?**

F: Technical support could be furnished with regards to training, actual model code changes or assistance to NWS staff in making code changes. The turn-around for such changes should be relatively short for minor changes relating to any software bugs or data output modifications. Minor computational improvements and enhancements should also be relatively short turn-around time. Adding new modeling capability such as sediment transport and groundwater ineraction woud require greater turn-around time.

M: DHI offers technical support via phone and internet (email and webcasts) with a purchase of MIKE 11. DHI experts are available in the US on both the East and the West Coast, as well as globally, and can be contacted usually with very short notice for solving problems. Support is never more than an e-mail away in the DHI global network.

R: We currently only provide full support to the Corps of Engineers offices, and those working with the Corps on specific applications of the software. We do take phone calls and emails from anyone on what is considered to be bugs in our software. We have in the past established full support to other federal agencies for a fee. This would depend on the number of users of the software. This has been done with the NRCS in the past. To the question of operational support. If the NWS were to pay HEC for full support, we would handle operational support in the same manner that we currently do with our Corps offices. When a problem arises with non-convergence of a data set, and the user can not figure out why it is occurring, the user can email us with their problem and attach a copy of the data set. We run the data set on our machines and find the problem. If the problem is a data problem, we email them back what is wrong and what to change or the changed data set. If the problem is a source code problem, we first try to find a workaround for the user to implement. If a workaround is not possible, we make the code changes and send the user an interim version of the software for their use. We also have come into other systems remotely and run the software on their machine. This is done with software products like Hummingbird Exceed and PuTTY. These software products allow us to get onto the user's machine and run the model there. However, because of increasing security restrictions, this is becoming less viable. With our CWMS system, because it is client server based, we can simply log onto a client here at HEC, open their watershed on their machine, run it on their machine, and see what they see. We do not have 24/7 support available. We do not currently have enough staff to support that type of operation.

S: For both Delft-FEWS and SOBEK Delft Hydraulics Software offers technical support in case the Software License & Maintenance Agreements are in place.

⇒ **If changes in the code are needed, can the NWS make a request for change? What is the request process for the NWS? What is average time for changes to become effective?**

F: Technical support could be furnished with regards to training, actual model code changes or assistance to NWS staff in making code changes. The turn-around for such changes should be relatively short for minor changes relating to any software bugs or data output modifications. Minor computational improvements and enhancements should also be relatively short turn-around time. Adding new modeling capability such as sediment transport and groundwater ineraction woud require greater turn-around time.

M: Yes, DHI gladly takes requests for code alteration. The time for the change to become available obviously depends on development effort and also to what extent the client is financially supporting the development. For smaller requests a revised version can often be delivered within a week or two as an unofficial update which will be included as a new feature in a sub-sequent official service pack.

R: If changes to the source code are required, the NWS can make a request to HEC for the change. The Corps of Engineers and the NWS already have a working MOA (Memorandum of Agreement) which allows us to do work for each other by transfer of funds through a MIPR. A scope of work, cost estimate, and time line would need to be developed for each effort. We can not give an estimate of the time required for a change, since it is very specific to what is being requested. We try to always work out ahead of time an estimate of the time required and the cost before we proceed. Once changes are made and tested, we have no problem in giving interim versions of the software that include the changes. Public releases of the software are not made more often than on a yearly basis. All changes to the software are included in public releases when they are made.

S: To be discussed; several options available.

⇒ **Can you provide model setup support within the NWS AWIPS/LINUX environment?**

F: Exportation to AWIPS would not be covered other than assistance on the PC version code.

M: MIKE 11 currently operates only on a Windows operating system. The cost to make the MIKE 11 / MIKE FLOOD system operate within the NWS AWIPS/LINUX environment is not currently known.

R: Yes we can provide model setup support for inclusion of HEC-RAS into the NWS AWIPS/LINUX environment. HEC-RAS could be incorporated in many ways, so we would need to meet with the developers/support team for the AWIPS system and discuss what would be the most appropriate way to incorporate HEC-RAS into the system. As discussed under then next question, were currently have an MOA with the NWS for incorporating software into the NWS systems. This could be used to develop task orders for HEC assistance with incorporation of HEC-RAS into the AWIPS system. Because the development and use of the AWIPS system is not a Corps of Engineers mission, any work that we do in this capacity would require funding in order to proceed. Scopes of work, time lines, and cost estimates would need to be developed jointly for each task requested.

S: No info provided.

⇒ **Can you provide support for model inclusion into the RFS environment?**

F: Not answered.

M: Yes, DHI is available to provide support for model inclusion into the RFS system, and it will be done at at mutually acceptable consulting rates. However, since do not currently have working experience with this system it is difficult to quantify the costs involved.

R: Yes we can provide support for inclusion of HEC-RAS into the RFS system. This could be accomplished in many ways, so it would be best to meet with the RFS developers/support team and discuss the most appropriate way for including HEC-RAS into this system. We currently have an MOA with the NWS Office of Hydrologic Development, which covers working together on developing, incorporating, and utilizing HEC models within the NWS operational software such as the RFS. We are currently working with the NWS on incorporating our HEC-ResSim program into the RFS. As far as cost is concerned, it would depend on the extent of our assistance that is needed in performing this work. A scope of work, time line, and cost estimate would need to be developed for this task. Since there are so many ways that HEC-RAS could be incorporated, we can not make an estimate of cost at this time.

S: Not answered.

9. OTHER

⇒ **Tell us items about your model that you want us to know.**

F: Other capacities of the FLDWAV Model include the following: 1) Automatic option for maximum stability simulation which includes checks for transcritical flow, large expansion/contraction of adjacent cross sections, wide-flat overbank floodplain, Courant Criteria, Δx selection, Δt selection, and downstream boundary selection stability. 2) The levee overtopping /breach has been improved for computational stability. 3) The conveyance option for treating S_f has been provided for cross sections that have been input to the model as composite cross sections. 4) The information on convergence and checks on volumetric conservation have been improved. 5) The simulation of mud flows has been improved.

M: MIKE 11 is part of a family of software products developed at DHI Water & Environment. DHI is a non-profit research and consultancy foundation with more than 500 employees based in offices around the world. Choosing MIKE 11 will give you a product: being used intensively internally at DHI and by thousands of external user worldwide; with a user interface and a numerical engine allowing the users to efficiently set up and run applications; with a long record of applications within real-time forecasting; with dynamic links to other DHI software allowing for combining MIKE 11 1-dimensional simulations with for instance 2-dimensional flood modelling, ground water modelling and models for piped networks; which is supported by a professional software development and support organization committed to providing timely quality support to our users.

R: The following is a list of capabilities available in HEC-RAS that were not asked about in the previous set of questions: 1) Pump Stations: HEC-RAS has the ability to model pump stations.

Appendix 5. Matrix of Capabilities document.

Pump stations can be connected to any cross section or storage area in the model. Up to 10 different pump groups can be entered at an individual pump station, and each group can have up to 25 identical pumps. Each pump group can have a different pump efficiency curve, and each individual pump can have a separate on and off elevation for controlling the pump. Additionally, there are pump station override rules for handling complex situations in which pumps may need to be turned off, or flow may need to be limited during a simulation. 2) Pressure Flow: For HEC-RAS version 4.0 we have added the ability to model pressurized pipe flow in conjunction with open channel flow. User's can have sections of reaches that are pressurized pipes, entire reaches, and even a complex set of interconnected pressurized pipes. 3) FEMA Encroachment Analysis: HEC-RAS is the most widely used hydraulic model for performing FEMA floodway encroachment analyses. HEC-RAS has extensive capabilities for automating the calculation of floodways for both steady flow and unsteady flow analysis. 4) Stable Channel Design: Once a hydraulic model is put together, users can perform an array of sediment transport calculations and stable channel design analysis from the HEC-RAS Hydraulic Design Section of the model. This section also includes bridge scour analyses based on FHWA procedures. 5) GIS Tools: We have added an extensive set of tools to the HEC-RAS Geometric Data editor to allow users to geo-reference models directly inside of HEC-RAS without having to go to a GIS. 6) Channel Design/ Modifications: HEC-RAS has tools to perform channel design and channel modification in an automated way. Users can develop templates that can then be applied to a range of cross sections and projected on a slope. These tools can be used for both flood control planning or river restoration analysis. 7) HEC-RAS also has the ability to model ice cover and dynamic ice build up and jams at bridges. HEC-RAS is used all over the world. When we release a new version of HEC-RAS, it typically averages around 7000 downloads per month for the first six months after the release (we automatically track download numbers and locations, and have verified these numbers several times) then diminishing slowly after that. HEC-RAS is used by all USACE offices; FHWA; USGS; NRCS; FEMA; USBR; Fish and Wildlife; The Nature Conservancy; and many other federal government agencies. The USGS, FHWA, and NRCS have adopted HEC-RAS as their official 1D river hydraulics model over their own models (WSPRO and WPS). HEC-RAS is used by most state and local governments that perform open channel river hydraulics work. HEC-RAS is used extensively in private industry all around the world. Numerous universities teach the use of HEC-RAS to their students, as well as using it as a teaching tool to demonstrate various aspects of computational hydraulics. HEC-RAS can be used for an array of study types and scales. Study types can range from initial screening level studies, through feasibility and design studies, as well as real time forecasting. There are no real limits to the size of a river that HEC-RAS can be applied to. Professors have applied HEC-RAS as a numerical model to compare against lab data (flume size model), and HEC-RAS has been applied extensively to large rivers such as the Mississippi. HEC-RAS can be used in steady flow mode with just peak flows, it can be run in unsteady flow mode for single events, or it can be run as a continuous simulation model .

10. RELATED COSTS (confidential information; deleted from report)

Appendix 6. *Summary of the Matrix of Capabilities document. Model capabilities not provided by model developers are highlighted.*

FUNCTION	MODEL			
	F	M	R	S
1. MODELING CAPABILITIES NEEDED FOR CURRENT NWS OPERATIONS				
1.1. Modeling river reaches				
Multiple rivers	√	√	√	√
Braided rivers	√	√	√	√
Split flow	√	√	√	√
River sinuosity	√	√	√	√
Flow diversions	√	√	√	√
Lakes, ponds, etc	√	√	√	√
Off-channel storage	√	√	√	√
Backwater due to tidal conditions, dams, bridges, large tributaries, etc.	√	√	√	√
Effects of tailwater conditions	√	√	√	√
1.2. Reservoir and dam break modeling				
Multiple reservoirs in series	√	√	√	√
Dynamic routing through reservoir and reverse flow option	√	√	√	√
Dam overtopping	√	√	√	√
Erosion based breach	√	√	□ 1)	$ 2)
Dam break initiated as a breach of the crest	√	√	√	$ 2)
Dam break initiated as a piping failure	√	√	√	$ 2)
Cascading dam failures	√	√	√	$ 2)
Dam break model could be setup in relatively short period of time	√	√	√	$ 2)
Dam break impact downstream	√	√	√	√
Comments: *1) Currently not available. It will be included in future version.* *2) Either MATLAB for 1D module or 2D module needed.*				
1.3. Levees				
In-river levees	√	√	√	$ 2)
Off-reach levees	√	√	√	$ 2)
Adding/removing temporary levees; failing levees in real-time operations?	√	√	√	$ 2)
Comments: *2) Either MATLAB for 1D module or 2D module needed.*				

Appendix 6. *Summary of the Matrix of Capabilities document. Model capabilities not provided by model developers are highlighted.*

FUNCTION	MODEL			
	F	**M**	**R**	**S**
1.4. Bridges and culverts				
Multiple bridge/culvert openings	√	√	√	√
Closely placed objects	√	√	√	√
Bridge scour	X	X	√	X
Import RAS bridge/ levee/ obstruction data?	X	X	√	√[3]
Import FLDWAV bridge/ levee/ obstruction data?	√	X	X[4]	X

Comments: *[3] Partial import only.*
[4] Currently not available;" ...willing to add this option"

FUNCTION	F	M	R	S
1.5. Advanced modeling capabilities				
Wind effects	√[4]	√	X[5]	√
Ice jam buildup/breakup hydraulics	X	□[6]	√	X
Floodplain mapping	$[7]	√	$[8]	$[9]
River and estuarine systems interface	√	√	√	□[10]

Comments: *[4] Can model only uni-directional winds with constant velocity*
[5] Not available, but "This could easily be added."
[6] Under development. It is expected to be released with version 2008.
[7] No direct mapping, but provides output to drive flood mapping software
[8] Can export to generic GIS file or HEC GeoRAS could be used (with Arc GIS, Spatial Analyst and 3D Analyst software; $)
[9] SOBEK Overland Flow module or GIS-type software needed
[10] Under development. 3D module will be needed.

FUNCTION	F	M	R	S
2. ADDITIONAL MODELING CAPABILITIES NEEDED FOR FUTURE NWS OPERATIONS				
Water quality	X	$[11]	□[12]	$[13]
Interaction with ground water	X	$[14]	□[15]	√[16]
Flow in karst areas	X	$[14]	□[15]	√[16]
Sediment transport	X	√	√	√
Debris flow	X	X	X	X
Salt water intrusion or salt wedge simulation	X	√	□[17]	$[18]

Comments: *[11] Ecolab model component needed*
[12] Limited. Only sediment and temperature modeling available; other under development
[13] 1D or 2D WAQ module needed
[14] Limited capability. MIKE SHE model needed.
[15] Limited capability. Link to USGS MODFLOW model under development.
[16] Limited capability. Could be combined with 3D groundwater model (e.g. MODFLOW)
[17] 2D/3D ADH model needed; link under development
[18] SOBEK-River product line needed.

***Appendix 6**. Summary of the Matrix of Capabilities document. Model capabilities not provided by model developers are highlighted.*

FUNCTION	MODEL			
	F	M	R	S
3. FLOOD WAVE APPROXIMATION				
Can the model be run in both, steady and unsteady state?	√	√	√	√
Fully dynamic flood wave approximation available?	√	√	√	√
Diffusive flood wave approximation available?	√	√	√	√
Can model be run in 1-D and 2-D modes?	X	$[19]	□[20]	√
Comments: *[19] Through dynamic coupling with MIKE 21 or MIKE SHE model* *[20] Through dynamic coupling with 2D/3D ADH model (link under development)*				
4. CROSS SECTIONAL DATA MANIPULATION				
Easy to create/modify data	√	√	√	√
Can import RAS-formatted cross sections?	X	√	√	√
Can import FLDWAV-formatted cross sections directly?	√	X	X[21]	X
Cross section interpolation available?	√	√	√	√
Graphical edit of cross sections possible?	X	√	√	√
Cross sections can be graphically viewed during calibration and operations	X	√	√	X
Possible to change cross section properties without recalibration	√	√	√	√
Variable roughness could be assigned to stage and discharge ranges	√	√[22]	√	√
Comments: *[21] Currently not available; "This option could easily be added."* *[22] Could be assigned to stage and flow velocity, not discharge.*				
5. BOUNDARY CONDITIONS				
Upstream stage or discharge hydrograph	√	√	√	√
Downstream stage or discharge hydrograph	√	√	√	√
Downstream single-valued rating curve	√	√	√	√
Tidal boundaries downstream	√	√	√	√
Multiple upstream and downstream boundary conditions	√	√	√	√
Easy to define and modify boundary conditions	√	√	√	√
Manual edits of lateral inflows available	√	√	√	√
Internal boundaries: weirs, locks, dams, rating curves, low flow crossings	√	√	√	√
Powerful structure operations module	√	√	√	√
6. MODEL OUTPUT				
Output time series can be exported in different formats	√	√	√	√
Model provides tables and graphs of different hydraulic properties	√	√	√	√
Resulting water surface elevations easily exported for inundation mapping	√	√	√	√
Graphical model outputs can be extracted for web use	X	√	√	√

***Appendix 6**. Summary of the Matrix of Capabilities document. Model capabilities not provided by model developers are highlighted.*

FUNCTION	MODEL			
	F	M	R	S
7. IMPLEMENTATION AND INTEGRATION IN NWSRFS				
Model is stable and converge in real time simulations for all flow regimes	√	√	√	√
Model works with local partial inertia technique	√	√	√	X[23]
Model is easy to calibrate	√	√	√	√
Model can be used in operations	√	√	√	√
Model used someplace for real-time forecasting	√	√	√	√
Calibration model can easily be implemented in operations	√	√	√	√
Model is easy to use by hydrologists with no significant hydraulics experience	√	√	√	√
Model can be coupled with a hydrologic model or a 2-D model	√	√[24]	√	√
Software source code available	√	X	X	X
NWS customized user interfaces/ scripts can be used with the model	√	√	√	√
Comments: [23] *Technique not needed for stability* [24] *Can be coupled with Open MI compliant models (NWS models are not compliant)*				
8. DOCUMENTATION AND SUPPORT				
Documentation adequate for debugging calibration and operational troubles	√	√	√	√
Model developer could provide calibration and model setup support?	NA	$[25]	$[25]	$[25]
Technical support available for operations?	NA	$[25]	$[25]	√[26]
NWS can request for changes in the code?	$[25]	$[25]	$[25]	$[25]
Can provide model setup support within the NWS AWIPS/LINUX environment?	NA	$[25]	$[25]	$[26]
Can provide support for model inclusion into the RFS environment	NA	$[23]	$[23]	$[26]
Comments: [25] *Available for a fee* [26] *Support is available for model schematization, not GUI (information from SOBEK support team)*				
Model: F – *FLDWAV,* M – *MIKE 11,* R – *RAS,* S – *SOBEK* *Model capabilities:* √ *- yes/has capability; X– no/ no capability;* $ *– has capability with licensed add-on module;* □ *– current version has no capability, but well under development,* NA *– not answered*				

Appendix 7. *Team members' comments on general model setup and manipulation.*

Model	Comment
	1. GENERAL MODEL SETUP AND MANIPULATION
	1.1. EASE OF USE
	1.1.1. Availability and quality of documentation
F	Variable definition guide is indispensable. Overall documentation lacking. Lots of documentation – PC stand-alone and AWIPS version has some differences – Operational version has free/not free formats inter-wound in segment definition -- Documentation is incomplete; it basically consists of a technical report and a listing of the parameters necessary to build a FLDWAV deck. No user manual is available. The examples have little or no explanation. FLDAT is a start but the documentation is also incomplete. Online help is limited. Additional training and support would be required to learn the model for all users. Documentation good on theory but severely lacking on how to calibrate and troubleshoot the model. PDF file is searchable. No documentation on error messages. No documentation on how to use Fldat. Very few examples are provided and they have very sparse explanatory notes. A major initiative to provide adequate documentation would need to be undertaken. Almost no documentation Documentation consists of a list of parameters organized by data groups used to build an input deck. Numerous technical papers and reports have been published on the theory and applications of FLDWAV. The user documentation is difficult to follow. Documentation includes Theoretical Description, User Documentation, Examples, and Parameter Description. Documentation lacks section on Error Description and Error Debugging. FLDWAV documentation is available on Internet.
M	There are 4 primary manuals provided for use with Mike11 – User's Guide – provides information on the "buttonology" of the system, providing a brief explanation of each input field on the various screens, and at times providing a more detailed explanation of the different aspects of the model. It is useful as a reference once the functionality is known, but in many cases does not provide enough background information for someone new to the system. Short Intro and Tutorial – small overview of Mike11 provides some of the best explanations of how the various portions of the model work together. As would be expected, this manual does not go into the intensive portions of Mike11, but does a very good job introducing the modeler to the system. Reference Guide – Technical manual that provides theoretical background for many of the deeper concepts modeled in Mike11. Very good explanations in many cases; unfortunately, however, the link between this theory and how to specifically implement it in the software is not always provided. This manual provides a very good view of the wide range of hydraulics that can be modeled with Mike11. MikeView Users Guide – Very good overview of the capabilities of the MikeView software to generate and view output graphics. I

__Appendix 7.__ Team members' comments on general model setup and manipulation.

Model	Comment
	found this manual very useful as a reference. The manuals (and software) in most cases do not provide much information on parameter values – the assumption is that the modeler will bring that information in from another source. Documentation looks very complete … hard to find a variety of examples and uses for the program in the documentation. Documentation is less extensive than HEC-RAS. The online documentation is not searchable and somewhat tedious to find what you are looking for unless you are familiar with the model. I couldn't find any examples or tutorials in the online documentation. Additional training would be required to learn the model with available documentation for most users. Documentation sketchy on how to use the model. Electronic user manual is not searchable which makes it difficult to trouble shoot. Not detailed enough, documentation contained frequent misspellings A detailed description of the computational process for computing unsteady flow is provided in the reference manual. The Saint-Venant equations (i.e. continuity and momentum), the derivations leading to the Saint-Venant equations, and the implicit finite difference scheme is described in the manual.
R	Extensive documentation in the three manuals – user guide, technical ref manual, and application guide. Online help embedded within windows (the "..." buttons that hotlink to the appropriate portion of the manual for the field you are attempting to edit) is incredibly useful. Documentation is very good … many examples …both steady and unsteady flow examples. Looks user friendly. Excellent online and written documentation. Online documentation is context sensitive and searchable. 17 fully documented examples are provided in an applications manual. A technical reference manual is provided in addition to the user's manuals. Model can be self-taught with the available documentation for most users. There are many user groups and forums to review for additional help since the model is so widely used. Very good (but not perfect) documentation overall. Training is recommended, but is no substitute for experience. User manual is searchable by word and by subject; plus there is a very good tree type index. There is a substantial amount of documentation to guide one on how to set up models to avoid instability and how to trouble shoot. Basically, it includes a course in hydraulics. But there are some holes in the documentation. They also provide an applications guide which presents detailed examples. The examples are helpful. In addition, a Hydraulic Reference Manual is provided which describes the theory, equations and assumptions used in their derivations. Discussions are also provided on how to estimate model parameters. There is often guidance on parameter estimation presented in a button right where you need to input the value. Very cool. The Applications Guide document also regularly explains what assumptions the software makes which are helpful when setting up a model. Model is easily set up by documentation alone without training. Details of hydraulic equations and theory associated with various geometry and property settings are typically listed along with the directions. Documentation is generally good. There are several examples which can be used for guidance. However, it is difficult to find an example which has a very basic hydraulic problem. Most examples implement several hydraulic structures (i.e. bridges, levees, etc.) into the river system. I would suggest that a very simple river hydraulic problem with no other structures such as bridges and levees be incorporated as the first example in the user manual.
S	Online documentation is fair. Covers the basic function and use of different parts of the software, but does not provide many examples. Easy navigate.

