A Report on NWS River Hydraulic Modeling for Both Inland and Coastal Applications

2/24/2012

• Transition to HEC-RAS: Model Development and Implementation
  – Goals
  – Accomplishments
  – Lessons learned

• Modeling of River-Estuary-Ocean (REO) Interactions to Enhance Operational River Forecasting – Chesapeake Bay Estuary – Phase 1
  – Goals
  – Accomplishments
  – Lessons learned

• Towards dynamic flood forecast mapping – leveraging external resources
Transition to HEC-RAS: Model Development and Implementation

HOSIP Project: P-2010-004

Alfonso Mejia, Seann Reed, James Halgren

In coordination with:
RFCs
HSEB: Kuang-shen Hsu, Varalakshmi Rajaram, Freddy Camacho, Chris Brunner, Russ Erb
Deltares, HEC, RMA
**Goal:** Support **model development and implementation** to fully transition the National Weather Service river hydraulic **models to HEC-RAS.**

### Unsteady HEC-RAS Models: Implemented or Planned

<table>
<thead>
<tr>
<th>No</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Umpqua R., OR</td>
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<td>Coquille R., OR</td>
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<td>Columbia R., WA</td>
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<td>4</td>
<td>Skagit R., WA</td>
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<tr>
<td>5</td>
<td>Missouri R: Nebraska City to St. Charles</td>
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<tr>
<td>6</td>
<td>Red River of the North</td>
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<tr>
<td>7</td>
<td>Mississippi - Anoka to Camanche</td>
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<td>8</td>
<td>Mississippi - Guttenberg to Saverton (L&amp;D 22)</td>
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<tr>
<td>9</td>
<td>Mississippi-Illinois - Saverton to Thebes</td>
</tr>
<tr>
<td>10</td>
<td>Grand R, MI</td>
</tr>
<tr>
<td>11</td>
<td>Mississippi: Chester_to_Helena (a.k.a the &quot;Upper&quot; Model)</td>
</tr>
<tr>
<td>12</td>
<td>Mississippi: Memphis to Vicksburg (a.k.a the &quot;Middle&quot; model)</td>
</tr>
<tr>
<td>13</td>
<td>Mississippi - Vicksburg to Gulf/Head of Passes(a.k.a. the &quot;Lower&quot; model)</td>
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<tr>
<td>14</td>
<td>Pascagoula, MS</td>
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<td>15</td>
<td>Atchafalaya, R</td>
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<td>Pearl, R.</td>
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<tr>
<td>17</td>
<td>Vermilion R</td>
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<td>18</td>
<td>Fourche LaFave River</td>
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<td>19</td>
<td>Colorado R., TX</td>
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<td>20</td>
<td>Houston Rivers, TX</td>
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<tr>
<td>21</td>
<td>Ohio River Community Model</td>
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<td>22</td>
<td>Hudson R., NY</td>
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<td>23</td>
<td>Connecticut R.</td>
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<tr>
<td>24</td>
<td>Kennebec R., ME</td>
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<td>25</td>
<td>Lake Champlain</td>
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<tr>
<td>26</td>
<td>Potomac R.</td>
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<tr>
<td>27</td>
<td>Susquehanna/Binghamton - Research</td>
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<td>28</td>
<td>Tar R, NC.</td>
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<td>Tar R, NC with tributaries - Research</td>
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<td>30</td>
<td>St.John’s R, FL</td>
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<td>31</td>
<td>Waccamaw R., SC</td>
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<tr>
<td>32</td>
<td>Kenai River, AK</td>
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</tbody>
</table>

**In NWSRFS (19):**

- 1-32 Umpqua R., OR, Coquille R., OR, Columbia R., WA, Skagit R., WA, Missouri R: Nebraska City to St. Charles, Red River of the North, Mississippi: Anoka to Camanche, Mississippi - Guttenberg to Saverton (L&D 22), Mississippi-Illinois - Saverton to Thebes, Grand R, MI, Mississippi: Chester_to_Helena (a.k.a the "Upper" Model), Mississippi: Memphis to Vicksburg (a.k.a the "Middle" model), Mississippi - Vicksburg to Gulf/Head of Passes(a.k.a. the "Lower" model), Pascagoula, MS, Atchafalaya, R, Pearl, R, Vermilion R, Fourche LaFave River, Colorado R., TX, Houston Rivers, TX, Ohio River Community Model, Hudson R., NY, Connecticut R.

