Quality Assurance Reviews of Hydraulic Models Developed for the Central Valley Floodplain Evaluation and Delineation Program

Techniques Applied and Lessons Learned

Seth Ahrens, P.E., CFM
Selena Forman, Ph.D., P.E.
ASFPM Conference – June 3, 2015
Outline

• Overview of the California Department of Water Resources’ (DWR) Central Valley Floodplain Evaluation and Delineation (CVFED) program
• Development of the modeling and quality management criteria
• The quality assurance (QA) review process
• Custom tools developed by Atkins to facilitate the QA reviews
• Lessons learned
A Little Bit About Me

• 2011-2015 – Sacramento, CA
  • Part of Atkins’ team supporting DWR
    – QA reviewer of CVFED hydraulic modeling (mostly FLO-2D)
    – Project manager for California Levee Database development
    – Project manager for population of DWR’s Library of Models
    – Central role in the development of 6,700 miles of Awareness Floodplain Mapping

• 2015-Present – Oakland, CA
  • STARR II Region Service Center lead for FEMA Region IX
Overview of the CVFED Program

- Initiated by DWR in 2008
- Develop foundational datasets, models, and tools associated with the State Plan of Flood Control to support State’s flood management programs and projects
- Improve quality and accuracy of flood hazard data to help communities comply with recent legislative mandates in CA
- Develop new hydraulic models acceptable to FEMA and USACE
- Provide information to support future planning and project design
Overview of the CVFED Program

• Hydraulic evaluation of the Sacramento River system and the San Joaquin River system in the Central Valley

• Major products:
  • 9,000 mi² of aerial photography
  • 7,800 mi² of topographic data (LiDAR)
  • 1,650 miles of 1-D modeling (HEC-RAS)
  • 5,950 mi² of 2-D modeling (mostly FLO-2D, some TUFLOW)
  • Field survey and bathymetric survey (5,500 cross sections total)
Overview of the CVFED Program

Hydraulic Model Development

DWR

ATKINS
Program Mgmt. Quality Assurance

USACE
Quality Assurance

CH2M
North Sac River Basin

Wood Rodgers
South Sac River Basin

HDR
North SJ River Basin

RBF
South SJ River Basin
Thinking About Quality Management

- CVFED hydraulic models are large and complex
- Many models needed to be created and reviewed in a short time frame
- Desirable to standardize model development across AEC teams
- Desirable to have an organized review process
- Tools can be useful for flagging potential problem areas that may require in-depth review
- These tools enhance review efficiency and quality
- Today’s talk will focus on FLO-2D
Development of the Quality Management Criteria

• Hydrology and Hydraulics Coordination Work Group (HHCWG) was created early in process
• Standardized approaches and techniques to be applied by the AEC modeling teams
• Established review processes to be followed by AEC teams (QC), Atkins (QA), and USACE (QA)
HHCG FLO-2D Guideline Documents

- ARF/WRF
- Infiltration
- Model Documentation
- Depth Variable Roughness
- Initial $n$ Values
- Overland Structures
- Embankments
- Limiting Froude Number
- Overlap Standards
The Quality Assurance Review Process

- Organized using CVFED hydraulic QA review spreadsheets
- Unique review spreadsheet for each model type
  - HEC-RAS
  - FLO-2D
  - TUFLOW
- FLO-2D: 78 questions grouped into 9 topics
- Other model types similar
The Quality Assurance Review Process

The FLO-2D QA review spreadsheet included 78 questions grouped into 9 topics

<table>
<thead>
<tr>
<th>Model Grid</th>
<th>Channel Flow</th>
<th>Street Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boundary Conditions</td>
<td>Levees and Levee-Like Features</td>
<td>Area Modification/Flow Obstruction</td>
</tr>
<tr>
<td>Overland Flow</td>
<td>Hydraulic Structures</td>
<td>Calculations and Results</td>
</tr>
<tr>
<td>Manning’s $n$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Review Element</td>
<td>FLO-2D Model Area:</td>
<td>Sample Model Name</td>
</tr>
<tr>
<td>----------------</td>
<td>---------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Does the procedure for interpolating grid elevations account for features that may bias the computation of the average grid elevation?¹</td>
<td>Internal Quality Control</td>
<td>Looks like elevated highway in vicinity of cell 11,548 was considered in cell elevation calculations when it should not have been included. Please review grid elevations this area.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

² Independent Reviewer Quality Control

| Comment: | No comment. | AR | Firm | 6/15/2014 |
| Response: |           |    |      |          |
| Backcheck: |          |    |      |          |