Appendix 7. *Team members' comments on general model setup and manipulation.*

Model	Comment
	Documentation included with Help system. Fairly complete with example and tutorials available. SOBEK provides online documentation that is searchable but not context sensitive. It provides sufficient information to input the various building blocks of the model in terms of inserting them into the network for most parameters. Some parameters are not explained at all and further searching provided very little information. You are required to go to outside sources to select appropriate values for some of the parameters such as "Form Factor" for bridge pillars. In some instances, the documentation refers you to a section and chapter number but the online documentation isn't labeled as such. There are a limited number of tutorials to help get started with SOBEK but the number and type of examples are inadequate to build a model without support and/or additional training. It would be extremely helpful to have a general section of documentation to explain SOBEK's philosophy of modeling and how it differs from other models such as FLDWAV or HEC-RAS. There are many different modules available such as the Rural, River, and Overland Flow but the documentation didn't explain when you would want use the different modules. After spending many hours searching through the documentation some of the modeling options became more clear but still not obvious. In the latest version of the documentation, SOBEK added a section of Frequently Asked Questions to help explain how to model certain objects. It seems that the user is dependent on SOBEK to assist in modeling questions since the documentation is not as complete as other models.

1.1.2. Understandable / user friendly

F	If you have a pre-formatted input file, the program becomes more users friendly, but still lags significantly. The FLDat is definitely promising …. Many in the hydraulics work like the theory but struggle with its use. Start-up screen for FLDWAV is not user friendly unless you are Danny Fread. It requires you to prepare an input deck and to run from a DOS window circa 1984. You would need to read the documentation to run this if you haven't looked at it for a long time. FLDAT is more useful to convert and build models but the software is not as intuitive as other software. I needed to refer to example FLDWAV input decks and the FLDWAV input documentation to determine which parameters were needed and appropriate values. FLDWAV did not run in FLDAT so you have to export the file, run it in a DOS window and then find the output to display. FLDWAV produced all of the output files needed for FLDAT named "DUMMY.*", I had to rename them the same as the input files to display the output in FLDAT. Menus are simpler than the other models. With experience it is relatively easy to setup a model. Calibrating is difficult. Without Fldat it is very hard to troubleshoot or to see what you have in the way of cross sections, inflow hydrographs, slope, water surface profiles or even what is going on. Fldat is only available for Linux and the Fldwav we are to evaluate is only for PC. FLDWAV is not user friendly. To set up a deck, I developed a template consisting of comment cards with each variable description prior to each line of input parameters. It was also very important to specify the number of the data group for each card since the data groups can have multiple non-sequential listings through the input deck. Without this, it is very difficult to keep track of the process. In summary, FLDWAV is a very difficult model to use. I also have had major instability problems at low flow conditions prior to the onset of significant flood events. FLDAT, the GUI interface to FLDWAV, is very good. FLDAT allows customization of screen layout. FLDATs strength is in visualization of cross-sections, inverts, flow, stage, upstream and downstream boundaries, in static or animated form. All parameters are editable. FLDAT can create a FLDWAV RFS deck from a FLDWAV calibration deck. FLDAT is available in PC or LINUX format. Documentation last updated 2004. The cross section builder takes quite a few clicks to create a cross section from scratch. It is easier to make edits to deck, run FLDWAV, display

Appendix 7. Team members' comments on general model setup and manipulation.

Model	Comment
	output in FLDAT.
M	Fairly intuitive interface. Hopping in and out of the different modules – especially when viewing results – does take a little getting used to. Many functions are available for modeling various features, but with varying levels of documentation. In some cases, the user is left in the dark as to what parameter values would be appropriate for a given structure. Online help is minimal. Some time is needed for the user to familiarize him/herself with the software. Many shortcuts are available, but not immediately apparent, for moving swiftly through the various windows and programs. The ability to right-click on any feature within the network display and open the editor for that feature is very user-friendly. I thought the example in our training exercise could have used some additional verbiage. List of users worldwide definitely indicates that this model is used and understood by many. Back in 1994, DHI tried to sell this model to OH for $20,000. The initial start-up screen for MIKE11 requires some knowledge to begin but the model does lead you through the development of the model once you have started. Review of the documentation would be required to run this model if you haven't run it for a long time. Starting a simple model from scratch seems more complicated than necessary because you have to eliminate complexity rather than build it. It required perusing the documentation extensively and several trial and errors to determine how to build a simple model. Screens are larger than windows but this can be reset once you find instructions. I suspect the documentation may be lacking to make the user more dependent on the vendor for training and support. For many people familiar with HEC-RAS, the Mike11 software will take a bit of adjustment. However, I don't believe the learning curve would be nearly as severe as with SOBEK. Basic organization of menus is easily grasped. Beyond the basics it is not so intuitive. I have reviewed the example MIKE11problem we did at the workshop. The instructions for the example on how to use the GUI for each hydraulic parameter were very deficient. However, with a good set of instructions, I suspect the model is user friendly. The example problem is good in that it is a very simple river hydraulic problem. This is important for establishing a framework before incorporating more complex situations into the model.
R	Once the basic structure of the software is understood, everything seems to fall into place where you would expect it. Default values are provided and reasonable in many cases. (have not had the same experience in Mike/Sobek) Online embedded help is great. Synchronization of all open windows is a powerful asset. Being an old HEC-2 user…this is very easy to understand. Do not have much unsteady flow experience with this model but I am hearing it takes a similar amount of time to get the "kinks" out of the model, although there are better error messages to let you know where to find runtime problems. The startup screen for HEC-RAS: The icons and set-up are intuitive. With a few button clicks and glancing at the subject sensitive help, simple model can be built in minutes. Once learned it is easy to come back and run again even if you haven't looked at for a long time. There are several options available to input the data including GUI's, tables, or importing. Many HEC-2/HEC-RAS input decks have already been developed by other local, state, and federal entities In general the Gui is very well organized. Gaining familiarity is quick. Much of the organization is consistent with other parts of the program because the GUI was written by one very organized individual. Even though there are several files in a project with different extensions; you can delete plans or geometry files from within the program and you can zip them all up for email purposes using a utility called Debug report in the File menu. This is very helpful when the modeler is requesting assistance from someone. HEC-RAS is very straight forward. I have used both the steady and unsteady components with little problem. HEC-RAS does appear to be more stable.

__Appendix 7.__ Team members' comments on general model setup and manipulation.

Model	Comment
S	Software structure, for me, was difficult to adjust to at first. This was not a pick-up-and-play program for me – without understanding the topology and structure of how each piece of the software fits together, the new user will get lost quickly. Geometry interface is cleaner since cross sections are represented by icons instead of the sections themselves, but can be confusing. Do a tutorial model first to adjust to the software. From the startup screen the program leads you to develop a model but not without significant study of the documentation. I was not able to build a simple model from scratch without support from SOBEK. I couldn't determine how to resolve the coordinates for the river network and set the units. This model would require review of the documentation to run the model if you haven't used it for a long time. I suspect the documentation may be lacking to make the user more dependent on the vendor for training and support. Warning: Don't push the Update Projects feature on the Projects tab of the start-up window. Without any warning it overwrites files necessary to run the program, requiring deletion of the Update directory and reinstall to get the program running again.
1.1.3. Other comments: Training and support	
F	Support is nonexistent. Training without Danny Fread has been inadequate. Excellent support is needed because the training and documentation have been and continue to be inadequate. Training and support personnel would need to be added to our agency or developed in house.
M	Support is inconvenient. Training and support are expensive and needs would be extensive. I looked at their 2007 training schedule on the web and their standard training classes are 2 days. A 2-day training seems inadequate for an unsteady flow model. They do have good instructors and they occasionally offer classes in the USA. They probably would conduct classes in USA for our agency.
R	Training is excellent. Support is excellent and HEC staff responses occur within a reasonable amount of time. If one person leaves HEC, the whole software support system does not vanish. HEC has a well trained staff of about 7 who are focused on HEC-RAS and a host of others well versed in RAS. It is an organization that will not be going away. There are many employees in NWS who already have some experience in RAS. Plus, there is an existing pool of potential employees who have expertise using RAS in the hydrologic community. RAS 4.0 Beta has a new feature that zips up all of your files for the project you are working on so you can email the right dataset to HEC for support purposes. This is handy because there are several files in a project.
S	Support is inconvenient. Training and support are expensive and needs would be extensive. The training we received was not evaluated since their trainer was a last minute substitute. Classes are usually held overseas and often in other languages. They would have to conduct classes in USA in English especially for our agency.
1.2. MODEL RUN	
1.2.1. Computational methods	
F	
M	Mike11 is a robust system that seems to be capable of handling the most complex hydraulic systems. There is a lot to this software – this analysis will unfortunately only scratch the surface of what this model is capable of. The computational methods used in MIKE 11 are sound. The model is based on the Saint-Venant equations (i.e. continuity and momentum) and uses an implicit finite difference scheme for computing unsteady flow in rivers and

Appendix 7. *Team members' comments on general model setup and manipulation.*

Model	**Comment**
	estuaries. The module describes sub-critical and super-critical flow conditions. Advanced computational procedures are available for flow over hydraulic structures. The computational scheme is applicable for steep river conditions to tidal influenced estuaries. MIKE 11 is designed for 1-D modeling; MIKE 21 for 2-D.
R	Z-R tables (conveyance vs. height) are prepared in the geometry step of the run before the computation. This enhances the speed of calculations by this simple Z-R lookup. Steady/Unsteady/Subcritical-Supercritical-Mixed flow regimes are permitted. RAS uses same Super-Sub-critical weighting scheme [LPI] as FLDWAV. The computational methods are well documented and hydraulically sound. The unsteady flow equation solution for subcritical flow was adapted from Dr. Robert Barkau's UNET model. Dr. Barkau expanded the work of Dr. Danny Fread, who utilized the Saint-Venant equations of continuity and momentum, in the interest of solution stability and computational efficiency. For mixed flow regimes, RAS uses, as an option, Dr. Danny Fread's Local Partial Inertial technique. RAS uses the solution of the one-dimensional energy equation (Energy losses evaluated by friction and contraction/expansion losses using Manning's equation) for steady flow applications. The momentum equation is utilized at bridges, junctions and at any cross section where a mixed flow regime occurs. HEC is continually researching ways to improve their computational schemes.
S	The underlying computational method for the SOBEK model is based on solution of the Saint Venant Equations just like the other models. The Delft-Scheme solves the equations by means of a staggered grid where water levels are defined at connection nodes and calculation points, while the discharges are defined at the reach segments. Structures are viewed a discontinuities in a branch. At these discontinuities the relation between discharge and water level is not described by the SV Equations, but by structure formulas. Structure formulas describe the relation between the upstream and downstream water level and the discharge through the structure. The SOBEK River module uses more complex equations than the Rural module and therefore requires more detailed input. It can be used stand alone or in combination with other modules. SOBEK also offers combination 1D and 2D solutions, however some features such as dam and levee breach are only available in the 1D2D module unlike other models.

1.2.2. Model stability

F	Stable once calibrated….but bad carryover will stop model if not caught ahead of time. At the NERFC, we have different programs and manually check for bad data, but on rare instances, one bad flow/stage will stop FLDWAV. From past experience, FLDWAV is very unstable at low flow conditions especially for very wide channels. In the evaluation period, FLDWAV remained stable when lateral inflows of .01 (very low), 10, and 100 times the original flows were considered. In my experience, if a full range of hydrograph conditions are incorporated in calibration and no convergence problems occur, then the model will perform similarly in operations.
M	Mike11 is subject to numerical stability issues like every hydraulic model, however for my evaluations no significant stability issues were encountered. The ability to handle adverse numerical conditions is impressive. For example, Mike 11 does not seem to have much of a problem with channels drying out completely, even without a manual insertion of a low-water slot. Although my experience with this model is limited, the model does appear to be relatively stable.
R	Good Stability issues that come up are the standard ones. RAS includes many options to increase stability of a model. If there is not enough flow in the channel, they suggest a pilot channel with at least a continual minimum flow to avoid

__Appendix 7.__ Team members' comments on general model setup and manipulation.

Model	Comment
	instability from this condition. The pilot channel is much faster to implement using HEC-RAS than with Fldwav. With Fldwav the pilot channel has to be coded in by adding a few additional top widths and elevations at each cross section. In RAS, the pilot channel can be easily and quickly applied to the entire reach at once. There is also the Min flow option that allows a user to set a single value and all values in the flow boundary hydrograph below that value will be changed to that value. The Min Flow option is very useful when too low of a flow is causing instability. The LPI method that Danny Fread came up with to increase stability when you have subcritical and supercritical flow regimes is also utilized by HEC-RAS. HEC has refined their methods of controlling rate of change of gate openings which lends stability for gated weirs. The modeler can set a weir/gate submergence decay exponents to help stabilize oscillations at weirs and gates~~.~~ Time slicing is a useful option when your model is not running all of the way through the storm event. This option has the capability of adjusting the time step automatically. RAS does not use the unsteady flow equations through an inline weir – RAS uses the weir equation resulting in greater model stability. HEC suggests that users model significant drops in channel bed elevation with an inline weir to avoid instability. The User's Manual and Applications Guide detail various solutions for stability problems. Too numerous to mention here. This information is invaluable. Similarly stable as other models [issues with low flows] however, unlike other models, RAS has variable gate settings for inline structures and the ability to set gate opening rates that prevent the model from bombing when dams make large gate changes....going from flood control mode [all gates out] back to normal operation [all gates in]. Additionally, when instabilities occur, the output and error messaging guides the user to the problem 90% of the time. The ease of adding internal boundaries of rating curves and stages stabilizes the model.
S	SOBEK features a time step estimation procedure to temporarily reduce the simulation time step internally under certain flow conditions to avoid numerical stability. SOBEK guarantees a solution with this technique. You also have the capability to set initial conditions and numerical parameters to deal with stability issues.

1.2.3. Convergence

Model	Comment
F	Watch for convergence problems with rapidly changing flows, rapidly changing channel/floodplain sections…..even low flow issues. FLDWAV has convergence issues for low flows in wide channels. For rapidly changes flow regimes, FLDWAV uses Local Partial Inertia (LPI) Filter. This approach neglects portions of the momentum equation based on the Froude number… to allow for accurate numerical solutions for mixed flows. For changes occurring at very low flows, FLDWAV incorporates pilot channels to reduce instability. The FLDWAV model indicates and inserts cross sections when the courant condition is violated.
M	
R	Had a problem with unsteady ice jam issues….took the bridge tops out that were not part of the active high flow section anyway, and problem disappeared. With training this should not be an issue. Non-convergence occurs especially at bridges with HEC-RAS but they are easier to handle in HEC-RAS due to the explicit error messages.
S	

1.2.4. Troubleshooting

Appendix 7. *Team members' comments on general model setup and manipulation.*

Model	**Comment**
F	Hard pressed to find errors at times Error messages are vague and almost useless when pinning down the input errors that keep the program from running. In this example, I had to compare each line of the input deck I built with the example deck to find my error. FLDAT verify data routine didn't find the error. FLDWAV allows the user to set the level of output detail for review by the user. INITIAL RUN: I had to review the input deck and compare with example input decks to find input errors to complete the initial run. FLDAT Verify FLDWAV Data utility didn't find the errors. Poor. Support, documentation, and training are essential. These elements are lacking. It is difficult to diagnose errors and non-convergence problems.
M	Error messages are provided during the simulation, and are generally accurate and informative. In every case in my testing, the error message accurately pointed me to the location that was causing problems, with little confusion. The documentation doesn't provide much information about errors but the program does provide messages when data is incomplete and the program won't run. The user can also select different output variable to check results. INITIAL RUN: Run Parameters in the simulation error provides messages to quickly find errors and omissions needing correction to get model to run. I have not had much trouble with this model. However, it should be noted that DHI developed the models for Red Rand St Johns Rivers. I am not sure how difficult it will be to trouble shoot a model we develop from scratch.
R	HEC-RAS performs a data completeness and consistency check prior to running and lists problems and locations to help find the data error. During computation, HEC-RAS produces a summary of Errors, warnings, and notes it encounters. Errors keep the program from running to completion while warnings point the users to hydraulic problems that may need corrected. There is also a flow log that can be set to different levels of detail. HEC-RAS provides sufficient documentation and examples to guide the user to correct hydraulic errors. INITIAL RUN: Program has an option to check data before computation. These messages quickly allowed me find the errors and omissions to get model to run. Errors are pretty well described. Usually gives you some information to help with debugging. The Application Guide describes under what general conditions the error messages are triggered. Support will be required to interpret some errors. It is handy to see all errors in one place (which is available in RAS) and in a printable file. HEC-RAS output tables are also diagnostic tools. In the RAS class, we learned about the Hydraulic property plot which is very helpful in showing you errors quickly. This is a very useful tool to help the modeler correctly place the ineffective flow and blocked areas. The animation in the cross sections is also helpful to see if you are modeling the river correctly. You can plot several key cross sections in separate windows and then run an animation of your storm to see what is going on. The training included a good lecture which is documented in the training class manual on common stability problems with unsteady flow models. HTAB-HT is a good check if program bombs before output phase. Troubleshooting on a completed run with errors or calibration issues has multiple tools: stage/flow hydrographs, user created output tables, animations, profile of complete river system, warning/error output messaging, 3D multi-cross-section view and animation.
S	SOBEK includes a Check Model routine to verify the model is complete. It didn't provide any insight into problems encounter when extreme changes were made to the model. These changes caused the model to bomb in the pre-processing portion of the simulation but error messages didn't point to the solution either. SOBEK doesn't provide many tools to isolate these types of errors that might occur in the input. SOBEK produces log files about the simulation but there is no help to interpret them.

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Model	Comment
1.2.5. Can various scenarios be set up within one model for comparison?	
F	Elevation top width sections differ from the other models. Looks like decks have to be created for each separate case. No, user needs to develop a new input deck but you may cut and paste parts of the input file. No. You have to create new files for each scenario. It is a bit challenging to manage the files. No. A new input deck needs to be developed for additional case scenarios. FLDAT can run several FLDWAV simulations and overlay results graphically for comparison.
M	Various geometries are saved as separate network files, and can be selected from the simulation module and assigned a different result file. Multiple result files can be viewed simultaneously in Mike View for analysis. All in put files and model run parameters are selected from within the simulation module; each configuration of the simulation module can be saved to preserve the differences. There does not seem to be a way to preserve all of the comparison runs under one umbrella project. Yes Yes, in the simulation window the user can pick and choose various networks, cross sections, boundary conditions and hydrodynamic parameters. Yes. Parameters, geometries, and flows can be easily changed within the GUI.
R	Yes, easily. Must be careful when editing geometry files to ensure that new files are generated when intended... and the existing geometry file is not overwritten. Must learn project/plan/geometry file structure... after those things are easily adjusted. Yes good plan/project comparison technique in framework Yes, start up window allows to use various geometries and flows Various geometries/plans can be set up within one project allowing the engineer to compare results, which is essential in the development of a model and for calibration. There is also good documentation on how to do this. It takes some practice. Yes, and it is easy to do and easy to document. Yes. Parameters, geometries, and flows can be easily changed within the GUI.
S	Case Analysis Tool should allow this. Have not successfully run this, however (error box pops up). Not sure but I think you can run different scenarios through the Case Manager by importing various networks but haven't tested yet.