**New with CHPS (13):**

- 1-32 Umpqua R., OR, Coquille R., OR, Columbia R., WA, Skagit R., WA, Missouri R: Nebraska City to St. Charles, Red River of the North, Mississippi: Anoka to Camanche, Mississippi - Guttenberg to Saverton (L&D 22), Mississippi-Illinois - Saverton to Thebes, Grand R, MI, Mississippi: Chester_to_Helena (a.k.a the "Upper" Model), Mississippi: Memphis to Vicksburg (a.k.a the "Middle" model), Mississippi - Vicksburg to Gulf/Head of Passes(a.k.a. the "Lower" model), Pascagoula, MS, Atchafalaya, R, Pearl, R, Vermilion R, Fourche LaFave River, Colorado R., TX, Houston Rivers, TX, Ohio River Community Model, Hudson R., NY, Connecticut R.
Accomplishments

• Supported final FLDWAV/DWOPER conversions
  – NCRFC
  – LMRFC

• Coordinated with OCWWS on operational support
  – Learn CHPS
  – Diagnose problems and document solutions

• Assisted in transitioning Red River Mapping Service to CHPS

• Developed recommendations for segmenting HEC-RAS models for LMRFC

• Provided documentation and contributed to training
  – “How to Add a HEC-RAS Model to CHPS”
  – LMRFC-hosted Advanced HEC-RAS Training
Support Activities for NCRFC

• Upper and Middle
  – Converted FLDWAV to RAS
  – Merged in USACE cross-sections where appropriate
  – Calibration

• Lower - MISILO
  – Advice and assistance

• Computed summary statistics to help identify areas where improvements are needed

• Developed example CHPS configurations

Forecast Points Associated with the NCRFC Mississippi Models
Support Activities for LMRFC

• Upper
  – Combined FLDWAV and lower part of OHRFC Community model
  – Calibration
• Middle
  – Selectively merged FLDWAV and USACE cross-sections
  – Calibration
• Lower
  – Selectively merged FLDWAV and USACE cross-sections
  – Calibration shows poor results on lower end; recommend pursuing more accurate cross-sections
• Examined effects of boundary conditions and recommended merging three models into one.

Chester
Upper = 400 mi

Memphis
Middle = 298 mi
71.4 mi overlap

Helena

Vicksburg
Lower = 459 mi

Head of Passes, Gulf of Mexico
Analysis of Boundary Conditions

Rating Curve for Vicksburg

Estimated Simulation Error (ft) Due to the Use of a Rating Curve Downstream Boundary at Two Times

Should combine models into one or provide more overlap

Chester
Upper = 400 mi

Memphis
Middle = 298 mi

Helena

Vicksburg
Lower = 459 mi

Head of Passes, Gulf of Mexico

River Mile

Sim w/ observed boundary - sim with rating curve boundary (ft)

Simulated Rating

Simulated Rating

Fitted Rating Curve

River Mile

May 26, 2011 0600

May 13 2011 0000

May 26, 2011 0600

May 13 2011 0000
Ensure CHPS-based Results Can Be Used by Red River Flood Forecast Display Tool (FFDT)

- Identified requirements to reproduce existing procedures
- Deltares/RMA enhanced Adapter handling of longitudinal profiles
- HSEB developed post-processing programs to produce exact file formats required by existing mapping scripts

http://ffdt.rrbdin.org/
A repeated cycle:
• Implemented new HEC-RAS model (RFC)
• Found new problem (RFC)
• Reproduced problem (HSMB)
• Fixed problem (HSMB, HSEB, Deltas or RMA)
• Updated test procedures and documentation (HSMB/HSEB)
• Delivered updated Adapter