Quality Assurance Reviewer - Atkins

| Comment: | No comment. | SA | Atkins | 6/21/2014 |
| Response: |           |    |        |          |
| Backcheck: |          |    |        |          |

Quality Assurance Reviewer - USACE

| Comment: | No comment. | JW | USACE | 6/21/2014 |
| Response: |           |    |       |          |
| Backcheck: |          |    |       |          |
1-Dimensional Unsteady HEC-RAS QA Review Tools

Developed tools to read the geometry file and model output to check the following and flag areas for more detailed review:

- Confirm stream centerline length corresponded to cross section stationing
- Compare lateral weir and storage area connection elevations with topography
- Check that user-specified lateral weir lengths corresponded to GIS layer
- Check storage area volume-elevation curves against topography
- Check that storage area minimum elevations were below the elevations of connected lateral structures
- Check lateral structure connectivity to storage areas
- Check storage area connectivity
Other HEC-RAS Review Approaches

• Review low-flow and high-flow water surface profiles for critical depth solutions and jumps/discontinuities
• Review energy grade line profile for any anomalies
• Review ground profile for large changes and appropriate modeling approach
• Check that bank station widths and elevations varied gradually along a reach
• Check that the active top width and velocity varied gradually along the reach
• Check that the flow is stabilized at the end of the warm-up period
• Review output messages for warnings such as:
  – Computed water surface elevations below storage area invert
  – Minimum error solutions
  – Interpolated values above computed curves
  – Unstable solutions
FLO-2D QA Review Tools

- Create output shapefiles and rasters
- Check elevations
- Check n-values
- Check embankment elevations
- Embankment hunter
- Check channels
Create Shapefiles and Rasters Representing FLO-2D Output

**FLO-2D Output Text Files**

Output shapefiles:
- Grid cell layout
- Flooding extents
- Hydraulic conveyance structures
- Levee-like structures
- NOFLOCs
- Width-area reduction factors

**Shapefiles and Rasters**

Output rasters:
- ARF assignments
- Floodplain depths and elevations
- Floodplain velocities
- Peak discharges
- Ground elevations
- $n$-value assignments
Output Shapefile Example

Legend

- **Hydraulic Structure**
- **Levee**
- **WRF**
- **Flood Extents**
- **Grid Layout**
### Attribute Table of Levee Output Shapefile

<table>
<thead>
<tr>
<th>FID</th>
<th>Shape</th>
<th>Cell</th>
<th>Elev_levee</th>
<th>Direction</th>
<th>Peakcfs</th>
<th>Overtop</th>
<th>Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>4547</td>
<td>Polygon</td>
<td>24750</td>
<td>252.7</td>
<td>NE</td>
<td>6353.2</td>
<td>1</td>
<td>2.7</td>
</tr>
<tr>
<td>4896</td>
<td>Polygon</td>
<td>25485</td>
<td>232.85</td>
<td>NE</td>
<td>3695.03</td>
<td>1</td>
<td>2.62</td>
</tr>
<tr>
<td>1340</td>
<td>Polygon</td>
<td>49288</td>
<td>215.61</td>
<td>NE</td>
<td>2878.81</td>
<td>1</td>
<td>2.07</td>
</tr>
<tr>
<td>4545</td>
<td>Polygon</td>
<td>24750</td>
<td>255.67</td>
<td>N</td>
<td>2679.71</td>
<td>1</td>
<td>5.67</td>
</tr>
<tr>
<td>1239</td>
<td>Polygon</td>
<td>47379</td>
<td>237.49</td>
<td>NE</td>
<td>2522.77</td>
<td>1</td>
<td>1.4</td>
</tr>
<tr>
<td>1246</td>
<td>Polygon</td>
<td>47583</td>
<td>215.89</td>
<td>SE</td>
<td>2361.31</td>
<td>1</td>
<td>2.51</td>
</tr>
<tr>
<td>2960</td>
<td>Polygon</td>
<td>17679</td>
<td>282.67</td>
<td>NE</td>
<td>2001.9</td>
<td>1</td>
<td>2.27</td>
</tr>
<tr>
<td>2110</td>
<td>Polygon</td>
<td>13232</td>
<td>296</td>
<td>SE</td>
<td>1977.27</td>
<td>1</td>
<td>8.14</td>
</tr>
<tr>
<td>5638</td>
<td>Polygon</td>
<td>27532</td>
<td>248.62</td>
<td>NE</td>
<td>1968.98</td>
<td>1</td>
<td>3.77</td>
</tr>
<tr>
<td>2964</td>
<td>Polygon</td>
<td>17680</td>
<td>282.86</td>
<td>NE</td>
<td>1949.98</td>
<td>1</td>
<td>2.21</td>
</tr>
</tbody>
</table>
Output Raster Example