1.3. INPUT INFORMATION

Appendix 7. *Team members' comments on general model setup and manipulation.*

Model	Comment
1.3.1. Can it import data from other programs?	
F	Incoming data must be slimmed down and converted using Fldat. Manual generation of input files cross section by cross section would be prohibitive. Time series data is difficult to deal with. Imports HEC-RAS data. FLDAT can read and import HEC-2 and HEC-RAS X-sections. There is an option to input HEC-2 or HEC-RAS decks into FLDat. However, I tried to import all of the HEC-RAS data sets I have and none of them would come in and the error messages gave me no clue how to correct the problem. Hopefully, it is easy once you know how, but not for a first time hack.
M	Imports HEC-RAS decks. Well defined geometry import file definitions. Fairly easy to manage resistance factor editing. Time series data manager useful in that it allows spreadsheet-style cuts and pastes, with real time plotting of data alongside. However, the RAS2M11 converter (not baseline software, but used during this evaluation to prepare model data sets) seems to have has several bugs, which I'm sure could be ironed out if we select this model and need to convert many RAS decks. They are noted here for completeness: * the created .nwk file was missing commas in between two fields, and had odd point numbering for some locations. These data were manually fixed. * Ineffective flow areas, levees, and structures are not imported (true when exchanging most data sets between the 3 main models) * M11 defines geo-referenced cross sections in space with 2 x,y pairs. For geo-referenced RAS cross sections with more than 2 x,y pairs the second x,y pair in the import file becomes 0,0 instead of the last x,y coordinate pair. I tried to import a MIKE11 file into MIKE11 and it would not do it because it was an older version. Importing cross section geometry is an important capability but many parameters and structures are lost when the entire project cannot be imported. MIKE11 has the capability to import cross sections but only if they are in one particular *.txt file format. DHI has not yet furnished a converter to convert from one format such as HEC-RAS into the MIKE11 *.txt format. Does a good job importing cross sections from HEC. IMPORTING STRUCTURES: Would not import dam structures from HEC RAS. Did not try to import from FLDWAV or HEC 2
R	Yes. Since the geometry file is open text, FLDWAV file geometries can be reformatted using excel with some effort. This open format made the St. John's import possible. Can import MIKE-11. Easy to build Manning's n, etc. back in. Best real time data management tools of the four models. Hec-2 import … close HEC-RAS says it can import MIKE11 cross sections and reach information but I got an error when attempting this. "Error converting MIKE11 Data Input past End of File." I received a similar error when I tried to import MIKE 11 into SOBEK. When importing HEC-2 files, a separate reach should be put into a separate file and imported into a separate river reach in RAS. HEC-RAS does not have a FLDWAV file importer. An HEC representative indicated that they would write a Fldwav importer for us if we select RAS. Most HEC-2 files can be imported; however, free format HEC-2 files cannot be imported. HEC-2 bridges, culverts, and ineffective flow areas do not import into RAS without modification. RAS will import UNET and MIKE11 geometric data, but lots of work is required to make it into project. To import MIKE11 it must be saved as a text file by the MIKE11 geometry editor first. Did not try it. Importing cross section geometry is an important capability but many parameters and structures are lost when the entire project cannot be imported.

Appendix 7. *Team members' comments on general model setup and manipulation.*

Model	Comment
	Importing Fldwav geometry that has been converted requires the deletion of Manning's n values. Could not successfully import MIKE geometry, received error "Input past end of file". IMPORTING STRUCTURES: HEC 2 imports, but would not successfully import MIKE file
S	Imports HEC-RAS decks. Multiple data editor useful, but not as useful for managing multiple cross sections at once as the tools found in Mike11 and RAS. Time series data manager difficult to work with. Can handle both x,z and height/width cross section definitions – which may be useful for importing FLDWAV geometries. SOBEK can import both MIKE11 and HEC-RAS networks. I received this error when I tried to import the MIKE11 cross sections: "Input past end of file Error in Function ReadCrossSections." I then had to stop the program through Windows Task Manager. This is similar to the error HEC-RAS gave when trying to import MIKE11 cross sections. Maybe the MIKE11 cross section export file has changed. I also received an error when I tried to import the HEC-RAS Network: "Error in Sub ReadHecRasNetwork" but then the program continued after acknowledging the error. It imported 4 cross sections and the units have been converted from feet to meters in the cross section. A search of HELP didn't find any reference to HEC-RAS. IMPORTING STRUCTURES: Seems to only import bridges from HEC RAS but truncated/terminated cross sections after encountering the first dam from a HEC deck

1.3.2. Data entry

Model	Comment
F	Easy to create simple geometry files using only topographic maps and a scale. Simple and straightforward. However, using real world surveyed cross section data is impossible in its native form. If you like elev/topwidth sections…..manually import No GUI included with FLDWAV to create cross sections. FLDAT can import cross sections and manipulate them and insert new cross sections in a tabular form. I don't think you can copy a cross section or input one graphically. It is an excellent tool to convert other traditional cross sections into FLDWAV top width cross sections. There isn't a river network GUI. GETTING AROUND IN THE PROGRAM: FLDAT is less efficient than some of the other software. It takes 11 mouse clicks to start the program and begin editing a cross section. NETWORK SETUP: Network is set up through input card decks; there is no graphical capability to build a network. FLDAT offers the option to set up the model from upstream or downstream Easy to enter cross section and hydrograph data. However, cross section data must be typed in. Adding ineffective flow areas (BSS) is untenable. Easy to enter n values. FLDWAV is not connected with a GIS package to develop cross-sections using DEM data. Unless previously developed cross-sections can be imported using FLDDAT, cross-sections for a new basin would need to be input by hand
M	Data entry and editing screens are fairly user friendly. Some tables do not behave as might be expected – at times additional rows are difficult to add or delete, for example – but the overall layout of the screens is generally user-friendly. The interaction between the network modules and other modules greatly assists the modeler in managing the

Appendix 7. *Team members' comments on general model setup and manipulation.*

Model	Comment
	data. Extensive cross section viewer / editor. Very good table/graphic interface, with lots of tabbed options. Cut/paste, import, and manual entry all available. I like the tree/hierarchy selection menu on the left for navigating through all of the cross sections/reaches in a model. When a new cross section is created, it always defaults to a three-point "V" cross section. You can create or edit a cross section from the river network window like HEC-RAS. In the cross section window you can create and edit cross sections both graphically and tabular. You can edit friction values from the cross section window. The editing features are more limited than HEC-RAS. NETWORK SETUP: The network has to be input through a graphical interface. The user can allow the program to set the chainages (river lengths) based on the graphical network (if the scale is correct) or the user can input the chainages manually and the graphic network will adjust accordingly. Cross sections and structures can be entered here. There are many graphical input tools to learn but it is simple to build the network once the user has determined which tools are needed. Some additional online help would definitely make this program more useful. Since the help is not subject sensitive, you have to manually search through the documentation to learn about the tool. Easy Data entry is relatively easy using the menu systems. The only problem I have is to know how to access a particular menu pertaining to a particular task (i.e. entering cross-sections, tributaries, bridges, weirs, etc.). Quite often, the manuals lack the necessary detail as to which set of menu buttons are required to accomplish a particular task.
R	Easy to enter x,y data by cut/paste, import or manual entry. Graphical editor available makes bank definitions easy to do upstream to downstream. Many options easily available from drop down menus to control resistance, ineffective flow, etc. Cross sections can easily be created or imported. There are many tools to manipulate cross sections either graphically or tabular. Cross sections can also be accessed through the river network schematic. You can edit friction and contraction/expansion coefficients from the cross section window. GETTING AROUND IN THE PROGRAM: It's easy to get around in this program. It takes 5 mouse clicks to start the program and begin editing a cross section. NETWORK SETUP: Schematic network can be set up through graphical interface. Channel and overbank flow lengths are input from each cross section. The schematic scale and coordinate system are set automatically by the program for the given data. Easy to enter a non-georeferenced network like this simple example. All cross sections and structures are entered in the same graphic Very straightforward setting up new schematic and cross sections. Various geometries/plans can be set up within one project allowing the engineer to compare results, which is essential in the development of a model and for calibration. The provision of ineffective flow areas and blocked areas is way more physically based and exact than I've seen in other models. It allows a user to have more control of overbank flow and accurately models various field conditions. The cross section graphical editor is easier than the regular cross section editor. You can add levees, ineffective or blocked areas in the cross section graphical editor. You can delete any feature you choose. In the unsteady flow editor you can enter observed water marks, an observed time series or rating curves. You can easily import cross sections developed in GeoRAS from a DEM. GeoRAS is easy once you have a processed DEM. Staff members would need training for accurately preparing DEMs. N values can be entered in tables which is very easy and convenient. You can highlight and copy the same value throughout the river system while specifying to which area of the cross section you are applying it. Reach lengths are also found in a tabular format which is easy to use. Tabular cut and paste abilities in tables, highlighting and "setting values" "scaling values" individually thru cross-sections, or graphically thru cross-sections are just some of the ways to input data. DSS can bring the data in for you and these DSS files can also be mathematically changed thru multiplication/additions/datum-additions etc. For example, on the St John River, I halved all the flows by opening the DSS file and running the math utilities on the selected files and changed all the hydrographs equally in minutes.

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Model	Comment
	HEC-RAS has a very nice interface using GeoRAS to develop cross-sections using DEM data. Some editing is required.
S	Best at defining geometric sections – trapezoids, ovals, etc – common to man-made canals and engineered streams. Data entry more difficult with natural cross sections when done by hand, since it seems only one node can be edited at a time. Moving to another cross section requires closing the dialogue box and selecting another node for editing? Seems ponderous, but I may have missed something. SOBEK provides online documentation that is searchable but not context sensitive. It provides sufficient information to input the various building blocks of the model in terms of inserting them into the network for most parameters. Some parameters are not explained at all and further searching provided very little information. You are required to go to outside sources to select appropriate values for some of the parameters such as "Form Factor" for bridge pillars. In some instances, the documentation refers you to a section and chapter number but the online documentation isn't labeled as such. There are a limited number of tutorials to help get started with SOBEK but the number and type of examples are inadequate to build a model without support and/or additional training. It would be extremely helpful to have a general section of documentation to explain SOBEK's philosophy of modeling and how it differs from other models such as FLDWAV or HEC-RAS. There are many different modules available such as the Rural, River, and Overland Flow but the documentation didn't explain when you would want use the different modules. After spending many hours searching through the documentation some of the modeling options became more clear but still not obvious. In the latest version of the documentation, SOBEK added a section of Frequently Asked Questions to help explain how to model certain objects. It seems that the user is dependent on SOBEK to assist in modeling questions since the documentation is not as complete as other models. GETTING AROUND IN THE PROGRAM: In preparing this comparison I noticed SOBEK required a lot of windows to be opened to get to the editor I was evaluating. It requires 15 mouse clicks to get into the program and begin editing a cross section. On more than one occasion I made an error in closing some of the windows but was unable to find the way out without going to the Window Task Manager. This program is not as "idiot proof" as others. NETWORK SETUP: I couldn't determine how to set up a simple coordinate grid to build a network. Netter is a useful tool to build a model since it utilizes georeferenced maps but I wasn't able to build a simple network from scratch without support from SOBEK. I want to be able to set the units before I begin building a network without having to convert my data into SI units. The netter is very complex with a lot of buttons to learn. It was challenging to just follow along with the tutorial without making an error.
1.3.3. Cross section edits	
F	Not tested in Fldat, but manual tweaks of flat file are out of the question FLDat quickly allows a view of the section to see if there is any bad info You can edit the text of the cross sections in the FLDWAV input files. FLDAT allows some graphical and tabular editing of the top-widths in cross section conversion utility. I didn't see an easy way to undo edits other than quitting without saving and restarting. The plots don't give any information about resistance values. Tedious. Each cross section must be edited by hand. Editing the text of the cross sections requires patience and experience/training. Adding a pilot channel is recommended but time consuming. Editing ineffective flow areas (BSS) is untenable. Easy to edit the n values during calibration. Cross-sections can be edited from the input decks. This can be cumbersome.
M	Data entry and editing screens are fairly user friendly. Some tables do not behave as might be expected – at times

__Appendix 7.__ Team members' comments on general model setup and manipulation.

Model	Comment
	additional rows are difficult to add or delete, for example – but the overall layout of the screens is generally user-friendly. The interaction between the network modules and other modules greatly assists the modeler in managing the data. Combined text and graphics editor makes adjustments easy. Slightly lower marks because I didn't find the mass change tables similar to RAS, where wholesale changes can easily be made on any subset of cross sections. MIKE11 does provide the capability for easily specifying global parameters. The graphical cross section editor is very powerful – especially the move multiple points feature. This allows moving several cross section points as a group. MIKE 11 has several different methods to edit cross sections including a graphical editor. It has most of the same capability of HEC-RAS including undo, zoom, and friction values. Once you become familiar with the terms and layout, it seems easy to use. GETTING AROUND IN THE PROGRAM: Input file window simplifies getting around the program. It takes 5 mouse clicks to start the program and begin editing a cross section. Easy. Includes a method to make edits to many cross sections at once. The tree schematic makes it simple to go to the cross section you want to see. The grey outline of previously view cross sections is a great way to visualize patterns in channel capacity. It would be good if one had more control of when it displayed. Shadowed views of the overlaid upstream cross-sections are distracting The data editors and menu systems are easy to use.
R	Thanks to creative use of tables, mass editing of variables is very easy. Graphical editor makes adjustments to cross sections very easy as well. Superior you can see quickly what you are changing, inserting, deleting HEC-RAS allows several different methods to edit cross sections. The graphical editor is simple to use but also provides all necessary capability including the important "undo edits" key. There are several tools to manipulate the cross section and compare with others. Friction values are displayed. Zooming in available in the editor. The editing of all the different types of structures is done in the geometry editor and they all function similarly. The cross section graphical editor is very easy and powerful. It makes it simple to shorten your cross section to cut off overlapping ends. You can add levees, ineffective or blocked areas and you can see how you are modifying the cross section as you edit it. A pilot channel can be added to an entire river at one time using a special editor. Putting ineffective flow areas or adding levees is a snap in the graphical editor which has zoom capability for accuracy of placement. You can type in a table of elevations for all the ineffective flow areas which might be a good option with some datasets. You can edit n values in several ways, all of which are easy and quick. Tools and editing utilities are essentially all in one location (geometry editor) and intuitively accessed. Cross-sections can be edited both graphically and from a table. It is fairly easy to do.
S	Again, editing one node at a time is slow and painful. I may be missing something. Some elements can be edited through a multiple data editor but others can only be edited through a single editor. For example you can change the surface level for all cross sections in a single table but the cross sections with multiple friction values have to be change on a single cross section at a time. Tabular lists of elements help you locate the features on the network to edit them.

1.3.4. Cross section interpolation

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Model	Comment
F	FLDWAV allows user controlled cross section interpolation by putting in the desired distance step and allowing the model to interpolate. The user can't vary the parameters of these interpolated cross sections. In order to interpolate cross sections one must always be consistent on the position of the topography regarding the slice order number. For example the 5^{th} slice must always be at top of bank. Too constraining. Cross-sections can be interpolated.
M	Straightforward. There a several user defined options to interpolate cross sections and once they are added they are editable the same as input cross sections. 'Identical resistance data required' error. Had trouble with all the options of interpolation
R	There a several user defined options to interpolate cross sections and once they are added they are editable the same as input cross sections. Very easy. RAS has a special gui for interpolation between two cross sections or throughout an entire reach. The "between two cross sections" option gives the best result. You draw major chords connecting bank stations and thalwegs between two adjacent cross sections where you want to add interpolated cross sections. Then you draw minor chords for any high ground or swales that are continuous between those two cross sections. You can delete all interpolated cross sections and then interpolate again at different intervals very easily. The top of bank stations are put into the interpolated cross sections automatically and so are ineffective flow areas. This is a handy tool. Being able to interpolate cross sections is very important if one doesn't have tons of surveyed cross sections throughout the study reach. Adding cross sections is often necessary to meet the Courant condition in order to stabilize a model.
S	There was not an option to input user defined interpolated cross sections but there is a reference in the documentation about how the model mathematically interpolates cross sections. *For a detailed description of this node's underlying mathematical equations and the applied interpolation methods, see the "Cross Section" section from the Technical Reference Manual".*
1.3.5. Manning's coefficient. Variable roughness (by HG and Q)	
F	Yes – created the method. You can vary Manning's n with stage or discharge and from reach to reach. Values can be input in the FLDWAV input deck or a tabular input in FLDAT. It took some trial and error to get the input correct since the documentation is lacking for cross section editing. Fldwav uses roughness factors by flow not by stage. FLDWAV allows for a variable roughness based on stage and discharge.
M	In most model applications, resistance values are assigned laterally across the cross section. However, there are two notable exceptions. The first accounts for vegetated reaches (primarily used in sediment modeling to simulate areas with slower velocity). The second divides the cross section into three zones – within channel below the vegetative limit, in-channel flow affected by vegetation on the banks, and overbank flow. Different roughness values can be set for each zone, which are set manually at each cross section.

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Model	Comment
	MIKE11 allows you to vary the roughness horizontally or by high/low flow zones that are set by markers in the cross section. You can't vary by flow. Did not import manning n correctly from HEC deck, applied a global which means hundreds of cross-sections would have to be manually corrected to keep the original values. MIKE is less flexible with respect to varying resistance across the cross section stationing. Can't vary resistance based on flow.
R	Flow factors are the best way of accommodating changes in roughness vs. flow or height. Static definitions of n vs. Q only work in steady flow models. Could be argued that flow factors are more technically sound. HEC-RAS allows you vary the roughness either horizontally or vertically. The vertical variation allows you to vary with either stage or discharge. Can utilize roughness factors vertically and horizontally across the cross section. The original dataset I used had vertical n values that I thought had already been removed and converted to horizontal n values. When I tried to change the n values, I used the n value editor table. I put the new values in there. After I ran the model, the new n values showed up across the top of the cross section plot but the program was using the vertical n values to do the calculations. I saw this in the weighted n value standard plot. The values were quite different. There were no warning messages when you input the horizontal n values that the cross section had vertical n values or that the horizontal n values you were putting in would not be used in the computations. HEC is aware of this problem and is working on a fix. Vertically varying Manning's n values are available but not recommended for use in HEC-RAS. It is recommended that horizontally defined Manning's n values are specified at each cross section. Once the model is stable and a rough calibration is done, you can then fine tune the calibration by applying different multipliers to those horizontally varying n values depending on the flow range. The window is found under geometry input, Tools, Flow Roughness Factors. Here you can specify the multiplier or "Roughness Flow Factor" and define up to 30 flow ranges. The weighted n value seen in the plots is not used in the computations. It is calculated later for display purposes only. The weighted n values are conveyance based. N values are displayed on each cross section plot. Can vary resistance with great flexibility (seasonal plus horizontal plus flow, and all simultaneously!). For a horizontal example, if you know that a marina has docks or un-surveyed obstruction that extends 90 feet into the river from the bank you can code this horizontally across the cross section regardless of depth.
S	Can accommodate Q vs. n, with what seems to be the most direct table for conversion from FLDWAV. SOBEK allows you vary the roughness horizontally across the cross section not vertically or by discharge. You input roughness at each cross section. There are less options for editing an display than HEC-RAS.

1.3.6. Lateral inflow

Model	Comment
F	User can assign a lateral inflow location at any cross section. The appropriate input lines and parameters must be inserted into the FLDWAV input file. The time step of the inflow hydrograph must be the same as the upstream boundary hydrograph. FLDAT has a tab for inputting the hydrograph and user can display graph of input. Lateral inflows are limited to being modeled as a point source.

Appendix 7. *Team members' comments on general model setup and manipulation.*

Model	Comment
M	Lateral inflows handled as boundary conditions, and can be specified as both point inflows and distributed inflows. MIKE 11 allows you to insert the lateral inflow as a boundary condition on the map and then the boundary file will pop up. The boundary file allows you to navigate to a time series file where the hydrograph is defined. The Time Series editor is located in MIKE Zero so you must open up an additional editor to create the time series. There is also an option to distribute the inflow equally at each computations point in the reach. A bit cumbersome to add laterals and associate time series files. However the "scale factor" edit capability within the time-series/boundary condition is a nice tool that could be used as a contingency forecast tool in modeling. Lateral inflows can be inserted at any cross-section along the channel.
R	In HEC-RAS, you input a lateral inflow as an internal boundary. All boundary conditions are defined through the flow editor. You can input the hydrograph in various time steps ranging from 1 second to 1 year. You can plot the data as you input it. RAS can model lateral inflows as a point source or distributed along a reach.
S	SOBEK allows you to add a lateral inflow through the map. After selecting on the map, you define the hydrograph by editing the model data. The editor allows you to build the table in various ways with various time steps. While testing the hydrograph input, I made an error that locked up the program(see SOBEK in Boundary conditions section)
1.3.7. Boundary conditions	
F	Boundary conditions are defined in the FLDWAV input file by using the appropriate data groups and parameters. FLDAT allows you to build the upstream boundary as a stage or discharge hydrograph through a table that can also be displayed graphically. The downstream boundary is also selected in the same window and there are 6 choices: Normal flow, Stage and Discharge Hydrograph, Single Value Rating and 2 looped rating options. Internal boundaries are set at each cross section. Locations can't be selected from a map. Not difficult for an experienced user. Fldwav cannot handle 2 downstream boundaries.
M	Boundary conditions added through the boundary condition editor. Boundary conditions can be automatically generated through the network editor for open portions of the network. Adding boundary conditions is fairly easy and straightforward in the editor – reaches within the model are available via dropdown menu, and the interface for selecting time series to associate with the various boundary points is intuitive and straightforward. MIKE 11 allows you to add boundary conditions on the map in the Lateral Inflow section above. From the boundary file, you can navigate to a time series file where the hydrograph is defined. The Time Series editor is located in MIKE Zero so you must open up an additional editor to create the time series. For the open downstream boundary, your choices are: inflow, water level or Q-h. The Q-h boundary type has an option to auto calculate the Q/h table or it may be entered manually. Cannot vary each gates width independently. Also, navigational dams that have gates and weir/locks must be added in two steps making the process more cumbersome and less continuous in the geometry cross-section.