Adapter and executables evolution:
Version 1.0.1 March 2011
• Handles observed time series at internal boundaries
Version 1.0.2: June 2011
• Handles missing data for observed time series at internal boundaries.
• Improves treatment of case for locationIDs
• Correctly uses inflow multipliers specified in the HEC-RAS Unsteady Flow File
• Correctly feeds a lateral inflow time series directly to a storage area
Version 1.0.4: Sept. 2011
• Output longitudinal profile data from HEC-RAS and ingest into CHPS
• Fixed “hecras_Hec_zgetDssVersion” error
• Fixed problem with Linux executables - one of NCRFC HEC-RAS models would not run correctly on Linux
Lessons Learned – Building Models

Using data from existing models (e.g. FEMA, USACE)

– Advantages
  • Relatively easy to acquire
  • More accurate cross-sections compared to FLDWAV can make calibration easier

– Requires sound engineering judgment
  • Each implementation is slightly different
  • Most existing models are built for steady-state
  • Steady to unsteady model conversion -- must remove sources of instability
  • Existing models often do not cover the desired domain – must extend or clip models
  • FEMA, USACE models often lack metadata and geo-referencing
Lessons Learned -- Data Used to Build and Calibrate Hydraulic Models

- **Data Used to Build and Calibrate Hydraulic Models**
  - **Topography**
  - **Stage data**
  - **Flow data**
  - **Existing models**
  - **Datum information**
  - **Data on structures**
  - **Bathymetry**
  - **High water marks**

**Difficulty to use**
- High
- Low

**Difficulty to obtain**
- High
- Low

**Reasons for difficult use**
- Poor documentation
- Complexity to use
- Lack of standard/digital format

**Reasons difficult to obtain**
- Not searchable on web
- Not downloadable from web
- Cost
- Not in digital format
- Doesn’t exist
Lessons Learned - CHPS

- Positive collaboration among HSMB, HSEB, RFCs, OCWWS, Deltares, HEC, RMA
- Inefficiencies
  - Multiple partners in Adapter development
  - Lack of CHPS training for HSMB
- Difficult to build test cases for all HEC-RAS model functions up front
Modeling of River-Estuary-Ocean (REO) Interactions to Enhance Operational River Forecasting – Chesapeake Bay Estuary – Phase 1

HOSIP Project: P-2008-009

Hassan Mashriqui, James Halgren, Seann Reed

in coordination with

MARFC, LMRFC, NWS MDL, NOS CSDL, and Deltares
REO Phase 1 Goal

Improve RFC total water level prediction (freshwater + tide + surge + waves) in River-Ocean-Estuary transition zone using operational or nearly operational models.
## Accomplishments and Schedule

<table>
<thead>
<tr>
<th>ID</th>
<th>Task Name</th>
<th>Qtr 1, 2010</th>
<th>Qtr 2, 2010</th>
<th>Qtr 3, 2010</th>
<th>Qtr 1, 2011</th>
<th>Qtr 2, 2011</th>
<th>Qtr 3, 2011</th>
<th>Qtr 1, 2012</th>
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<tr>
<td>1</td>
<td>Gate 2 Meeting</td>
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<td>11/25</td>
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<td>2</td>
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<td>5</td>
<td>Milestone: Joint Federal Interagency Conference</td>
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<td><strong>Sobek Modeling</strong></td>
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<td>ADCIRC Modeling</td>
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<td>9</td>
<td>Write Journal Paper</td>
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<td>Milestone: Submit Journal Paper</td>
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<td>11</td>
<td>Deliver guidance to RFCs for coastal HEC-RAS implementations</td>
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<td>12</td>
<td>Develop sample CHPS configuration and documentation for available coastal boundary data</td>
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<td>13</td>
<td>Real-time testing of Potomac configuration for Hurricane Irene</td>
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<td>14</td>
<td>Assist MARFC with final configuration adjustments</td>
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<td>Milestone: Lecture on &quot;Coastal Boundary Conditions&quot; for HEC-RAS course</td>
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<td>17</td>
<td>Milestone: Provide example CHPS template for configuring coastal data</td>
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<td>18</td>
<td>Gate 3 Meeting - TBD</td>
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</tbody>
</table>
Phase 1: Improvements Using Existing Operational Models