Legend

ARF Raster Value

- High : 0.9
- Low : 0

FLO-2D Model Domain
Tools for Checking Cell Elevations and Manning’s $n$-value Assignments

- These tools computed the ground elevation and the $n$-value assignment for each cell and then compared them to what was in the model.
- Both tools worked in a similar fashion in that they intersected the grid layout with the topographic data or the $n$-value shapefile.
Checking $n$-value Assignments

Legend

- $n$-value Polygon
### Checking $n$-value Assignments

| FID | Shape  | Cellnum | Flo2d
val | Calcnval | Delta | Demcells | AbsDelta |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>Polygon</td>
<td>16</td>
<td>0.12</td>
<td>0.12</td>
<td>0</td>
<td>1600</td>
<td>0</td>
</tr>
<tr>
<td>16</td>
<td>Polygon</td>
<td>17</td>
<td>0.12</td>
<td>0.119</td>
<td>0.001</td>
<td>1600</td>
<td>0.001</td>
</tr>
<tr>
<td>17</td>
<td>Polygon</td>
<td>18</td>
<td>0.1</td>
<td>0.1</td>
<td>0</td>
<td>1600</td>
<td>0</td>
</tr>
<tr>
<td>18</td>
<td>Polygon</td>
<td>19</td>
<td>0.1</td>
<td>0.1</td>
<td>0</td>
<td>1600</td>
<td>0</td>
</tr>
<tr>
<td>19</td>
<td>Polygon</td>
<td>20</td>
<td>0.1</td>
<td>0.1</td>
<td>0</td>
<td>1600</td>
<td>0</td>
</tr>
<tr>
<td>20</td>
<td>Polygon</td>
<td>21</td>
<td>0.055</td>
<td>0.054</td>
<td>0.001</td>
<td>1600</td>
<td>0.001</td>
</tr>
<tr>
<td>21</td>
<td>Polygon</td>
<td>22</td>
<td>0.04</td>
<td>0.04</td>
<td>0</td>
<td>1600</td>
<td>0</td>
</tr>
<tr>
<td>22</td>
<td>Polygon</td>
<td>23</td>
<td>0.04</td>
<td>0.04</td>
<td>0</td>
<td>1600</td>
<td>0</td>
</tr>
<tr>
<td>23</td>
<td>Polygon</td>
<td>24</td>
<td>0.052</td>
<td>0.054</td>
<td>-0.002</td>
<td>1600</td>
<td>0.002</td>
</tr>
<tr>
<td>24</td>
<td>Polygon</td>
<td>25</td>
<td>0.12</td>
<td>0.12</td>
<td>0</td>
<td>1600</td>
<td>0</td>
</tr>
</tbody>
</table>
Embankment Hunter

• Modeling guidelines stated that all embankments with heights greater than two to three feet were to be included in the modeling.
• This tool looked for steep slopes in the terrain and estimated embankment heights near these slopes.
• Useful for confirming that all “tall” embankments were modeled.
Tool for Checking Channel Modeling

- Channels can be tricky in FLO-2D
- Channel tool created shapefiles of the channel features
- Channel tool created hydrograph for each channel cell (PDF)
Channel Shapefiles

Legend

- **Centerline**
- **Channel XS**
- **Channel Cells**
## Channel Cell Attribute Table