Appendix 7. *Team members' comments on general model setup and manipulation.*

Model	Comment
R	Upstream, downstream and lateral flow boundaries are defined in the Lateral inflow section. Downstream boundaries can be defined 5 different ways: Stage or Flow hydrographs, Stage/Flow Hydrograph, Normal Depth or Rating curve. Structures and other internal boundaries are defined in the geometry window. Boundary conditions are saved to a separate file so you can have different flow scenarios with the same geometry and keep track of them. Boundary conditions are entered using the unsteady flow data editor. DSS takes a little getting used to. The cut and paste option for inserting flow data is good. Can vary individual gate openings (like the Corps does in reality) based on various criteria. Can have weirs and controlled structures both inline
S	Boundary conditions are set through the netter window as shown in the "EASE OF USE, Other- Network Set-up" section shown above. You add in the same way as described in the lateral inflow section. Building of the network is confusing with available online help. I had to go back and work through the tutorial to figure out how to input the boundary conditions and connect them to the model. When using the table generating feature to build the U/S hydrograph, I received a "Type Mismatch" error that threw me out of the feature and back to the Netter screen. This screen was locked up and I had to go to the Windows Task Manager and stop the process. Within the boundary conditions window, I couldn't figure out how to set the D/S boundary to calculate normal depth as selected in the FLDWAV and HEC-RAS solutions. A search of the online help didn't help. SOBEK Response: "SOBEK does not accept a water level slope as a downstream boundary condition. For this reason a constant water level has been set at this location. You may replace this by a rating curve (combination of conveyance and water level slope) for you evaluation, but it may not have much effect on the routed hydrograph. We may decide, of course, to make the gradient boundary condition also available in one of the future versions of SOBEK.
1.3.8. Other: Units	
F	FLDWAV will run with both U.S. and S.I. units. You would need to find the appropriate parameter to change in the input deck. It doesn't have the capability to convert from one unit system to the other.
M	From the File button on the start-up window, you select Edit Unit Base Groups and the program will take you to a window where you can select various units for every parameter and then save your on units file to use. The program also has files set up for both S.I. and U.S. units, you just have to navigate to the location to find these files since they are located in the default directory. I didn't find any conversion utility in the software to convert from one unit system to the other. You have to load in an "imperial units" file to change units, not quite as easy as FLDWAV and HEC RAS. Additionally, each time you reload the same project file if you do not FIRST load in the English units before opening the project file, it can corrupt your cross section file or structure file and you have to re-import/transfer the geometry all over again.
R	The user can select US or SI units from the Options button in the start-up window. From this button, you can also convert your project from one unit system to the other. The start up window indicates which units you are working in.
S	In the setup window, there is an options button that takes you to a window where you may be able to select units but currently SI is the only choice. From the documentation, I couldn't find any way to change the units for the model nor is there anyway to convert the data from one system to another. SOBEK confirmed works only in SI units.

__Appendix 7.__ Team members' comments on general model setup and manipulation.

Model	Comment
1.4. OUTPUT INFORMATION	
1.4.1. Output table detail (Q/Froud/Vel/Enery/ etc.)	
F	A lot of output … Standard FLDWAV summary table includes maximum WSEL, Flow, and velocity. Other parameters such as Froude are available in the individual cross section tables. FLDWAV does not provide a table listing Energy as a parameter. FLDAT can display the same parameters as a graph or table at each cross section or time step. Each parameter is displayed separately but not in a summary table. FLDWAV has a very detailed summary table
M	Output from model simulations must be viewed in Mike View – a separate application – which is a bit cumbersome at times. If the NWS ever pursues other DHI models (such as Mike21 or MikeSHE), however, the benefit to this approach is that only MikeView will be needed to view output from every application. Every data set generated in Mike View can be viewed as tabular time series. There are no predefined tables containing computed hydraulic parameters, but the user can build is data can, with some effort, be extracted. MIKE 11 requires you to open a separate application, MIKEVIEW, to review the results. They have not yet been integrated. MIKEVIEW has extensive graphical output capability but I couldn't find a summary output table. You have to specify the output variables you want in the HD parameters input file. You can add Froude, energy, and velocity if you want but if you don't they won't be available for display in MIKEVIEW. I could not determine how to display more than one variable in the table but I think you can graphically. MikeView is outside the hydraulic program which is inconvenient. There is a great table that shows how the conveyance and area changes with depth. Output must be exported to another application MIKE View. I was not able to find tabular output.
R	Many tables for varied output … make your own table HEC-RAS has standard summary output tables or they can be customized to produce any parameters. Parameters may also be plotted on profile for any time or for the maximum. Units may be set separately for all parameters. All time series can be copied and pasted into another program if desired. There are plenty of viewing tools within the program. They have so many tables of hydraulic parameters to choose from. They have specific tables for bridge hydraulics, cross sections, and basically all the structures you can put into the dataset. At the bottom of each table it will show you the errors. You can also define your own tables and you can view multiple tables at the same time. Can create user defined output tables which include breakdowns of overbank/channel/weir flow vs. gate flow/individual gate flows and closing times/velocities of channel vs. lft and rt bank/etc. Tables can break down data variables per cross-section or between storage areas or through inline structures and lateral structures etc.
S	SOBEK doesn't have any features to view tabular output in the program. Data has to be copied over to other applications to create and view tabular output. Your choices of output variables are limited to those shown below and you can't display any of the computed hydraulic parameters such as area of conveyance. The Delft-Scheme calculates

Appendix 7. *Team members' comments on general model setup and manipulation.*

Model	Comment
	water levels at nodes (connections and calculation points) and discharges on branches (reach segments) so this how the results are displayed as well Output must be exported to another application From the workshop, I do not remember looking at an output summary table.
1.4.2. Output detail for individual cross section?	
F	FLDWAV provides a table of variables at each cross section if you select the level of output in the input deck. FLDAT can display each parameter separately in a graph or table. I have not used Fldat. It seems very limited and awkward FLDWAV does not display graphically the cross-sections. I think FLDDAT has this capability.
M	All data is automatically computed at cross sections, and is available in both tabular and graphical format. See extended write-up on Mike View in section 1.4.4. MIKEVIEW can display one variable in a time series at each cross section in a table. In the graphical view, I could only determine how to display levels. Excellent display of cross sections. It shows other cross sections using same scale in same window grayed out to distinguish last viewed cross section with current viewed cross sections to make cross section comparisons for volume, channel shape, top width, depth and invert easy to assess. All parameters can be plotted. Cross-sections can be displayed graphically.
R	Standard cross section output includes most variables and both the table and graph can be customized. You can add labels, lines, grids and set the scale of all plots. Excellent display of cross sections. You can fix the scale so all cross section show up using same scale or not. You can scan thru all the cross section s quickly. You can keep previous cross sections to view others in the same screen. You can animate the water surface elevation throughout the storm length at that and other cross sections. You can see them in the 3D plot all lines up together and from several angles. The maximum water surface shows up in all cross section plots after you run the model. Cross-sections can be displayed graphically.
S	SOBEK will display water level and depth at a cross section(node)
1.4.3. Can output time series be exported?	
F	Neither FLDWAV nor FLDAT have any method to directly export time series. Linux version You can cut and paste and then graph it in Excel. You may need to write a macro to unwrap the time series for use in Excel.

Appendix 7. *Team members' comments on general model setup and manipulation.*

Model	Comment
	Yes, w/ respect to NWSRFS Linux/Unix compatible FLDWAV does not export time series data. Any parameter defined in the FLDWAV RFS segment can be stored in the NWS OFS database.
M	Yes, through Mike View. See extended write-up on MikeView in section 1.4.4. A popup menu on a time series graph allows you copy the plotted data to the clipboard. Again I think you can only copy one variable at time.
R	Time series of all variables at each cross section can be exported to a text file , some time series such as stage and flow hydrographs can be exported to a HEC-DSS database. In addition, water surface profiles; computed rating curves; and storage-outflow information can be exported to DSS. HEC utilizes the DSS database which may not be compatible with other systems. A MS Excel Add-In is available to retrieve data from an HEC-DSS database file and place in a Excel spreadsheet. It can be downloaded from HEC's website. Time series is exported to a HEC-DSS database. All time series can be copied and pasted into another program if desired. However, there are plenty of viewing tools within the program. Time series can be exported to a HEC-DSS database.
S	SOBEK will export the time series from the graph to the clipboard or into MS Excel.
1.4.4. Graphical output & animation	
F	FLDWAV and FLDAT are not integrated; you have to run FLDWAV outside of FLDAT and then import the results back to display. No animation tools are available. Fldwav cannot graph anything, you must use FLDAT or Excel.
M	Output from model simulations must be viewed in Mike View – a separate application – which is a bit cumbersome at times. If the NWS ever pursues other DHI models (such as Mike21 or MikeSHE), however, the benefit to this approach is that only MikeView will be needed to view output from every application. The Graphical Output options are the primary means of accessing data from MikeView. There are three main graphical views – a horizontal view, a profile view, and a hydrograph view. The horizontal view shows the schematic of the system, and can be set to display elevation, depth, discharge, or depth above defined river banks. Profile views can be generated for any set of reaches within the model. Structures do not appear automatically, but can be manually added to the plots. Time series hydrographs can be generated for any parameter at any computation point. Mike View can animate any of these three plots, and automatically synchronizes the graphics if multiple plots are open at the same time. MikeView has some powerful statistical analysis tools for calibration, with statistical data available in both tabular and graphical format. Observed data is used to compute the statistics, and multiple points may be computed simultaneously. Shown below are screen captures of the statistical input screen and available output plots which include 1) a plot of observed vs. modeled data, 2) absolute error vs. time, 3) a scatter plot of observed vs. modeled data, 4) error vs. stage (average of modeled and observed data), 5) % error vs. observed stage, and 6) a coefficient of determination plot (R2) vs. lag time. The animation is very good. MikeView is outside the hydraulic program which is inconvenient. MikeView is outside the hydraulic program which is inconvenient.

Appendix 7. *Team members' comments on general model setup and manipulation.*

Model	Comment
	The graphical output is adequate.
R	Excellent display of input and output. The way HEC-RAS displays cross sections is very helpful to the modeler. You can fix the scale so all cross sections show up using same scale or not. You can scan thru all the cross sections quickly. You can see as many different plots of cross sections or time series or profiles, etc. as you want and at the same time because they pop up in separate windows. You can animate the water surface elevation throughout the storm length at that and other cross sections. So at the same time you can view the flow profile of the ds boundary and the upstream boundary, and you can plot stage and flow at each gage. Most graphical output has animation capabilities. If you plot a cross section and a profile of the storm, and a flow/stage hydrograph at a cross section and animate them all at the same time and you can see where you are on the hydrograph with a line throughout the storm while you watch the flow overtop the bridge or go into the overbanks. The standard plot window plots the following parameters: velocities, flow, weighted n values, area, top width, Froude #, hydraulic depth, surface area, shear, volume, stream power. There are separate icons that plot water surface profiles for the rivers and reaches of your choice, rating curves, and stage and flow hydrographs at a cross section. The HT (Hydraulic Property Table plots area (total, channel and overbanks) and conveyance (total, channel and overbanks), storage area and top width for individual cross sections. It also plots variables for internal boundaries and storage area connections. You can select from a long list of variables for plotting as a profile down the river. You can plot the right and/or left bank levees and/or lateral structures, the right and/or left main channel bank stations, pilot channel, the usual thalweg, and any combination of water surface profiles. This is such a great check to see what is in the dataset and what is actually happening. ANIMATION TOOLS: Looking at the Red River unsteady flow run animation in the XYZ perspective – it looks very unrealistic the way the flow goes into the overbank. This is a very helpful tool to help the modeler correctly place the ineffective flow and blocked areas. The animation in the cross sections is also helpful to see if you are modeling the river correctly. You can plot several key cross sections in separate windows and then run an animation of your storm to see what is going on. Can create user defined output graphs
S	Graphical output is provided in SOBEK through the Netter application. Here you can produce time series plots of your output data at all nodes and reaches and produce profile plots of your results. You can animate and produce movies of the results if desired. You can't display results in cross sections.
1.4.5. Can graphical model outputs be extracted for web use?	
F	FLDWAV doesn't produce graphics but FLDAT graphics can be saved to a file.
M	Not tested, but DHI noted capability for web-based output exists. The graphical contents of any MIKE View presentation windows can be copied to the either the clipboard or to a metafile (emf-file) using the <Metafile> function on the Pop-up Menu as shown in the section above.
R	HEC-RAS allows you save the graphics to a clipboard or write them to a *.dxf file(CAD file).
S	Graphs may be exported from the graph to a file or clipboard.

Model: F – *FLDWAV,* M – *MIKE 11,* R – *RAS,* S – *SOBEK*

Appendix 8. *Team members' comments on specific model capabilities.*

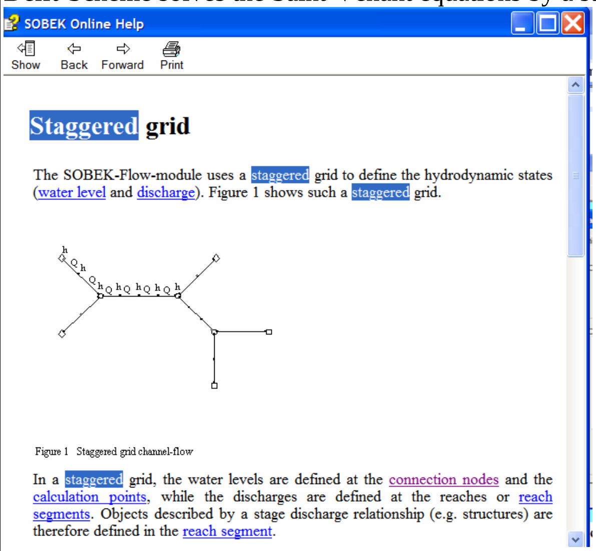
Model	Comments
	2. MODELING TRIBUTARIES, JUNCTIONS AND SPLIT FLOW
	2.1. DOCUMENTATION
F	Model Documentation is complete. Model Trouble Shooting and Error Messages are below average.
M	The documentation for developing tributaries, junctions, and cross-sections is fairly good. However, it could definitely use more detailed instructions on which menus to select and how to access these menus to accomplish a particular task. Example problems with detailed instructions (i.e. step by step instructions as to which menu buttons to select) for accomplishing each task would also be helpful. Three manuals were available: (1) Short Introduction and Tutorial, (2) User Guide, and (3) Reference Manual. The Short Introduction and Tutorial provides a good basic example for establishing tributaries and cross-sections. However, no information is provided for adding new points within the cross-section. The User Guide provides a good overview on this process and good definitions of each menu button. However, it lacks specific instructions as to navigating through the menu system.
R	Examples and pictures given in manuals. There are a few junction examples in the Applications Guide. HEC-RAS handles 12 types of junctions. I only tried a subcritical junction. RAS will optimize the flow split for the user and I used that option. There were no problems with it. I found a few holes in the documentation. I chose not to rename the reaches of the main stem when I put in a tributary (trying to keep it simple and quick!) and then you could not name your junction so I had to redo all the cross sections etc. Once you went down that road I didn't see a way to give the junction a name. But when I redid it, renaming the reach ds of the tributary, it worked very easily. If I had read through the example, I may have been guided away from finding the hole in the documentation and in the data entry. The order in which you do the steps makes a big difference. Why give the user a choice when it is actually a requirement?
S	The documentation shows how to use a *12, Flow-Connection Node* but there isn't any general guidance on what is required to set-up a model with split flow. No complex examples are provided. The Red River model converted by SOBEK included additional connection nodes to define a compound bridge section. Since SOBEK Rural only allows one opening at a bridge, it was necessary to "split" the flow to model a bridge that experiences both culvert and weir flow. No examples are shown for this modeling application.
	2.2. DATA ENTRY/DATA EDITOR
F	I perform data entry reformatting outside FLDWAV. Data sets were provided to me in this instance. I understand a file can be made from scratch in FLDAT; however, I did not exercise this function.
M	The data entry/ data editor is very simple to use when you can figure out which buttons to push.

__Appendix 8.__ Team members' comments on specific model capabilities.

Model	Comments
R	TRIBUTARIES AND JUNCTIONS: Tributaries can be dynamically modeled or entered as single point or range of distributed lateral inflow. Changes in the junction dialogue box automatically update the 'unsteady flow data editor' [with the added/deleted reach and location] to prompt the user to fill in boundary condition changes. SPLIT FLOW: If a user renames or adds/subtracts reaches in the geometry, the unsteady flow editor still reflects the old geometry and reach names and therefore these must be independently re-entered/revised which could be a small inconvenience if there are allot of laterals or navigational gate setting entries. See documentation. It is almost as simple as entering a single reach of cross section data. However, each reach needs to have a unique name. The junction dialog is simple but it asks if you want to rename the reaches. If you say no it doesn't tell you that you cannot have a single name for the river US and DS of the tributary. And then you can waste lots of time. Although, it isn't a mistake a user would make more than once.
S	<u>Data Entry</u> Connection nodes are added to the model in netter. After selecting the appropriate node type, you add it to the model in the location where you want to place it. You continue to build your network and finally connect the nodes graphically with your chosen reach type. <u>Data Editor</u> There isn't any other model data to add to a connection node once it is added to the schematization and connected by reaches. You define the direction of a reach when you create it and the direction can be displayed in netter as shown above. There is a tool provided to reverse the direction of the reach if needed.
2.3. COMPUTATIONAL METHODS	
F	I could not get the model to fail due to tributary contributions
M	MIKE 11 is based on the Saint-Venant equations and uses an implicit finite difference technique to solve the equations
R	SPLIT FLOW: An initial 'internal boundary' must be set at junctions (flow or stage), but an increase in time or lack of stability is not a result of these additions. RAS gives the user a choice between energy or momentum equations at a junction. It can solve it for any flow regime and it will optimize a flow split.

Appendix 8. Team members' comments on specific model capabilities.

Model	Comments
S	Delft-Scheme solves the Saint-Venant equations by a staggered grid as described below.



SOBEK Online Help

Show Back Forward Print

Staggered grid

The SOBEK-Flow-module uses a staggered grid to define the hydrodynamic states (water level and discharge). Figure 1 shows such a staggered grid.

Figure 1 Staggered grid channel-flow

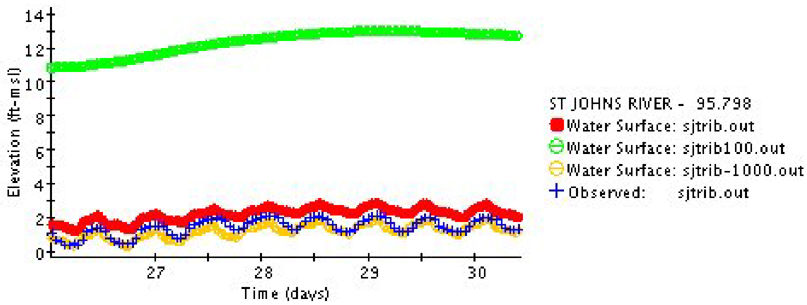
In a staggered grid, the water levels are defined at the connection nodes and the calculation points, while the discharges are defined at the reaches or reach segments. Objects described by a stage discharge relationship (e.g. structures) are therefore defined in the reach segment.

Model	Comments
2.4. MODEL STABILITY	
F	I could not get the model to fail due to tributary contributions
M	No stability issues have been noted.
R	I have never encountered stability issues due to junctions or tributaries. Adding junctions on the three models I have worked with have not resulted in stability issues owing to the split.
S	No stability issues were noted for split flow problems tested.
2.5. TROUBLESHOOTING	
F	Very Good hydraulic table tabular displays
M	Hydraulic tables are available for trouble shooting the model.
R	To troubleshoot junctions, split flow, and tributaries see tools under geometric data for reach order and reach connectivity. Also look at the schematic in the cross section editor. There is a standard profile output table that is specifically designed for junctions.
S	SOBEK has a utility to check the flow model when you exit the schematization task. It will check for model completeness and warn it there is a problem with the model network. There isn't any documentation about this feature online.

__Appendix 8.__ Team members' comments on specific model capabilities.

Model	Comments
2.6. TABULAR OUTPUT	
F	FLDAT – provides both tab and graphic displays of tributary data
M	Hydraulic tables are available for trouble shooting the model
R	In geometry "tools" the user can view "river connectivity" to verify correct schematization of the model. See also comments under General evaluation There is an output table specifically for junctions. You can see how much flow is going into each river reach.
S	No special output for split flow modeling
2.7. GRAPHICAL OUTPUT	
F	FLDAT - graphical displays are FLDAT strong point
M	The graphical output is adequate.
R	Schematic of the river network can be overlaid onto GIS maps or photos. See also comments under General evaluation. You can graph all profiles for all river reaches at the same time. In this view you can see how the water surface and thalweg, etc. lines up at the junctions.
S	A side view plot of the split flow area described above is shown below. Both branches were selected but only the culvert portion is available for plotting. Nothing in the documentation explains how to view both branches in side view. You can plot both the discharge and stage hydrographs at each structure. 