**Existing Model/System Name** | **Lead** | **Main Purpose**
--- | --- | ---
HEC-RAS | NWS RFCs | Forecast river stages
ET Surge - Extra Tropical Surge (SLOSH-based) | NWS MDL | Continuous water level prediction. Covers Gulf, East, and West coasts, including **Alaska**.
ESTOFS – Extratropical Surge and Tide Operational Forecast System (ADCIRC-based) | NWS NCEP and NOS CSDL | Continuous water level prediction for East and Gulf coasts. Higher resolution than ET Surge.
NOCMP - National Operational Coastal Modeling Program, e.g. CBOFS | NOS CSDL and COOPS | Tide and current forecasts for navigational community.
We used overlapping domains and multiple models for validation (including HEC-RAS, Sobek, and ADCIRC).

We’ve also started examining the benefits of dynamic 1D-2D coupling (not part of Phase 1).
• A loosely coupled 1D river hydraulic model for the Potomac is an effective forecast tool that improves upon existing RFC techniques
• HEC-RAS simulations for Potomac
  – 0.03 m average amplitude error in predicted tidal constituents
  – < 0.4 m peak error for historic freshwater floods
  – 0.7 m error for peak surge during Hurricane Isabel
• Higher error for Hurricane Isabel is due to lack of a wind forcing function in HEC-RAS
• SOBEK 1D and ADCIRC 2D implementations with wind forcing can match Isabel peaks if a wind reduction factor is calibrated
Application of Wind Forcing in 1D SOBEK Model for Hurricane Isabel

<table>
<thead>
<tr>
<th>No</th>
<th>Model</th>
<th>Downstream Boundary Condition</th>
<th>Wind forcing</th>
<th>Wind forcing Description</th>
<th>Peak surge error at Washington D.C. Waterfront [meters]</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>HEC-RAS</td>
<td>COOPS obs stage</td>
<td>No wind</td>
<td></td>
<td>-0.7</td>
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<td>2</td>
<td>HEC-RAS</td>
<td>Flow from CBOFS2</td>
<td>No wind</td>
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<td>-0.4</td>
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<td>3</td>
<td>SOBEK</td>
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<td>SOBEK</td>
<td>COOPS obs stage</td>
<td>Obs COOPS wind at Lewisetta</td>
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<td>5</td>
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<td>COOPS obs stage</td>
<td>Obs COOPS*0.75 wind at Lewisetta</td>
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<td>0.08</td>
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<td>6</td>
<td>SOBEK</td>
<td>WL from ADCIRC at Lewisetta</td>
<td>Wind from ADCIRC at Lewisetta</td>
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<td>-0.2</td>
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<td>7</td>
<td>ADCIRC</td>
<td>Ocean tide from ADCIRC database</td>
<td>Holland wind model</td>
<td></td>
<td>0.008</td>
</tr>
</tbody>
</table>

Use of raw wind data without calibration does not improve accuracy. However, calibrated Sobek is close to calibrated ADCIRC.

Application of ADCIRC boundary conditions (WL and wind forcing to Sobek) yield similar results but not as accurate as calibrated models. Differences include drag coefficients, wind reduction factors, modeled vs. observed wind. Need to eliminate differences for coupled implementations.
Conclusions (Cont.)

- For coupled REO models, common wind forcing data (observed and forecast) and drag coefficients should be used for riverine and coastal models.
- NWS RFCs implementing HEC-RAS models along the coast would benefit from adding a wind forcing function to HEC-RAS.

15 existing or planned coastal HEC-RAS models would likely benefit... with more to come.
Operational Forecasting – HEC-RAS in CHPS

Important Considerations
- Multiple data sources for boundary conditions
- Forecast/observed data locations relative to model nodes
- Vertical datum consistency
- Data time scales and time zones

- Includes a data processing script co-developed by LMRFC and OHD Hydraulics to access ET-surge data.
- Includes documentation on the available tide/surge products.
Users Want Flexibility to Select Different Downstream Data Sources: CHPS Allows This

Radio buttons allow selection of downstream boundary data source via CHPS modifier.
Data Available at HEC-RAS Downstream Boundary Varies from River to River – Affects Accuracy

No observed data at the river mouth. Gap to ESTOFS grid but not ETSurge grid. CI-Flow model could solve the latter problem but not the former.