<table>
<thead>
<tr>
<th>Xtype</th>
<th>Xsid</th>
<th>Xlen</th>
<th>Nvalue</th>
<th>Wse</th>
<th>Velocity</th>
<th>Depthchan</th>
<th>Bedeleve</th>
<th>Area</th>
<th>Topwidth</th>
<th>Wetperim</th>
<th>Maxq</th>
<th>Maxqtime</th>
<th>Maxstage</th>
<th>Maxstgtame</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>260</td>
<td>370.03</td>
<td>0.045</td>
<td>203.5</td>
<td>0.63</td>
<td>5.43</td>
<td>198.07</td>
<td>83.85</td>
<td>55.16</td>
<td>55.63</td>
<td>105.71</td>
<td>132.24</td>
<td>203.5</td>
<td>144.9</td>
</tr>
<tr>
<td>N</td>
<td>261</td>
<td>549.38</td>
<td>0.045</td>
<td>203.47</td>
<td>0.79</td>
<td>5.53</td>
<td>197.94</td>
<td>82.66</td>
<td>51.21</td>
<td>51.7</td>
<td>169.26</td>
<td>132.24</td>
<td>203.47</td>
<td>143.51</td>
</tr>
<tr>
<td>N</td>
<td>262</td>
<td>345.01</td>
<td>0.045</td>
<td>203.49</td>
<td>0.98</td>
<td>4.78</td>
<td>198.71</td>
<td>20.03</td>
<td>30.1</td>
<td>30.24</td>
<td>132.47</td>
<td>147.9</td>
<td>203.49</td>
<td>143.59</td>
</tr>
<tr>
<td>N</td>
<td>263</td>
<td>502.33</td>
<td>0.036</td>
<td>203.48</td>
<td>4.81</td>
<td>5.33</td>
<td>198.15</td>
<td>76.47</td>
<td>58.01</td>
<td>58.68</td>
<td>201.89</td>
<td>154.75</td>
<td>203.48</td>
<td>144.93</td>
</tr>
<tr>
<td>N</td>
<td>264</td>
<td>363.86</td>
<td>0.046</td>
<td>203.25</td>
<td>0.43</td>
<td>6.01</td>
<td>197.24</td>
<td>127.17</td>
<td>53.36</td>
<td>54.31</td>
<td>158.5</td>
<td>132.21</td>
<td>203.25</td>
<td>144.89</td>
</tr>
<tr>
<td>N</td>
<td>265</td>
<td>396.48</td>
<td>0.06</td>
<td>203.23</td>
<td>1.24</td>
<td>6.37</td>
<td>196.86</td>
<td>105.04</td>
<td>303.2</td>
<td>304.84</td>
<td>207.77</td>
<td>144.95</td>
<td>203.23</td>
<td>144.58</td>
</tr>
<tr>
<td>N</td>
<td>266</td>
<td>402.12</td>
<td>0.035</td>
<td>202.99</td>
<td>0.53</td>
<td>6.86</td>
<td>196.13</td>
<td>839.41</td>
<td>269.48</td>
<td>271.03</td>
<td>657.42</td>
<td>127.46</td>
<td>202.99</td>
<td>147.46</td>
</tr>
<tr>
<td>N</td>
<td>267</td>
<td>394.71</td>
<td>0.035</td>
<td>202.99</td>
<td>0.5</td>
<td>6.88</td>
<td>196.11</td>
<td>802.8</td>
<td>285.4</td>
<td>286.07</td>
<td>738.37</td>
<td>131.58</td>
<td>202.99</td>
<td>147.44</td>
</tr>
<tr>
<td>N</td>
<td>268</td>
<td>464.66</td>
<td>0.035</td>
<td>202.98</td>
<td>0.46</td>
<td>6.91</td>
<td>196.07</td>
<td>573.13</td>
<td>262.62</td>
<td>263.09</td>
<td>634.38</td>
<td>131.59</td>
<td>202.98</td>
<td>147.44</td>
</tr>
<tr>
<td>N</td>
<td>269</td>
<td>568.96</td>
<td>0.045</td>
<td>202.98</td>
<td>1.01</td>
<td>7.06</td>
<td>195.92</td>
<td>627.29</td>
<td>300.14</td>
<td>300.66</td>
<td>782.65</td>
<td>120.03</td>
<td>202.98</td>
<td>147.46</td>
</tr>
</tbody>
</table>
Channel Hydrograph

Channel Node: 32971  XSEC: 2  Max Q: 1111.24 cfs  Max Q Time: 45.24 hrs
Sample Applications of FLO-2D QA Review Tools

- Point out high flow rates over levees
- Confirm levee elevations at levee junctions
- Color-code levees to show which were overtopped
- Point out unstable hydrographs
- Confirm channel alignment, cross section layout, NOFLOCs
- Confirm model captured embankments
- Confirm model captured hydraulic structures
- Confirm ground elevation and n-value assignments
- Confirm ARF/WRF assignments
Lessons Learned

• Models of this size are extremely complex
• Taking time up front to plan will pay off later
• Automated processes are not foolproof
• Additional layers of review provide benefit
• Custom tools can enhance review efficiency and quality
Thank you

Feel free to contact me with additional questions:
seth.ahrens@atkinsglobal.com
(415) 671-7185

If you’d like to find out more visit:
www.atkinsglobal.com

© Atkins Limited except where stated otherwise.