Appendix 8. *Team members' comments on specific model capabilities.*

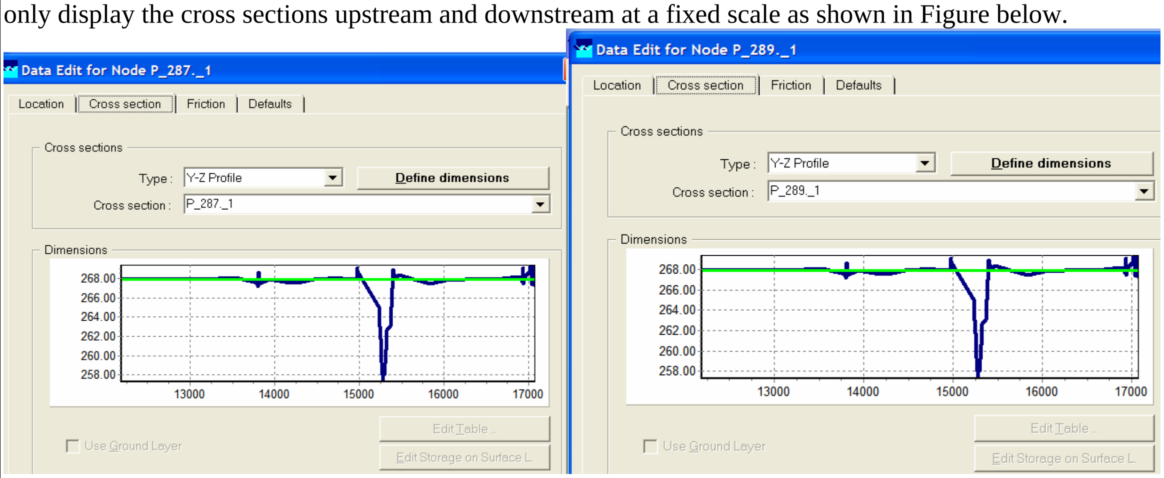
Model	Comments
2.8 OTHER COMMENTS (not graded)	
F	FLDAT significantly reduces Calibration Time and RFS Implementation Time. TRIBUTARIES and JUNCTIONS were modeled for St. Johns. The St Johns River is defined as a single river with 11 lateral inflows. The confluence of the largest contributing lateral inflow and St Johns River occurs near river mile 67.8 (NEWLCJ). To test model stability at tributary/river junctions, I increased and decreased NEWLCJ flows. The initial NEWLCJ flow was 4319.5 cfs. FLDWAV produced a successful run with .01, 10, and 100 times the original NEWLCJ lateral inflows (Fig8).  Fig8. FLDAT – PALF1 stage with .01, 10, and 100 times NEWLCJ lateral inflow.
M	
R	
S	<u>CONVERSION OF HEC-RAS.</u> SOBEK converts the HEC-RAS junctions as connections. It doesn't convert a compound structure such as bridge with multiple openings into a split flow feature since it only converts the bridge locations and not the structures.

Appendix 8. *Team members' comments on specific model capabilities.*

Model	Comments
3. BRIDGES AND CULVERTS	
3.1. DOCUMENTATION	
F	
M	BRIDGES: Detailed documentation is very limited. Three documentation manuals are available (i.e. Short Introduction and Tutorial, User Guide, and Reference Manual). The Tutorial documentation is extremely brief. It lists the 8 types of bridges which may be implemented into MIKE 11. No other information is provided. No example bridge problems could be found in the documentation. The User Guide provides a basic overview and definition of terminology for each type of bridge. The menus to accomplish each task for each bridge are shown. Unfortunately, it is difficult to determine how to access each of these menus. The manual should contain specific instructions as to which buttons to push. Also, example problems would really help the user develop these bridge routines. Unfortunately, no bridge examples are provided. The reference manual provides a lot of detail for each type of bridge. The equations, derivations, etc. are shown in detail how the hydraulic processes work for each bridge structure. Information on selecting coefficients is limited. CULVERTS: Detailed documentation is fairly good. Three documentation manuals are available (i.e. Short Introduction and Tutorial, User Guide, and Reference Manual).The Tutorial documentation is somewhat brief. However, it does give some guidelines for modeling a culvert in MIKE 11. The User Guide shows the culvert menu. Definitions for the culvert terminology are also provided in the manual. The reference manual appears to give detailed information concerning the development of the culvert procedures found in MIKE 11.
R	The User's Manual includes 35 pages of documentation focused on modeling bridges/culverts. In the Hydraulic Reference Manual it has a 33 page chapter on bridge hydraulics and a separate chapter on modeling culverts that is 34 pages and then a chapter on modeling multiple bridge and/or culvert openings. Appendix B to the Hydraulic Reference Manual is titled Flow Transitions in Bridge Backwater Analysis. The Applications Guide has an example on single bridge, single culvert, multiple culverts, multiple openings (both bridge and culverts), a mixed flow regime example with a bridge and an example of how to use multiple plans that uses the optimization of a bridge as an illustration. It would take a long time to read it all. Detailed examples given for various bridge and culvert needs, types, manning, and coefficient choices.
S	Additional documentation was required for details on bridge piers, but provided by the support group Documentation is very limited. There is a basic listing of bridge and culvert functionality and also the equation SOBEK uses to calculate flow through the bridge. There are no examples or details available in the online documentation. It is not clear how to enter the bridge cross section and whether additional cross sections are needed upstream and downstream of the bridge. The documentation didn't describe how to model complex situations such as bridges that act as a dam, bridges with multiple openings, skewed bridges, or perched bridges. SOBEK doesn't have context sensitive help. Without training it would be difficult to effectively develop more complex models with SOBEK. Note: There hasn't been a response to email questions about bridge modeling sent more than one week ago.

Appendix 8. Team members' comments on specific model capabilities.

Model	Comments
3.2. DATA ENTRY/DATA EDITOR	
F	
M	GUI allow for easy entry of data. Data editor is easy to follow.
R	Fairly easy with some experience. Data entry is very detailed, allowing any configuration imaginable to be modeled. There is also a GUI in unsteady flow editor for entering observed water marks or observed time series or rating curves. HEC-RAS includes a Bridge Culvert Data Editor, with many options such as add, copy, delete or rename a Bridge/culvert. It has a Pier editor, a sloping abutment editor, a multiple opening analysis editor and a deck/roadway editor. All bridge modeling variables are in a central location in the geometry editor. The user can maneuver thru them easily.
S	Required manual translation of HEC bridge information into Sobek form A bridge node is added graphically to the schematization; the documentation didn't specify whether it could be added any other way. You select the type of flow model, 26, Flow-Bridge and then click the Add node button in the desired location. X and Y coordinates are displayed at the bottom of the screen to guide you, if you know the coordinates. If you don't have them, you can move the location along the reach to get the correct reach lengths. After inserting the node, you can edit the flow model data. There are four types of bridges: Pillar, Abutment, Fixed Bed and Soil Bed (See Figure 2). The pillar method allows you to enter one effective pillar to represent all the pillars, a bottom elevation, a length (of the pillar?), and a form factor. You don't enter a cross section or a friction value with the pillar option, so SOBEK probably uses the cross section defined for the reach. This option is only valid if the water level doesn't exceed the bottom of the bridge; otherwise you need to define it as a culvert. There isn't any online help to select parameters such as Form Factor; you have to seek outside references. There is no graphical display of your bridge input; you can only display the cross sections upstream and downstream at a fixed scale as shown in Figure below.



Appendix 8. *Team members' comments on specific model capabilities.*

Model	**Comments**
S	SOBEK does not import the ineffective flow and blocked areas from HEC-RAS (Figure 4) so it seems you would need to add additional cross sections to describe the effective bridge cross sections if the geometry is different. Help didn't explain which cross sections are used or show an example of this situation. Cross sections are input for the other bridge options; Abutment, Fixed Bed, and Soil Bed. For the Abutment method; there are only two options to enter a bridge cross section: a tabulated cross section (a symmetrical cross section similar to FLDWAV), or a rectangular cross section. SOBEK doesn't provide a display of the hydraulic properties calculated for a Y-Z cross section to assist in the development of an effective cross section to use here. Using the hydraulic properties tables defined in HEC-RAS to define the ineffective and blocked flow areas, an abutment type bridge is defined. You can't graphically edit existing cross sections for bridge modifications Culverts are added to the SOBEK model in a very similar manner. You add the FLOW Model, 24, Flow-Culvert and input the parameters. More cross section choices are available but you must use the culvert option to define a bridge that experiences pressure flow. This means you have to input a tabulated cross section like you would for a bridge and somehow account for the bridge piers in the effective cross section.
3.3. COMPUTATIONAL METHODS	
F	
M	The computational methods appear to be sound.
R	There are four bridge/culvert hydraulic methods available in HEC-RAS for open channel flow through the bridge/culvert: standard step method, momentum balance, Yarnell equation and the WSPRO method which was developed by USGS for the Federal Highway Administration. Using the multiple plan option within a single project, one can select the computation method based on which result more closely simulates observed water surface elevations. This would be really helpful during calibration, especially if there are high water marks at the bridge. For high flows HEC-RAS has 2 alternate computational methods available for the user to choose: Standard step (considers bridge as an obstruction to the flow, which is true most of the time), pressure or weir flow. The user can select whether to use the water surface or the energy grade line in order to determine if pressure flow is occurring. The user can also let the program optimize which computation method results in the highest energy solution. The user can add a friction or weight component to the Momentum equation. The user can input the skew angle of the bridge/culvert to the flow which will be incorporated in the hydraulic computations. The culvert routines include the ability to model circular, box, elliptical, arch, pipe arch, low profile arch, high profile arch, and semi circular culverts. The user of RAS can model multiple culverts at a single location with different shapes, sizes, elevations, and loss coefficients. The user can also specify the number of identical barrels for each culvert type. There are choices for varying energy/momentum approach equations to headwaters of structures as well as inflow/outflow options for culverts. RAS can smooth out the equations going from free-flow to submerged flow with these choices, avoiding large conveyance jumps and instabilities.
S	SOBEK uses one equation to compute discharge through a bridge or culvert:Q= $\mu \bullet Af \bullet \sqrt{2 \bullet g \bullet (h1 - h2)}$ The various bridge options use different parameters to calculate the loss coefficients for the Coefficient. Bridges are open channel flow only while culverts can be free flow or submerged. This approach isn't valid for long culverts. For long culverts you will need to add another reach bounded by cross sections depicting the culvert instead of using the river cross sections. This seems to be a simplified approach to bridge computations but might not be enough accuracy for some applications. The input is less straight forward because you input effective cross sections instead of specific bridge geometry.

Appendix 8. *Team members' comments on specific model capabilities.*

Model	Comments
3.4. MODEL STABILITY	
F	
M	I have had problems with the stability of a couple of bridge routines. The error I received was an invalid floating point operation. Culvert procedures appear to be stable.
R	The user will need to follow the instructions about placement of cross sections US and DS of the bridge.
S	This simplified approach seems like it would be stable once the parameters are properly defined. The only question is whether there is enough detail to adequately define complex situations.
3.5. TROUBLESHOOTING	
F	
M	I have had problems trouble shooting the problems I have encountered with a couple of the bridge routines. Trouble shooting for culverts appears to be average.
R	There is good guidance on how to interpret the results and how to do the data input. The error messages are helpful.
S	Overall calibration tools are very limited in the program. There are some log files you can display that might be useful if you were familiar with the program but no listing of common errors in the documentation. There is a utility to check your flow model prior to running your simulation but it will not find errors that might keep the program from running.
3.6. TABULAR OUTPUT	
F	
M	I was not able to find a tabular output option.
R	There is a table specific for bridges and culverts.
S	You also must copy the data to another application such as Excel to view data in a tabular form. There aren't any predefined summary tables available in the program for output. You have to create your own outside of the program
3.7. GRAPHICAL OUTPUT	
F	
M	Graphical output is adequate.
R	The graphical output for bridges and culverts is detailed enough that you can see if the input is incorrect.

__Appendix 8.__ Team members' comments on specific model capabilities.

<table>
<tr><th>Model</th><th>Comments</th></tr>
<tr><td>S</td><td>The graphical output is obtained through the "Results in Maps" option. Figure below shows the type of information that can be displayed for a structure on the map. There isn't an option to display the results on the cross section and the Pillar input parameters can't be displayed graphically to check your input. You can display and animate the output time series for Water level and discharge. The documentation doesn't include any information about using the output to evaluate the results or any explanation about manipulating the graphics to display your desired output. It is difficult to determine where your bridge or culvert is located in the side view if you're not familiar with the project. Scaling and legend options are very limited on the side view . "Results in Charts" selection allows you display the output graphically for a limited number of parameters. You can plot results at nodes or results at structures but not both together. So you can't plot hydrographs at bridges and bounding cross sections at the same time in the program.

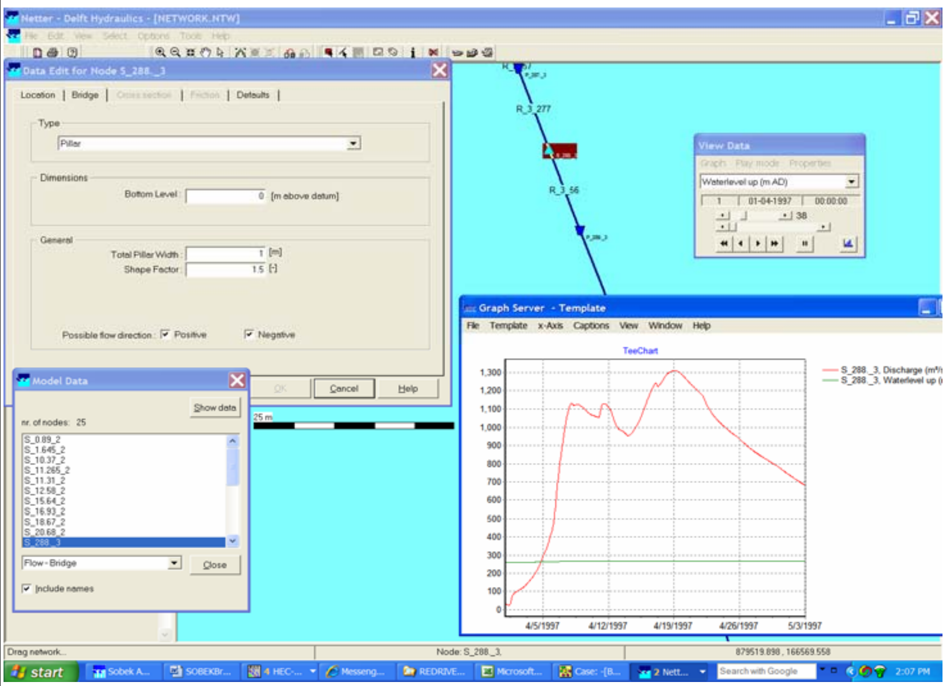


FIGURE . Results in Maps for a Pillar Bridge at S_288_3</td></tr>
<tr><td colspan="2">3.8 OTHER COMMENTS (not graded)</td></tr>
<tr><td>F</td><td></td></tr>
<tr><td>M</td><td></td></tr>
<tr><td>R</td><td>They really emphasize bridge input in their training classes.</td></tr>
<tr><td>S</td><td><u>CONVERSION OF HEC-RAS</u> Since most of our new data sets will be a conversion of HEC-RAS files, it's important to evaluate that capability. Although some bridge data is included when HEC-RAS files are converted to SOBEK, it may not be complete or accurate since the conversion instructions tell you to delete the structures after converting. The bridge locations are correct but the structural data isn't. The conversion does not include any of the HEC-RAS cross section geometry for ineffective flow or blocked areas.
-</td></tr>
</table>

Appendix 8. Team members' comments on specific model capabilities.

Model	Comments
4. GATES, LATERAL STRUCTURES, WEIRS & STORAGE AREAS	
4.1. DOCUMENTATION	
F	
M	GATES: There is a considerable amount of documentation outlining the many windows, sub-windows and options available for modeling controlled structures. For the most part, the manuals provide a basic overview of the modeling approach and a brief explanation of each window and parameter. Example problems would be extremely helpful. The explanation of control versus target points was very helpful, as this method of addressing operational constraints is unfamiliar. However, there are some notable deficiencies. A definition for PID is never given. It is unclear how the Control Definitions correlate with the "Details..." screens. The method for adding Control Definitions or additional logical operands is not outlined. WEIRS: Detailed documentation is very limited. Three documentation manuals are available (i.e. Short Introduction and Tutorial, User Guide, and Reference Manual). The Tutorial documentation is extremely brief. It discusses in a couple of sentences what weir processes are available. No example weir problems could be found in the tutorial. The User Guide shows the various menus including a weir property page, the 3 weir equations, and the special weir case. Descriptions for each menu parameter are provided. A schematic showing the definitions of a weir is also given. No example problem is provided. The reference manual shows the 3 weir formulas. The definition of each term in the equations is given. However, no information is provided which discusses under what hydraulic conditions the user should use a particular equation. Also, recommended coefficients to use in each equation were not available.
R	The documentation for lateral structures and storage areas is vague in a few areas. See graphical output below. There are several examples-tutorials that include these hydraulic structures. Familiarity can be gained rapidly. A picture in the documentation of the graphical weir/gate input window describing the orientation of these hydraulic features would be helpful to new users. The labels could be improved. The explanation was a bit confusing on how they measure the placement of a lateral weir. HEC support personnel cleared this up quickly.
S	

__Appendix 8.__ Team members' comments on specific model capabilities.

Model	Comments
4.2. DATA ENTRY/DATA EDITOR	
F	
M	GATES: Adding a structure to the system is easy and straightforward - it can be done either by right clicking on a branch in the network editor, or by manually entering the data in the tabular view of the network. The fields in the main input screen are populated by default values, and values not needed for different modeling options are grayed out automatically. Adding additional rows to tables is accomplished by tabbing completely through the previous row – this is a tedious process. (If there is a more formal means of accomplishing this task I have not yet found it) Fields that have constrained definitions – such as identifying a river reach for a computational control – have all available options in a dropdown menu. Once the modeler gains an understanding of how to implement structures, there is an unbelievable amount of possibilities for setting up rules for managing gate operations both in a look back and predictive environment. 36 different parameters can be used for specifying the control of a gate operation (independent variable), and 27 different parameters can be used for the dependent (controlled) variable. Gate settings can be determined directly by a lookup table, or iteratively by specifying a different parameter as the dependent variable. Virtually any parameter (such as water level, discharge, velocity) and its derivative (such as rate of change, etc.) can be used for setting constraints and gate operations. Tables can be clumsy to navigate, column headers confusing at times. WEIRS: GUI allows for easy entry of data. Data editor is easy to follow.
R	The modeler can place the lateral weir at the bank station or on the right or left overbank area. Once familiar with the data entry/editor it is quite simple, straightforward and comprehensive. Gate settings allow a lot of flexibility and capability. If entering gates, don't forget to add internal boundary conditions in data editor after setting up dam. Very easy to run mode, analyze, quickly change gate settings or geometries, then rerun again.
S	Weirs and gates are added to a reach rather than in the cross section itself. Multiple weirs and gates are combined into a single effective structure. The SOBEK Rural 1D flow model offers two weir types to insert into the channel. There is a *21, Flow-Weir* node and a *22, Flow-Universal Weir* node that can be added to a reach in netter. The weir is added graphically at the desired location and then you can input the model data. With the *21, Flow-Weir* you set the weir dimensions (height and width), discharge and contraction coefficients and controller. The weir may kept at a constant level or be controlled by a time series of crest heights, hydraulic parameters (water level and discharge) at specific locations, an interval of hydraulic parameters, or a Proportional Integrating Difference (PID) for a hydraulic parameter. A measurement station, node type *18, Flow-Measurement Station* must be added to provide the data to utilize any of the options dependent on hydraulic data. SOBEK-RTC Real Time Controller provides more complex controls of structures but it was not tested on the evaluation data sets. This type of weir is used to simulate broad-crested weirs; you should use the *22, Flow-Universal Weir* for any other weir shape. You input the discharge coefficient and a cross section to define the shape of the weir not the entire cross section. There is no option shown to add a controller to the universal weir but the documentation didn't explain if it is possible or not. A gate is added to the model using *23, Flow-Orifice* node type. Features are similar to the Weir node type as shown below. You input the dimensions and any controller as explained above. SOBEK River offers additional types and controllers for weirs and gates. You can use a *30, Flow-River Weir* or *31, Flow-Advanced Weir* to add more definition, additional controllers, and triggers to your model. <u>Data Editor</u>: With the Multiple Data Editor you can edit parameter for the Weir node type but not the Universal weir (one with the controller).