No observed data anywhere near the river mouth and gap to both ESTOFS and ETSurge grids.
Data Available at HEC-RAS Downstream Boundary Varies from River to River – Affects Accuracy

No problem for Hudson R. Data from two models and observed data available.

More challenging for Conn. R where model data exist at the mouth but no observations.
Two Projects: Joint Achievements and Key Messages

- **NOAA has a modernized REO capability**
- RFCs have developed in-house expertise on HEC-RAS: **32 models in different phases of development and implementation**
- The OHD Hydraulics Group has developed sufficient expertise to support RFC HEC-RAS modeling and CHPS implementation
- The OHD Hydraulics Group has developed in-house expertise in more complex models such as SOBEK, MikeFlood, ADCIRC which will help guide future development. First use of this expertise: **How to improve forecasts strongly affected by wind?**
- **Successful collaborations**
  - LMRFC, with OHD and OCWWS assistance, hosted essential HEC-RAS training
  - Working with NWS-MDL and NOS-CSDL, OHD and RFCs have developed CHPS configurations that loosely couple HEC-RAS models with the latest operational estuary-ocean models
  - Successful collaboration with HEC, Deltares, RMA, HSEB, RFCs, and OCWWS HSD has yielded a robust HEC-RAS Adapter.
What’s next for hydraulic modeling R&D? (proposed)

- Adapter performance enhancements for ensemble forecasting
- Wind into HEC-RAS: high reward, low cost
- Dynamic flood forecast mapping using existing operational hydraulic modeling techniques
  - Including maps derived from river-estuary-ocean model output
  - Efficiently designed mapping algorithms for use with ensemble forecasts
- Expanded dynamic mapping for ungauged locations, requiring...
  - High performance computing
  - Advanced techniques for modeling, model building and parameterization
  - Advanced integration of distributed hydrologic, riverine hydraulic, and estuary-ocean models
  - Quantification and reduction of uncertainty
Towards Dynamic Flood Forecast Mapping – Leveraged Resources

NRC Post-Doctoral Research
Alfonso Mejia

Coupled distributed hydrologic and hydraulic models.


Predicted hydraulic geometry with no locally observed cross-section data.


Effective of hydrograph properties on the diffusive wave contribution to St. Venant equations.

Use of dynamic modeling to expand the domain of flood forecast maps

Current static map libraries: Tar River, NC

Dynamic HEC-RAS model: between forecast points

Research HEC-RAS model: ungauged tributaries

Examining connection scenarios from a distributed hydrologic models to a hydraulic model
Binghamton, NY, Area Dynamic Mapping Study:

- Dynamic tributary
- Multiple forecast points
- Recent major events: 2006, 2011
- Testing Flood Visualization Software – LMRFC, Mississippi State
- Testing Quasi-2D Flood Plain Mapping Algorithm – Kansas Biological Survey
- Built unsteady HEC-RAS with steady-state model from Dewberry
- LIDAR data from Broome County, NY
- Levee data from USACE Baltimore
- Observed inundation polygons, flood videos and still photos for verification
Flood Depth Grid estimate for September 2011 flood event (FloodViz)

This estimate was developed by NWS using the Mississippi State University FloodViz software. This depiction was geo-rectified from a screenshot graphic that was provided by NWS. We do not know the depth values represented by the depicted color gradient.
Flood Depth Grid estimate for September 2011 flood event (FLDPLN SLIE)

This estimate was developed for NWS by the Kansas Biological Survey at the University of Kansas using NLD-conditioned DEM data. The applied WSE profile targeted peak USGS gage height readings from the Sep 2011 flood event. 100-yr WSE values at stream cross sections provided by NWS were scaled to fill in WSE values between gages.
The End!!!