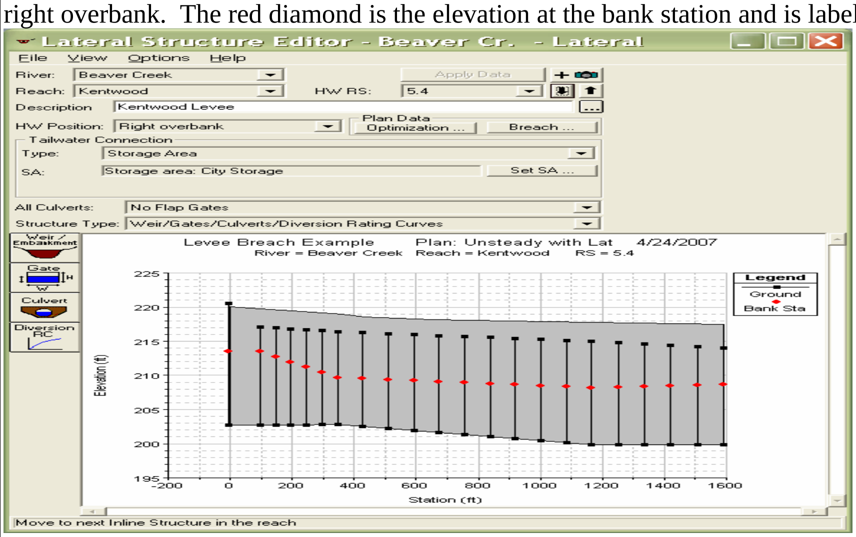
Appendix 8. *Team members' comments on specific model capabilities.*

Model	Comments
4.3. COMPUTATIONAL METHODS	
F	
M	GATES: There are 9 calculation modes available for computing the flow through a regulated structure – 5 that prescribe a specific gate condition (Fully Open, Fully Closed, Unchanged, Specific Change, Specific Setting), and 4 that allow a computed gate opening - Tabulated (gate levels are specified via a lookup table), PID Operation (gate settings set by PID equation), Momentum (replaces energy equation for flow calculations), Iterative Solution (allows indirect computation of gate settings and discharge). These methods can be specified for each gate individually, and can be combined into a full regulation plan using logical operands. WEIRS: Three weir equations and an option to manually insert Q/h relations for a special weir case are available. The methodology appears to be sound.
R	The computational methods are well documented and hydraulically sound.
S	SOBEK uses water levels to calculate flow through the weir depending on whether the weir is submerged or not. Flow across the orifice can be of the following types: submerged weir flow, free weir flow, submerged orifice flow, free orifice flow or no flow depending on the dimensions of the structure and the flow conditions. SOBEK switches from one flow type to another. SOBEK River weir calculations utilize submergence factors, energy levels and weir shape for more detailed computations.
4.4. MODEL STABILITY	
F	
M	GATES: The introduction of gate structures can introduce numerical instabilities, especially for poorly specified control point locations in iterative solutions. Stability was not a problem during testing. WEIRS: The weir equations appear to be stable.
R	RAS provides the user with the ability to gradually open the gates which helps stabilize the model. Very stable.
S	There were no stability issues encountered during testing of weirs. The documentation included a note for weir simulations as follows: *Note: Broad weirs can cause oscillations, because the discharge calculated with the broad crest move a lot of water at a time step. This large discharge can lower the upstream water level significantly resulting in a discharge with a reverse flow direction at the next time step. The following (rather conservative) rule-of-thumb can be used to avoid oscillations: As = 1.5 . Ws, As Storage area upstream of the structure [m2], Ws Crest width*

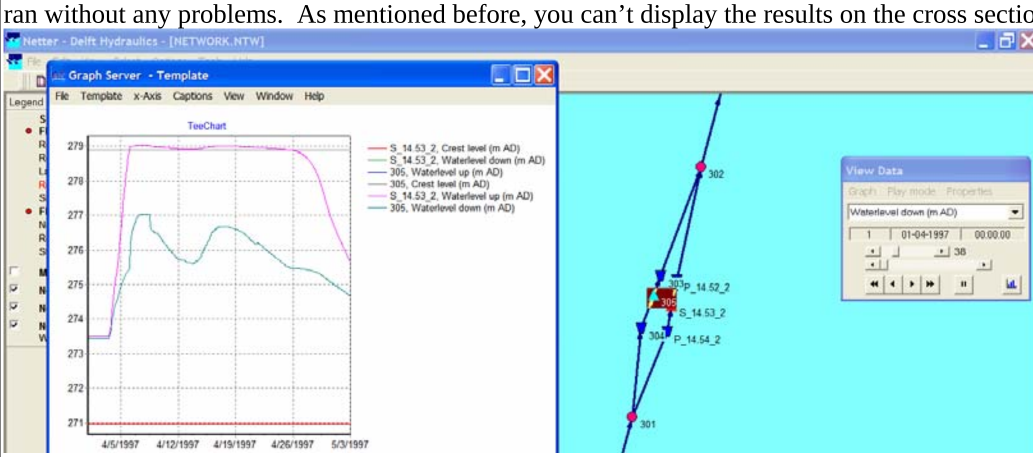
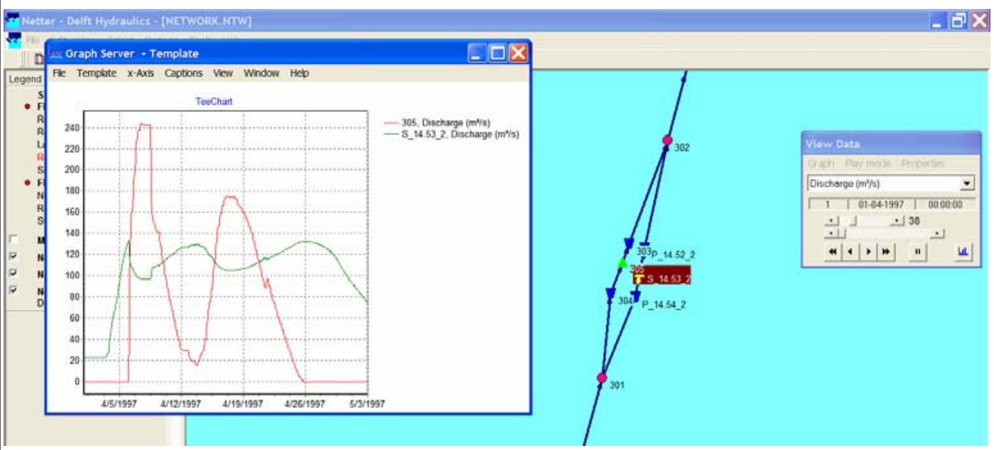
Appendix 8. *Team members' comments on specific model capabilities.*

Model	Comments
4.5. TROUBLESHOOTING	
F	
M	GATES: The model will stop and yield error messages during the initial stages of the simulation if parameters for the structure have been incorrectly specified or are missing. While these messages are brief, they nearly always correctly point the modeler to the correct trouble spot. Trouble shooting is about average when there is a problem.
R	see graphical and tabular output - You can look at the tabular output profile for lateral structures and see the hydrograph of the flow over the lateral weir for the entire storm event. Look at reach connectivity gui. See comments in "6.Modeling dams/ dam break analysis"
S	Other than the Check Flow Model utility, there was nothing documented to help troubleshoot weir simulations. There is a list of errors in the documentation but none were encountered during the evaluation.
4.6. TABULAR OUTPUT	
F	
M	By requesting additional output from the HD module, information specific to the structure can be output to a secondary output file. Data from this file can be viewed simultaneously in MikeView. This can be a cumbersome process. I was not able to find a tabular output option.
R	There is a standard profile output table for lateral weirs and they provide a standard profile output table for storage areas. This output table for lateral structures lets you know when and how much overflow occurs. This can be used to make adjustments for reducing or increasing overflow. In the standard table for cross section output there is another table specific to lateral structures or storage areas at each cross section.
S	No special output for weirs.

__Appendix 8.__ Team members' comments on specific model capabilities.

Model	Comments
4.7. GRAPHICAL OUTPUT	
F	
M	Available through the separate MikeView application. It should be noted that while their presence is easily identifiable due to the abrupt changes in water surface, the location of structures are not automatically shown in the profile plots. The only means to displaying them that I've found is to manually add a marker to the profile. Graphical output is adequate
R	Lateral structures are not displayed on cross section plots. The cross section animation doesn't give the user the complete picture if the water is being confined by a lateral structure. If the flow exceeds the ground elevation but is actually being confined by the lateral structure you cannot see hide nor hair of any reason why the water is just going straight up in the cross section plot animation. Users might assume that the model has defaulted to a vertical wall at the end of the cross section since several programs make that assumption once the water goes beyond the cross section extents. Lateral structures are displayed on the schematic. On the lateral structure profile plot, you have to go into a menu to turn an option on to display the River Miles. It seems reasonable to have it turned on as the default and let the user turn it off as an option. See the picture below showing the profile of the lateral structure in the Geometry editor. The grey rectangle is not really the lateral structure. Most of the grey rectangle is actually underground. I found it a bit difficult to understand what this view was depicting. The legend says ground for both black squares. Actually, the bottom black square is the channel invert and the top black square is the elevation at the end of the cross section in the right overbank. The red diamond is the elevation at the bank station and is labeled correctly. 

Appendix 8. *Team members' comments on specific model capabilities.*

Model	**Comments**
S	The pictures below show some of the graphical output available at the Red River bridge describe in the Split Flow Modeling section. Node 305 is the overflow portion of the bridge section which is defined as a weir and node S_14.53_2 is the culvert portion of the weir. SOBEK can plot both the discharge and stage hydrographs for structures. You can plot multiple time series on the same plot but you cant' bring up multiple plots at the same time for comparisons. Some of the oscillations mention above can be seen in the weir discharge hydrograph but the simulation ran without any problems. As mentioned before, you can't display the results on the cross sectional view.  
4.8 OTHER COMMENTS (not graded)	
F	
M	A simpler type of control structure – a *regulating structure* – may also be defined within Mike11. This is a simpler means of adding in a simple reservoir or structure with pre-determined gates settings through time. Documentation for this type of structure is very lacking; the structure requires the definition of two points (J1 and J2), but a description of where these points should be defined is missing. The technical reference manual uses a different terminology altogether.
R	
S	CONVERSION OF HEC-RAS. SOBEK converts the HEC-RAS structure locations only. Structures are modeled completely different in the two models.

Appendix 8. *Team members' comments on specific model capabilities.*

Model	Comments
5. LEVEES/LEVEE BREECH	
5.1. DOCUMENTATION	
F	
M	Documentation for basic levee modeling is best found in the reference manual under "Flood Plains". If flow in the overbank area will occur after a levee is breached, levees are best modeled within Mike11 as a quasi-two dimensional system with 2 or 3 parallel reaches - representing channel and overbank flow paths – connected by link channels which contain a broad crested weir control structure representing the levee in that section of the river. Documentation for this approach is a little difficult to follow, and an example is not provided within the documentation. It should be noted that the preferred means of addressing levee modeling within DHI software is through a coupled 1D/2D model using MIKE FLOOD. The MIKE FLOOD documentation contains a considerable amount of discussion of the lateral links used to simulate the levees which are the connection between the 1D and 2D model. Two scores are given; the first is for the quasi-2D method in Mike11, the second is for the MIKE FLOOD method.
R	The documentation for levees is good. Examples given
S	A search of the documentation reveals that SOBEK Rural 1D model has no direct method of modeling levees or levee breaches. The SOBEK River 1D model adds the capability to model a summer dike where the area behind the dike isn't added until the level of the dike is exceeded. This area may be further divided in to flow and storage areas. Additionally the combined 1D2D model can simulate levee breaches and is especially useful where the river and floodplains details aren't available. Most examples provided in the documentation for levees where developed for the 1D2D model which wasn't tested for this evaluation. The documentation doesn't provide any examples for modeling levees for either the Rural or River 1D models but there is adequate explanation describing how to define the SOBEK River "Summer Dike" option but the Red River data set wasn't set up for this module.
5.2. DATA ENTRY/DATA EDITOR	
F	
M	Creating the river schematic and defining levees in the quasi-two dimensional mode is an intensive process; each link channel must be connected, with a separate weir segment defined within the link channel. If floodplain conveyance is not anticipated should the levee be overtopped, a simple levee area may be modeled by adding a weir as a side structure with an attached storage area. For the 1D/2D MIKE FLOOD approach, defining levees is accomplished by setting levee markers within the cross section editor at the appropriate elevations of the levee, and then defining parameters for weir flow at each cell linkage point.

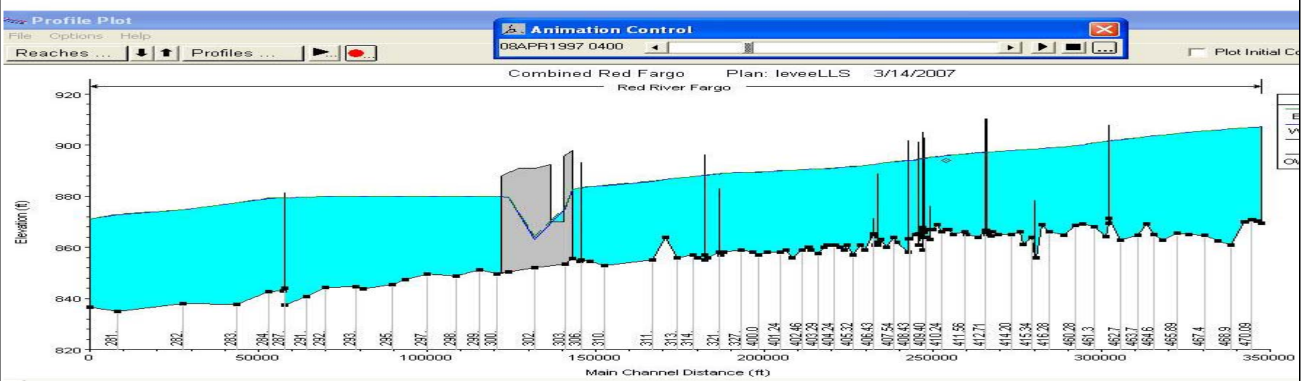
Appendix 8. *Team members' comments on specific model capabilities.*

Model	Comments
R	Adding levees is awesomely quick using the graphical data editor. To model a levee breach, you end the cross sections at the levee and then put in a lateral structure to model the top of the levee and any overflow. It is fairly easy to cut off the cross sections in the overbanks using the graphical editor. Cutting off your cross sections graphically could be pretty accurate if you georeferenced cross sections and an aerial photo as a background for the schematic. You could represent the area behind the levee as a storage area or another river reach. Water that goes above the top of the (lateral structure) levee is modeled using the weir flow equations. There is also a table to help input levees or edit levee elevations and locations. However, if you want to raise your levee but your cross section is scaled so the ground elevation is near the top of the graph, you have no room to increase the height of the levee graphically. In this case you would need to use either the levee table or the individual cross section plot editor and enter numbers into the table at the correct horizontal station. The levee table is the best choice for most applications. In the levee table you can add a user entered number of feet of elevation to all levees you highlight at once or you can use a multiplier. Setting up lateral levees for floodplain storage or for flood control takes only minutes
S	The SOBEK Rural 1D module offers very few options to enable you to model a levee. You can enter a surface level at the cross section node and then change how the model handles the water above this surface level. This water can be stored or removed from the system. SOBEK River 1D module allows you to add a levee to a cross section and set some parameters about its behavior. The River Profile cross section is symmetrical like FLDWAV instead of a Y-Z profile. It would be necessary to define these for each cross section if the levee spanned beyond two cross sections. It seems you would need to add a lateral discharge location to define a specific breach location. The combined channel and overland flow 1D2D model would provide the most flexibility in modeling levees and levee breaches. There is and example in the documentation but 2D modeling wasn't tested for this evaluation. **Data Editor** The multiple data editor allows you to set the surface level quickly in a tabular format but not the options a concerning storage and loss of water above the surface level.
5.3. COMPUTATIONAL METHODS	
F	
M	There are several different methods of modeling levees, depending on the complexity of the system.
R	Levee overtopping is modeled using the weir flow equations. There are options for computing breach growth rate.
S	As explained above, the SOBEK Rural 1D model only allows you to set a surface level where the water will leave the channel. Once the water leaves the channel you can either store it or remove it from the system. Your storage area can be a fixed or variable with of the cross section. This would be a very limited method to define levees since you can only select one surface level for a cross section. SOBEK River options offer more capability but not for the Y-Z type cross section.
5.4. MODEL STABILITY	
F	
M	Issues with stability are inevitable with levee modeling, given the relatively large number of lateral structures and the wetting and drying of storage areas. This is discussed briefly within the MIKE 11 documentation. Many troubleshooting tips are provided within the MIKE FLOOD documentation to help with stabilizing the 1D/2D modeling approach.

__Appendix 8.__ Team members' comments on specific model capabilities.

Model	Comments
R	I tested levees and breached levees – no problems with stability. However, one would need to watch for rapid changes in depth and velocity which could easily occur in a leveed reach and especially during a breach. RAS uses a linear growth rate for forming the breach. If this causes instability, due to rapid change in flow when the breach begins to form, RAS offers an alternative option: a non-linear breach growth rate (sine wave) which will lend stability to the solution by smoothing out the change in flow. The modeler can also increase the breach time and try using a smaller time step. I added a breached levee and a storage pond into the St John's tidal model with no instabilities.
S	Levees weren't tested in the Red River model but SOBEK offers a transition scheme in the River module which would help prevent rapid transitions
5.5. TROUBLESHOOTING	
F	
M	Warnings are provided, and usually help isolate the problem. Documentation for MIKE FLOOD provides many troubleshooting tips for levee modeling.
R	First off, it can be helpful to run the geometry preprocessor and look at the hydraulic output for anomalies before running the unsteady flow part of the model. After that has been cleared up look at the warnings and errors and the tables specially prepared for cross sections. The modeler can also increase the breach time and try using a smaller time step. The modeler can turn on the "Detailed Output for Debugging" option, rerun the program and view the detailed log output of the computations. Check the geometric data in the problem area. Graphical and tabular tools are available for viewing inflows and outflows to a storage area for calibrating/editing. The user may simultaneously view an upstream or downstream cross-section or inflow/outflow hydrographs to troubleshoot why too much or too little water is at a particular location.
S	The documentation doesn't provide any information about troubleshooting cross section definitions and no cross sectional output is available.
5.6. TABULAR OUTPUT	
F	
M	All time series data can be accessed from the MikeZero time series viewer. For MIKE FLOOD simulations, data for individual grid points may be accessed.
R	There is a standard cross section output table that provides errors and warning messages as applicable.
S	No output specific for levees
5.7. GRAPHICAL OUTPUT	

__Appendix 8.__ Team members' comments on specific model capabilities.

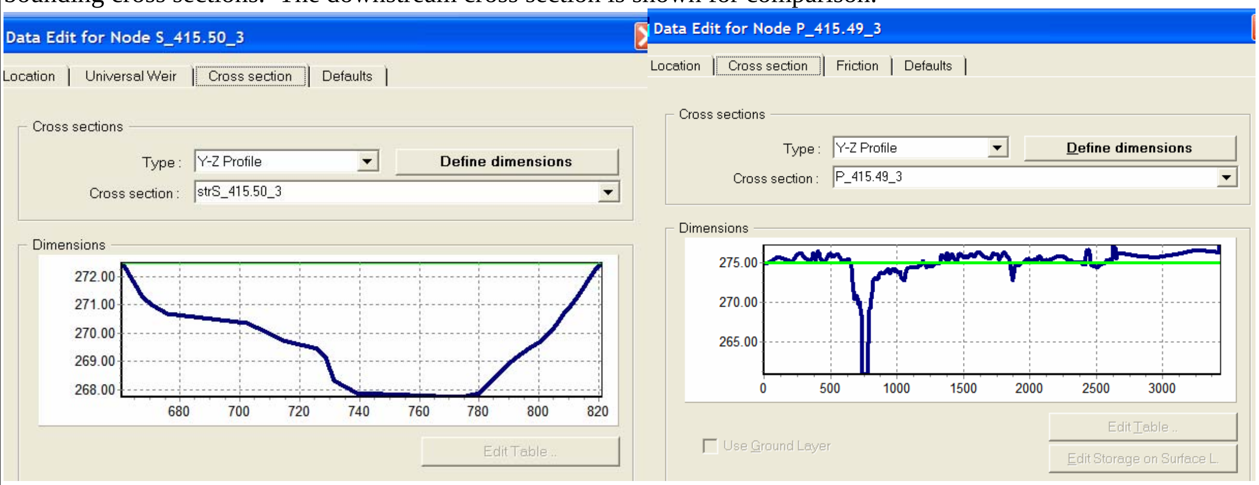
Model	Comments
F	
M	For Mike11 1D and quasi-2D modeling, the standard Mike View output is available for river channels and structures. The graphical output is by far most dramatic with the MIKE FLOOD 1D/2D approach, which has the capability of graphically depicting the inundation of storage areas behind levees.
R	Levees are shown on cross section plots, on the schematic, and on water surface profile plots. Using the general profile plot, you can see the ground line at the right and left bank stations and you can see the top of levee elevations. You can also plot the left or right levee freeboard. If you were to change levees into lateral structures it could be time consuming. On the lateral structure data entry editor, the levee doesn't show up. It would be handy to see the top of levee profile in the lateral structure data input editor. Cannot view levee with cross-section, only in the schematic 'plan' view 
S	No output specific for levees
5.8 OTHER COMMENTS (not graded)	
F	
M	
R	For modeling overtopping or piping failures you define levees as lateral structures.
S	<u>CONVERSION OF HEC-RAS.</u> The Red River model only had one cross section that included a levee option. SOBEK didn't convert any information about this feature. It is unclear how SOBEK sets the surface level for each cross section imported but it may be necessary to reset these levels after conversion. If you want to use the summer dike option for a SOBEK River model, you would have to define these cross sections in SOBEK since a River Profile is a symmetrical tabulated cross section instead of a Y-Z Profile.

6. DAMS AND DAMBREAK

Appendix 8. *Team members' comments on specific model capabilities.*

Model	Comments
6.1. DOCUMENTATION	
F	I was able to easily add a dam using existing references/templates. Very little trouble shooting documentation.
M	Dam breaks are one of the better documented aspects of the Mike11 model. Modeling a dam failure requires configuration within the network editor and the boundary condition editor at a minimum, with alterations within the cross section editor required for some types of breach modeling. Documentation within the User's Guide and Reference Manual is fairly thorough for each of the possible dam failure computation methods. The User's Guide outlines each of the menu options, and the Reference Guide provides an overview of theory used in Mike11's approach to modeling failures. A brief, but technical, explanation of the NWS DAMBRK methods (available as an option within Mike11) is provided in the Reference Guide
R	Examples given
S	Dams are entered into the SOBEK Rural model as a *22, Flow-Universal Weir* or a *21, Flow Weir*. The *Universal Weir* allows you to enter a cross section including the dam and a loss coefficient while the *Weir* option allows you to input the dimensions of the dam, loss coefficients, and controllers as explained in the weir modeling section. SOBEK–River offers an additional type of weir called the *Flow-River Weir*. It offers additional capabilities and computational method. No detailed examples of dam modeling are included in the online documentation. SOBEK documentation also includes a *3, Flow-Dam Break* reach and a *45, 2D-Breaking Dam* node. Both options are only available in the 1D2D Module. In the SOBEK Rural/River 1D modules you can only model a dam breach by inserting the discharge time series as a boundary condition or possibly a lateral discharge. SOBEK provides an example of modeling a 2D dam break and the Frequently Asked Questions explain the application of the Flow-Dam Break reach. Dam breaks can be modeled either 1D or 2D but only within a combined 1D2D model.
6.2. DATA ENTRY/DATA EDITOR	
F	I perform data entry reformatting outside FLDWAV. Data sets were provided to me in this instance. I understand a file can be made from scratch in FLDAT, however, I did not exercise this function.
M	**Data Entry – Element Creation.** Jumping between modules tricky. Dam Failures are treated as compound structural entities within Mike11, with the breach acting as a secondary – and growing – outlet to an existing dam structure. Dam Failures are added directly to the network geometry by right clicking. It should be noted that there is nothing to prevent the addition of a Dam Failure at a location without a previously defined structure – Mike 11 allows the addition of the different structural elements in any order. The dam failure is associated to a structure through the structure ID field. This field is not a drop down selection. **Data Editor**: Very thorough. Like most other screens in Mike 11, the data entry assists the modeler by dynamically activating only the appropriate parameter fields for whatever options have been selected. If numerous other parameters are needed (such as parameters for an erosion-based failure), data is entered through a secondary pop up window. Unfortunately, default values are extremely limited. Most values default to zero. Piping failures assume an initial diameter of 1 meter. Recommended values are not provided in any of the documentation.

Appendix 8. *Team members' comments on specific model capabilities.*

<table>
<tr><th>Model</th><th>Comments</th></tr>
<tr><td>R</td><td>Data entry: Setting up dams are very quick, they require 2 US cross-sections. Can vary individual gate openings (like the Corps does in reality) based on various criteria…Ex.: The Corps will keep a reservoir or navigational dam at a certain elevation or release. These can be established and run in forecast/future modes. Data editor: Dams (and Levees) can be modeled for breaching based on water surface, time, flow…or via a cascade breach from an upstream failure. Additionally, these breach criteria can be toggled on or off to avoid resetting the conditions from scratch. The user can set up every dam/levee in their model to breach (in advance) but toggle it off for years until someone wants the modeled result. Two geometry files would not necessarily be required.</td></tr>
<tr><td>S</td><td><u>Data Entry</u>   The data entry is the same as described for the weir section. The Red River model includes three low water dams that were entered into HEC-RAS as inline structures and in SOBEK as Universal Weirs. The dam was entered as a Y-Z profile cross section with the dam area removed as shown below. The surface level (green line) was set by the bounding cross sections. The downstream cross section is shown for comparison.


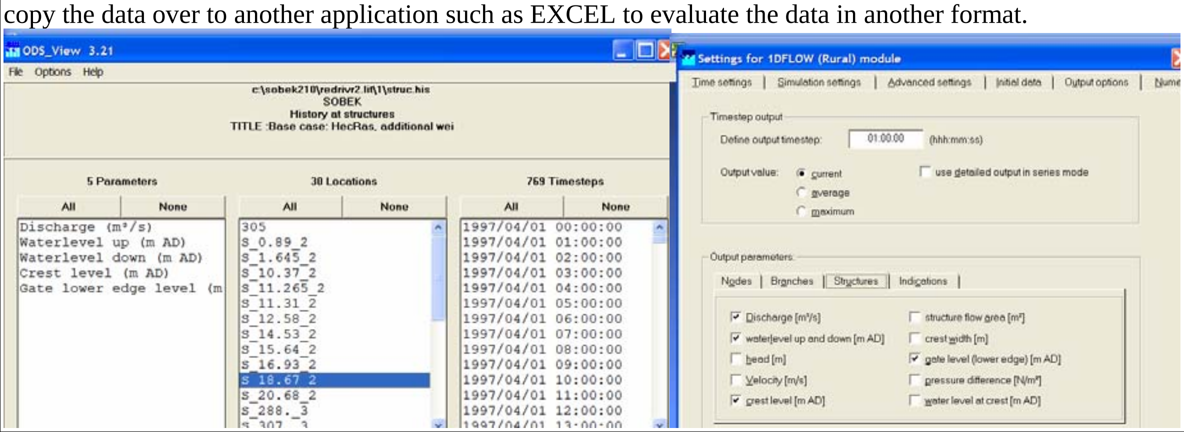
The 2D capabilities of SOBEK weren't tested in this evaluation; therefore a dam break analysis would be modeled as a discharge boundary condition in a 1D mode. This would be a 14, Flow-Boundary node that is added to the schematization through netter as explained in previous sections. The combined 1D2D model includes tools to calculate the breach and controls for the simulation but the 1D module doesn't. The RTC (Real Time Controller) offers advance controls for Reservoir Simulations.
<u>Data Editor</u> The Weir option can be edited in the multiple data editor but the Universal Weir can't. The multiple data editor is not available to edit boundary conditions. It must be edited through the single data editor.</td></tr>
<tr><td colspan="2">6.3. COMPUTATIONAL METHODS</td></tr>
<tr><td>F</td><td>Same as COE</td></tr>
<tr><td>M</td><td>Many, many options available. Excellent. Mike11 provides the following options for dam failure modeling, allowing the modeler to make the simulation of the dam failure as simple or as complex as they choose. The full range of parameters that can be specified is shown in the above figure, and is summarized here: <u>Calculation Methods:</u> NWS DAMBRK breach and piping equations (trapezoidal pipe) ; Mike 11 energy equation – breach and piping (circular pipe). <u>Cross Section Limitations:</u> breach size can be limited (to simulate bedrock) or unchecked; <u>Failure Initiation:</u> specific time relative to start, Absolute time, Triggered by reservoir water level; <u>Failure Mode:</u> time dependent (manually specified breach) or erosion based. Note that erosion based modeling requires many more parameters for computation; <u>Time Step Manipulation:</u> three methods are provided to shorten the computational time step to improve model stability</td></tr>
<tr><td>R</td><td></td></tr>
</table>

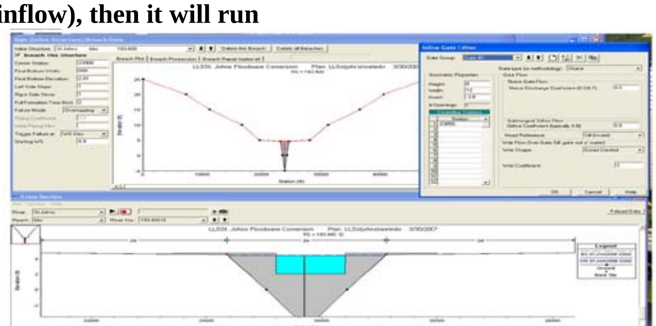
Appendix 8. *Team members' comments on specific model capabilities.*

Model	**Comments**
S	Computational methods for the dams are explained in the weir section of the evaluation. The 2D features were not evaluated but there is explanation in the Technical Reference Manuals.
6.4. MODEL STABILITY	
F	
M	Not a significant issue in my testing. The user's manual provides several simple, and effective, tips for helping control stability in the simulation.
R	Added breached levee **and** dam breach below storage pond with tidal model without instabilities.
S	No stability issues were encountered for the Red River or Tutorial examples. After shifting the crest level of the low water dam at River Station 415.5 up 6 meters, the model crashed during preprocessing. Check flow didn't detect any errors. The warnings and error messages point to a large delta x but not to the location where the change was made except by grid location. This is the same error message received during lateral inflow testing. The error message is copied below. It's not clear how this message would help in troubleshooting. View - [PARSEN.DMP] File Search Options Sobek Parser V2.04.23 Warning: x gridpoint < previous x Object-id : R_3 Object-nr : 547 Warning: change of delta x very large Object-id : R_3 Grid: 20831.28 21031.32 21131.22 Warning: change of delta x very large Object-id : R_3 Grid: 30621.18 30820.80 30920.53 Warning: change of delta x very large Object-id : R_3 Grid: 35707.62 35807.36 36007.11 Warning: change of delta x very large Object-id : R_3 Grid: 54712.02 54812.05 54343.95 Warning: change of delta x very large Object-id : R_3 Grid: 54812.05 54343.95 55012.10 Warning: change of delta x very large Object-id : R_3 Grid: 54343.95 55012.10 55112.12 Warning: change of delta x very large Object-id : 1 Grid: 5109.429 5185.713 5209.614 Warning: change of delta x very large Object-id : 1 Grid: 5185.713 5209.614 5309.799 Error: One or more branches with invalid grid 0 informative messages 9 warnings 1 errors!
6.5. TROUBLESHOOTING	
F	
M	Error messages are usually useful – only significant errors are generated, and these errors, while brief, do provide the correct and necessary information.
R	There are occasions that error messages with dam settings are not very detailed. For example, if flows above/below a navigational dam are changing quickly but you have your gate opening rates too slow, the model may go unstable but not say why….but if you can get output this can be remedied via troubleshooting with the inflow/outflow/gate flow graphics/tables.
S	See 6.4.

__Appendix 8.__ Team members' comments on specific model capabilities.

<table>
<tr><th>Model</th><th>Comments</th></tr>
<tr><td colspan="2">6.6. TABULAR OUTPUT</td></tr>
<tr><td>F</td><td></td></tr>
<tr><td>M</td><td>Same as data that is generally available at structures within Mike View. Data can be exported to Excel if needed.</td></tr>
<tr><td>R</td><td></td></tr>
<tr><td>S</td><td>No special output tables are available for dams in the 1D simulation. The output available is the same for other structures. The default "Results in Charts" options are shown below. In the "Settings" task block you can request the additional output variables shown below. There are no summary tables of variables generated for review. You have to copy the data over to another application such as EXCEL to evaluate the data in another format.


</td></tr>
<tr><td colspan="2">6.7. GRAPHICAL OUTPUT</td></tr>
<tr><td>F</td><td></td></tr>
<tr><td>M</td><td>Available through the separate MikeView application. It should be noted that while their presence is easily identifiable due to the abrupt changes in water surface, the location of structures are not automatically shown in the profile plots. The only means to displaying them that I've found is to manually add a marker to the profile.</td></tr>
<tr><td>R</td><td>Can view headwater/tailwater inflows and outflows, gate flows and openings/closings, and stages simultaneously in hydrograph output graphs. See picture below. NOTE: there is a beta bug observed in creating a dam/storage as the most US boundary. The way around this is to add two cross sections above the US dam/storage (tiny reach with 2 cross section with a trickle inflow), then it will run

</td></tr>
</table>

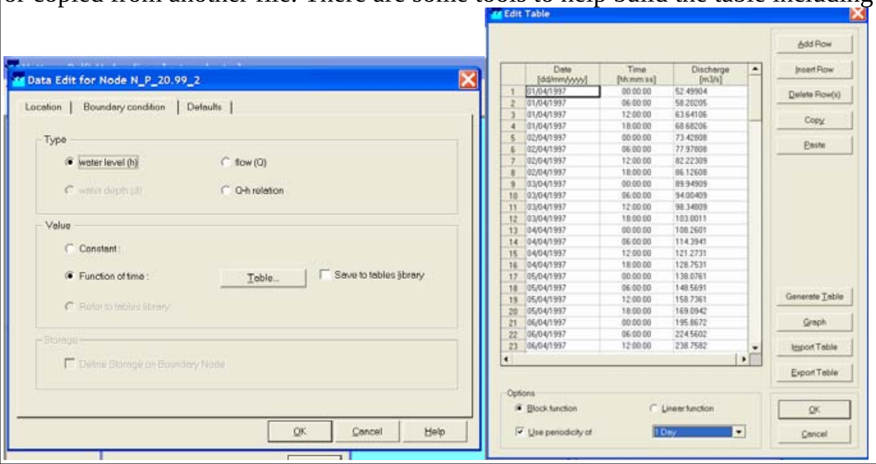
Appendix 8. Team members' comments on specific model capabilities.

Model	Comments
S	Animated profiles are available in Sideview. The picture below is zoomed into the location on the Red River with the three low water crossings. Results aren't available in a cross sectional view.  -
6.8 OTHER COMMENTS (not graded)	
F	
M	Removing dam break structures from the geometry can be difficult to do. I have noticed with behavior with other structures as well – when attempting to delete the last of a given structure type from the network, the data will clear, but the model still believes a structure – undefined on the network – exists. This causes a problem at run-time, when the model throws an error due to the undefined data for the "deleted" structure. At times, deleting the structure by right-clicking on the network graphic works, but I cannot get the dambreak structure to leave the system this way.
R	
S	<u>Conversion of HEC-RAS</u> SOBEK conversion of HEC-RAS imports the location of structures but not the details. Details have to be manually input into SOBEK.

Appendix 8. *Team members' comments on specific model capabilities.*

Model	Comments
	7. TIDES
	7.1. DOCUMENTATION
F	Model documentation is complete. Model Trouble Shooting and Error Messages are below average
M	No documentation specific to modeling rivers with tidal downstream boundary conditions. Coverage of boundary conditions is adequately covered within the manuals.
R	Not much there except a mention of tides, however no documentation is needed, it is merely an easy stage/ DS-boundary condition. Nothing specifically tidal related.
S	A frequently asked question in the documentation tells how you can model tides in SOBEK. Since it is modeled as a boundary condition, there isn't any additional explanation or examples.
	7.2. DATA ENTRY/DATA EDITOR
F	I perform data entry reformatting outside FLDWAV. Data sets were provided to me in this instance.
M	Data entry for tidal boundaries consists of simply adding a downstream boundary condition. This can be manually specified in the boundary condition editor, or by using the Auto-Boundary Free Ends function within the Network editor. In many tidal situations it is necessary to add additional storage areas and outlet channels to the network near the mouth of the system to simulate harbor and/or estuary storage. This is done by modifying the network channel by adding additional reaches. No specific editor for tidal boundaries.
R	Either using DSS or cut/paste tabular entry of tidal stages, it is easy to enter or change. I ran it with observed tides and then set up a separate plan with higher stages (10 feet fake Hurricane surge), First I tried 5 feet surges but they were so dampened I raised them to 10 feet. Nothing specifically tidal related. Should include winds. Can it bring in the annual NOAA tide forecast?

Appendix 8. *Team members' comments on specific model capabilities.*

Model	**Comments**
S	Tides are modeled as a boundary with a varying water level. You input the tide as a *14, Flow Boundary* node in netter. After the boundary node is added, you edit the parameters in the model editor window shown below. Table can be input or copied from another file. There are some tools to help build the table including a sine fn 
S	You can only edit the data through the netter application and you can't use the multiple data editor to edit boundary conditions.
7.3. COMPUTATIONAL METHODS	
F	Does extremely well with low slope, tidal boundary conditions.
M	The model computations are not changed for tidal boundaries.
R	Steady or Unsteady can be run on tidal boundary.
S	Tides are computed the same as any other boundary.
7.4. MODEL STABILITY	
F	Study included 7' tidal range – no stability troubles.
M	The simulations I conducted were all stable, even with a sharp wave propagating downstream in the initial stages of the simulation (see screen captures). The model was also tested using inline weirs to model flood and tidal control structures within the river – M11 provides the option of specifying flow direction over a weir in only one direction (to allow spilling from the river channel when the tide allows downstream) or in both directions. Stability was not impacted. Addition of a looped network of channels with multiple channels having a downstream boundary did not prevent the solution.
R	I halved the US inflows and lateral inflows while maintaining a very high and then a very low DS tidal stage and model was completely stable.

__Appendix 8.__ Team members' comments on specific model capabilities.

Model	Comments
S	Abrupt water level changes may have an impact on the stability of the model. SOBEK has a built-in time step estimation to resolve these situations. If the selected time step is too large causing negative depths or not converging fast enough, it will be reduced by a factor of 2 until simulation criteria are met.
7.5. TROUBLESHOOTING	
F	Very Good hydraulic table tabular displays.
M	Error messages from model run pop up in a window during the computation. Have not had any issues tracking down problem areas.
R	Did not have any issues to troubleshoot
S	SOBEK has a utility to check the flow model when you exit the schematization task. It will check for model completeness and warn it there is something missing such as a boundary condition. There wasn't anything in the documentation about this feature.
7.6. TABULAR OUTPUT	
F	FLDAT – provides both tab and graphic displays of tributary data
M	Available, but must be specifically requested prior to the simulation in the HD-parameters window. No specific data is added for tidal boundaries.
R	You can see the tidal fluctuations in a tabular output if you want but the graphical profile is way better.
S	No special output for tide modeling
7.7. GRAPHICAL OUTPUT	
F	FLDAT - graphical displays are FLDAT strong point
M	Plots are available in both plan view (network can be color-coded and animated based on depth, discharge, depth overbank, or several other parameters) and elevation view (traditional profile plots). Hydrographs for specific points difficult to locate. Must launch separate program to view results.
R	This shows the tidal fluctuations so well. It is so helpful to see the animation of the tidal flow.
S	No special output for tide modeling

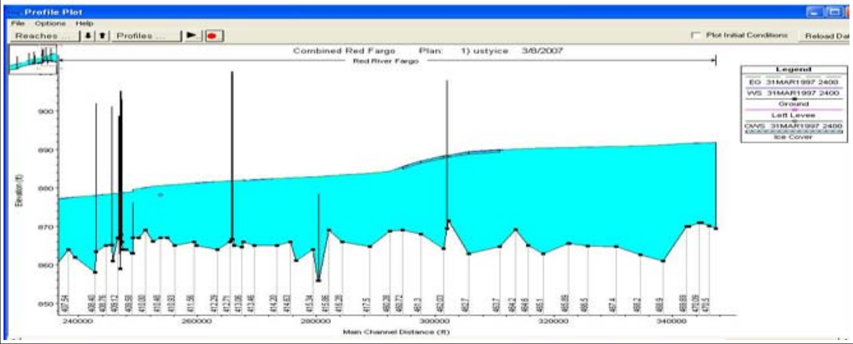
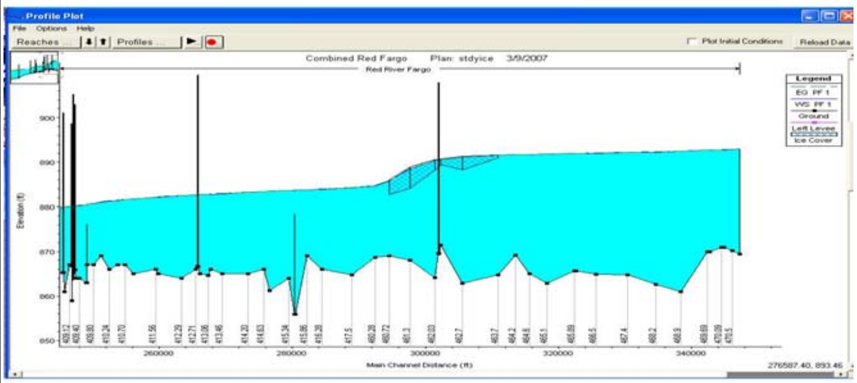
__Appendix 8.__ Team members' comments on specific model capabilities.

Model	Comments
8. MODELING ICE	
8.1. DOCUMENTATION	
F	
M	
R	Ice Jam force balance equations described. Would be interested in differences between equations in floating ice and ice jam RAS provides an easy to follow example in the Applications Guide.
S	
8.2. DATA ENTRY/DATA EDITOR	
F	
M	
R	Very easy. Table allows for easy changes, or can enter through cross-sections individually. Thickness of the ice cover is easy to enter for an entire reach of the river at once. Estimating the thickness or getting measurements from the field is another matter. Adding an ice cover, editing the thickness or other related variables is easy in the ice cover gui.
S	
8.3. COMPUTATIONAL METHODS	
F	
M	
R	Steady state ice jam (US to DS) alternates with water surface (DS to US) calculations and iterates until tolerance is reached, this is called "global convergence". I'm not sure how the floating ice computations in unsteady state calculate this.
S	

Appendix 8. *Team members' comments on specific model capabilities.*

Model	Comments
8.4. MODEL STABILITY	
F	
M	
R	Stable This model doesn't actually reproduce real time ice accretion, ice break up or ice melt.
S	
8.5. TROUBLESHOOTING	
F	
M	
R	No issues to troubleshoot
S	
8.6. TABULAR OUTPUT	
F	
M	
R	With both unsteady (floating ice) and steady state (ice jam) the user can view each time series or profiles' tabular hydraulic data: velocity head, wetted perimeter, calculated composite manning numbers, thickness, etc. They have a standard table for ice cover.
S	
8.7. GRAPHICAL OUTPUT	
F	
M	

__Appendix 8.__ Team members' comments on specific model capabilities.

Model	Comments
R	Profile/cross-section/3D-plot all show floating ice and ice jam. See comments under "General capabilities." See Figures 1 and 2 below (ustLLSice=unsteady run, stdyice=steady run). FIGURE 1. Floating ice (RAS Graphical output) 
R	FIGURE 2. Ice Jam (RAS Graphical output)  In the general profile plot, you can plot the Ice Bottom in channel, LOB, or ROB; the Ice thickness in the channel, LOB, or ROB; the elevation of the top of the ice in channel, LOB or ROB; and the ice volume in the channel, LOB, or ROB.
S	
8.8 OTHER COMMENTS (not graded)	
F	
M	Ice Jam Modeling is currently under development and is not available at this time.
R	Ice jam in steady state added 3 minutes to run, Floating ice added 1/2 hour to the run in unsteady state.
S	

Appendix 8. *Team members' comments on specific model capabilities.*

Model	Comments
9. FLOODPLAIN MODELING	
9.1. DOCUMENTATION	
F	
M	The reference manual addresses the various techniques that can be used in the different floodplain modeling approaches available in Mike11. This manual provides a decent theoretical view of the modeling process, but I found it lacking in explaining exactly how to implement these approaches in Mike 11. The User's Guide does a modest job of explaining the various fields needed to create features such as link channels.
R	Examples are given in both and descriptions on the differences in equations for using normal vs. permanent ineffective areas and blocked obstructions. The documentation is very descriptive.
S	An extensive search of the documentation was necessary to determine SOBEK methods of floodplain modeling. More training would probably have given more insight to the different modules and products and which are best for various situations. The documentation doesn't provide enough examples or explanation to be self taught. After thoroughly searching the documentation for flood plain modeling capabilities in SOBEK-Rural 1D module, it was obvious that the 2D overland flow module or the SOBEK-River 1D module is needed to model floodplains. There is a tutorial for the 1D2D module included to explain how these models are set up but none for the River module. There isn't an extensive manual to explain complex modeling scenarios.
9.2. DATA ENTRY/DATA EDITOR	
F	
M	The level of complexity associated with modeling floodplains depends on the approach taken. Simply modifying the cross sections is easy and straight-forward to add additional storage to a given cross section. Additional area can either added by modifying the x,z coordinates or by manually adding additional storage area to the processed data table. The river can also be modeled as a quasi-two dimensional system, with parallel channels representing the overbank areas and channels periodically connected by short "link channels". This approach allows the 1-D model to resolve complex flow areas that have elements of two dimensional flow – especially in broad floodplains that are shared by more than one river near a confluence. There is a good deal more work involved with implementing this approach. Adding the extra reaches is easy in the network editor. Providing all of the input data can be somewhat tedious, however. The Mike11 option of using link channels does simplify the process – no cross sections are needed for the linking channels.

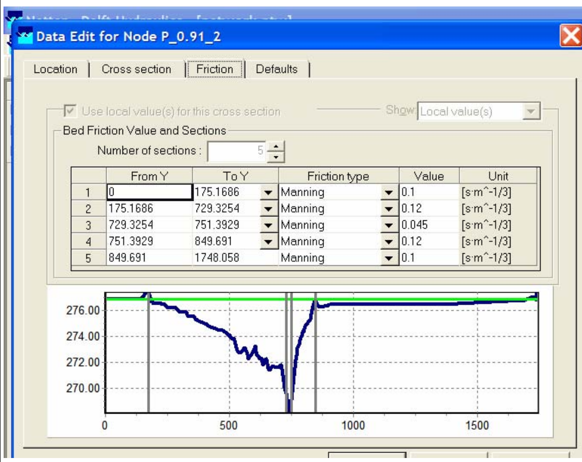
Appendix 8. *Team members' comments on specific model capabilities.*

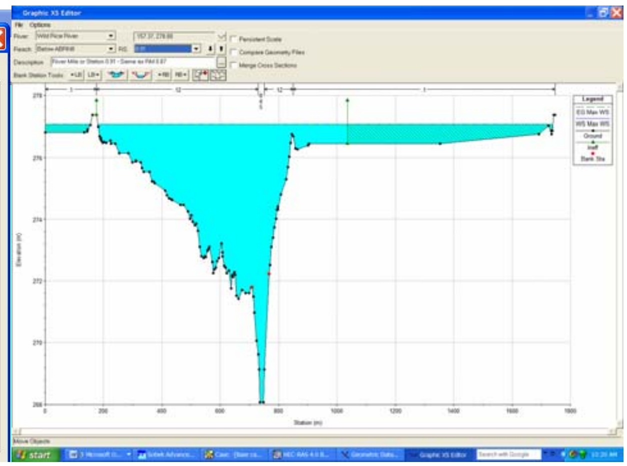
Model	**Comments**
R	Ineffective bank flow can be entered by typing the station location's data into cross-section info or via graphical entry. Storage areas can be drawn over a background map. Dialogue boxes prompt entry of storage/elevation tables or acre-feet tables, or data may be imported from a GIS DEM that will carry the surface areas (or under many circumstances, volumes) in with it. Lateral weirs are easily entered and defined or edited within the geometry editor. Combinations of lateral weirs and storage areas are a simple way to model ponded storage areas. Calibration of these areas is done by simple tweaking of weir heights and volumes to match water exit and return out-of-bank. Putting ineffective flow areas or adding levees is a snap in the graphical editor which has zoom capability for incorporating accuracy of placement. You can type in a table of elevations for all the ineffective flow areas which might be a good option with some datasets. Being able to interpolate cross sections is very important if one doesn't have tons of surveyed cross sections throughout the entire study reach. . You can interpolate an entire reach or between two cross sections. The "between two cross sections" option gives the best result, although it takes longer. When you interpolate areas where adjacent cross sections that have the same features, (e.g. ineffective flow areas) it also interpolates and places those features in the interpolated cross sections. During interpolation, the top of bank stations are put into the interpolated cross sections automatically and so are ineffective flow areas. You can delete all interpolated cross sections and then interpolate again at closer intervals - which is handy. You draw major chords connecting bank stations and thalwegs between two adjacent cross sections where you want to add interpolated cross sections. Then you draw minor chords for any high ground or swales that are continuous between those two cross sections. RAS does not have a Courant condition wizard which would be very handy.

__Appendix 8.__ Team members' comments on specific model capabilities.

<table>
<tr><th>Model</th><th>Comments</th></tr>
<tr><td>S</td><td>

<u>Data Entry</u> The 'Settings" task block is used to select the SOBEK modules that you want to use for your project. You would have to purchase all modules you might need. Options in the Netter application depend on your selection of modules.
The SOBEK-Rural 1D option doesn't offer a cross section you can divide into areas of main channel and flood plains. The cross section input has an option to set a single surface level or also referred to as the level of the embankments; this is shown as the green line on the cross section shown below. You can set it to two different types of storage either reservoir or loss. The reservoir option will act as storage capacity above this level and the loss will remove any water above this level from the system. You can use higher friction values to model non-conveyance areas or additional cross sections. The Red River model converted from HEC-RAS into the SOBEK-Rural module didn't define the non-effective areas as shown below instead it set the surface level at maximum computed water surface level in the HEC-RAS run.





The SOBEK-River 1D module adds another type of cross section called the River Profile where you can define non-conveyance areas. The cross section is tabulated so it is similar to a FLDWAV type cross section where you enter the total width and the flow width. SOBEK doesn't provide any conveyance plots to assist in developing these cross sections.

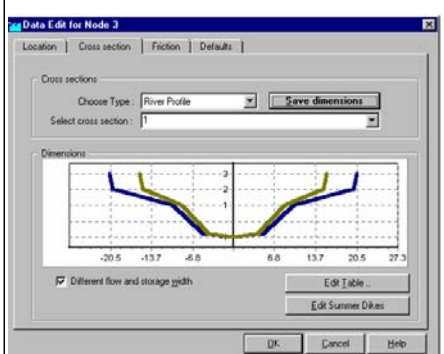
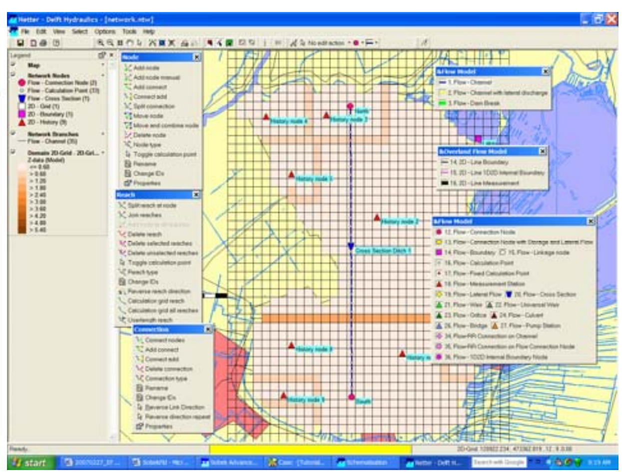


Figure 1 Example of a 'river profile' type cross section



Data entry for the 1D2D is performed in Netter just like the 1D module as shown below. In addition to your background map, you have to import your 2D grid file. Additional options are available and 1D2D connections are required for the 1D2D model but you enter and locate features in the same way.

<u>Data Editor</u> In Netter you can select multiple points and open the multiple data editor but there is limited editing capability as shown in the example from the Red River project below. There isn't any graphical editing capability for cross sections but you can plot the cross section in the data editor.
</td></tr>
</table>

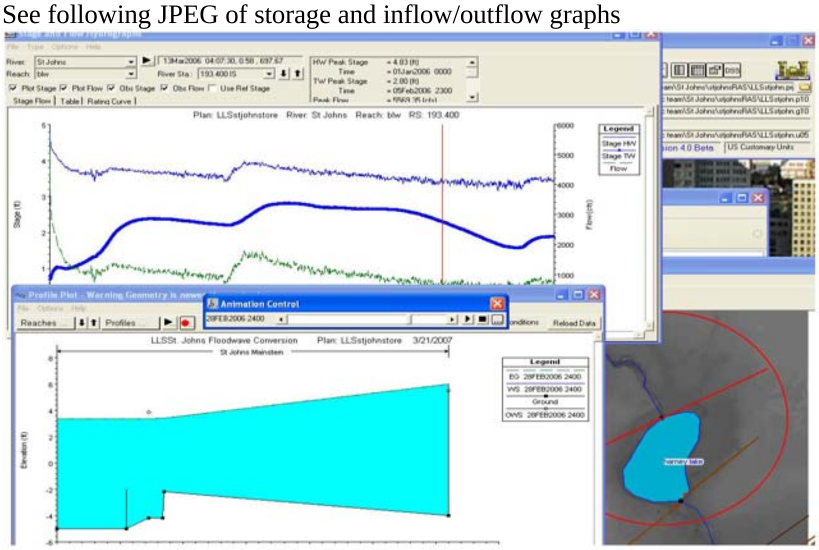
Appendix 8. *Team members' comments on specific model capabilities.*

Model	**Comments**
9.3. COMPUTATIONAL METHODS	
F	
M	As noted above, there are several ways to approach modeling floodplain areas within Mike11. The link channel approach is unique to Mike 11, and is potentially a very powerful means of modeling difficult areas.
R	By putting inline levees/weirs above a lake/storage, equations are stabilized by calculating energy weir flow at these points. Even with effects of positive and negative flow from tides, this was stable. The cross section animation shows you where you need to add ineffective flow areas or where you need to block out water until it gets to a certain elevation. You also get a warning message that says divided flow at cross section RM#.
S	All modules compute flow by solving the complete De Saint Venant either for the 1D or 2D scenarios. As mentioned above, the modeling method depends on the module selected for the project. The SOBEK-Rural module only allows one section per cross section but allows multiple friction values across the profile. SOBEK-River allows you to define non-conveyance areas in a tabulated cross section. The combined 1D2D model combines the 1D channel flow and 2D overland flow.
9.4. MODEL STABILITY	
F	
M	No significant differences seen from other test scenarios, but the Users Manual does note that a long horizontal lateral weir needs to be modified to a slight v-shape to avoid numerical instabilities.
R	When water levels approach each other near levee tops or large overbank storage areas the modeler should subdivide the weirs/levees/horizontal-manning-stretches to avoid sudden and enormous changes in conveyance (true for all hydraulic models). For example if a levee stretches for 20 miles the user may want to put an ever so slight slope in the levee top to prevent the model from a looping calculation of a tenth of an inch of water flowing back and forth across that divide or a sudden leap of conveyance with a tiny change of elevation. Adding cross sections is often necessary in order to stabilize a model to meet the Courant condition, and the easiest way is to interpolate. Interpolation is easy and the way RAS does it is excellent.
S	SOBEK-Rural 1D model is stable, adding a cross section with extremely different geometry near an existing cross section didn't create any instability in the tutorial example. SOBEK calculates the hydraulic parameters at cross sections using the entire cross section and then interpolates and extrapolates these values at all calculation points. The user can define the number of calculation points.
9.5. TROUBLESHOOTING	
F	
M	No significant differences from other evaluations

Appendix 8. *Team members' comments on specific model capabilities.*

Model	Comments
R	Graphical and tabular tools are available for viewing inflows and outflows to a storage area for calibrating/editing. The user may view separate gate opening or culvert flows into or out of an area while simultaneously viewing an upstream or downstream cross-section to troubleshoot why too much or too little water is at a particular location. You can see at what location and at what point in time water enters and leaves the floodplain by utilizing the animation feature with cross sections, & the xyz plot of the entire river in plan view. It is also helpful to view the Q&H hydrographs at the same time. You can also plot the elevations of the ineffective areas separately for left and right banks on the general profile plot. RAS has a tool that will check to make sure no adjacent ineffective flow areas are overlapping and it will even adjust the stationing of the block with the lower elevation. I like to look at the node table to see what structures are at what locations. If your dataset does not meet the Courant condition you will get a message in the error/warning output that tells you that more cross sections are needed. Another message will let you know if you have divided flow and at what location. Utilizing the cross section animation helps you to see if your ineffective flow areas are operating the way you intended. It also will help you determine where you need to add ineffective flow areas or where you need to block out water until it gets to a certain elevation. Looking at the connections table in the geometry editor would be a good thing to check.
S	SOBEK doesn't provide plots of the hydraulic parameters to evaluate the simulation. There are also no results displayed on cross sections to assist in definition of storage areas versus flow areas.
9.6. TABULAR OUTPUT	
F	
M	Newer module allows the data from the overbank regions to be evaluated separate from the channels, in a manner similar to HEC-RAS.
R	Can create user defined output tables which include breakdowns of overbank/channel/weir flow vs. gate flow/individual gate flows and closing times/velocities of channel vs. lft and rt bank/etc. Tables can break down data variables per cross-section or between storage areas or through inline structures and lateral structures etc. All time series can be copied and pasted into another program if desired. However, there are plenty of viewing tools within the program. Time series can be plotted or copied to the clipboard. They have so many tables of hydraulic parameters to choose from. They have specific tables for bridge hydraulics, cross sections, basically all the structures you can put into the dataset. And at the bottom it will show you the errors. You can also define your own tables and you can view multiple tables at the same time.
S	No special output for floodplain modeling
9.7. GRAPHICAL OUTPUT	
F	
M	See Mike View evaluation in General section.

__Appendix 8.__ Team members' comments on specific model capabilities.

Model	Comments
R	You can see at what location and at what point in time water enters and leaves the floodplain by utilizing the animation feature with cross sections, & the xyz plot of the entire river in plan view. It is also helpful to view the Q&H hydrographs at the same time. You can also plot the elevations of the ineffective areas separately for left and right banks on the general profile plot.
S	No special output for floodplain modeling
9.8 OTHER COMMENTS (not graded)	
F	
M	
R	See following JPEG of storage and inflow/outflow graphs 
S	CONVERSION OF HEC-RAS. Ineffective flow areas aren't converted from HEC-RAS data sets. There is a surface level imported to define the level of the embankments in the cross section but it wasn't clear how the version was selected. It seemed to be the maximum calculated water surface elevation from the HEC-RAS run.

Appendix 9. Highest ranks overall based on team members' evaluations.

TOPIC EVALUATED	MODEL			
	F	M	R	S
1. GENERAL MODEL SETUP AND MANIPULATION				
1.1. EASE OF USE				
1.1. Availability and quality of documentation			√	
1.2. Understandable / user friendly			√	
1.2. MODEL RUN				
1.2.1. Computational methods	√	√	√	√
1.2.2. Model stability			√	
1.2.3. Convergence				
1.2.4. Troubleshooting			√	
1.2.5. Can various be set up within the model for comparison?			√	
1.3. INPUT INFORMATION				
1.3.1. Can it import data from other programs?			√	
1.3.2. Data entry			√	
1.3.3. Cross section edits			√	
1.3.4. Cross section interpolation			√	
1.3.5. Manning's coefficient. Variable roughness (by HG and Q)			√	
1.3.6. Lateral inflow			√	
1.3.7. Boundary conditions			√	
1.4. OUTPUT INFORMATION				
1.4.1. Output table detail			√	
1.4.2. Output detail for individual cross section?			√	
1.4.3. Can output time series be exported?		√	√	√
1.4.4. Graphical output and animation			√	
1.4.5. Can graphical model outputs be extracted for web use?		√		
HIGHEST RANK			√	

Appendix 9. *Highest ranks overall based on team members' evaluations.*

TOPIC EVALUATED	MODEL			
	F	M	R	S
2. MODELING TRIBUTARIES, JUNCTIONS AND SPLIT FLOW				
2.1. DOCUMENTATION			√	
2.2. DATA ENTRY / DATA EDITING			√	
2.3. COMPUTATIONAL METHODS	√	√	√	√
2.4. MODEL STABILITY	√	√	√	√
2.5. TROUBLESHOOTING	√		√	
2.6. TABULAR OUTPUT	√		√	
2.7. GRAPHICAL OUTPUT	√	√	√	
HIGHEST RANK			√	
3. MODELING BRIDGES AND CULVERTS				
3.1. DOCUMENTATION			√	
3.2. DATA ENTRY / DATA EDITING		√	√	
3.3. COMPUTATIONAL METHODS		√	√	
3.4. MODEL STABILITY			√	√
3.5. TROUBLESHOOTING			√	
3.6. TABULAR OUTPUT			√	
3.7. GRAPHICAL OUTPUT			√	
HIGHEST RANK			√	
4. MODELING GATES, WEIRS AND LATERAL STRUCTURES				
4.1 DOCUMENTATION			√	
4.2. DATA ENTRY / DATA EDITING			√	
4.3. COMPUTATIONAL METHODS		√	√	√
4.4. MODEL STABILITY		√	√	√
4.5. TROUBLESHOOTING			√	
4.6. TABULAR OUTPUT			√	
4.7. GRAPHICAL OUTPUT			√	
HIGHEST RANK			√	

Appendix 9. *Highest ranks overall based on team members' evaluations.*

TOPIC EVALUATED	MODEL			
	F	M	R	S
5. LEVEES/ LEVEE BREACH				
5.1. DOCUMENTATION			√	
5.2. DATA ENTRY / DATA EDITING		√	√	
5.3. COMPUTATIONAL METHODS			√	
5.4. MODEL STABILITY		√	√	
5.5. TROUBLESHOOTING			√	
5.6. TABULAR OUTPUT		√	√	
5.7. GRAPHICAL OUTPUT			√	
HIGHEST RANK			√	
6. DAMS/ DAMBREAK ANALYSIS				
6.1. DOCUMENTATION			√	
6.2. DATA ENTRY / DATA EDITING			√	
6.3. COMPUTATIONAL METHODS	√	√	√	
6.4. MODEL STABILITY		√	√	
6.5. TROUBLESHOOTING			√	
6.6. TABULAR OUTPUT			√	
6.7. GRAPHICAL OUTPUT			√	
HIGHEST RANK			√	
7. TIDES				
7.1. DOCUMENTATION		√		√
7.2. DATA ENTRY / DATA EDITING				
7.3. COMPUTATIONAL METHODS	√	√	√	√
7.4. MODEL STABILITY	√	√	√	√
7.5. TROUBLESHOOTING	√			
7.6. TABULAR OUTPUT	√		√	
7.7. GRAPHICAL OUTPUT	√		√	
HIGHEST RANK	√			

Appendix 9. *Highest ranks overall based on team members' evaluations.*

TOPIC EVALUATED	MODEL			
	F	**M**	**R**	**S**
8. ICE JAM				
8.1. DOCUMENTATION			√	
8.2. DATA ENTRY / DATA EDITING			√	
8.3. COMPUTATIONAL METHODS			√	
8.4. MODEL STABILITY			√	
8.5. TROUBLESHOOTING			√	
8.6. TABULAR OUTPUT			√	
8.7. GRAPHICAL OUTPUT			√	
HIGHEST RANK			√	
9. FLOODPLAIN MODELING				
9.1. DOCUMENTATION			√	
9.2. DATA ENTRY / DATA EDITING			√	
9.3. COMPUTATIONAL METHODS		√	√	√
9.4. MODEL STABILITY		√	√	
9.5. TROUBLESHOOTING			√	
9.6. TABULAR OUTPUT			√	
9.7. GRAPHICAL OUTPUT		√	√	
HIGHEST RANK			√	

Model: F – *FLDWAV*, M – *MIKE 11*, R – *RAS*, S – *SOBEK*