Advantages of 2-D Versus 1-D Hydraulic Modeling

August 20, 2014
Iowa DOT Projects Using 2D Modeling

- Statewide Lidar – Completed in 2010
- U.S. 69 over Iowa River near Belmond
- IA 330 over Iowa River near Albion
- I-35 over South Skunk River south of Ames
- U.S. 65 over Des Moines River near Pleasant Hill
- City of Dumont Flood Mitigation
- I-80 over N. Raccoon River – Bendway Weirs
LiDAR Data Received
October 14, 2010

Data set is now complete.
New Tiles (LAS and XYZi formats):
CNC01, CNC02, CNC04, CNC05, CNC06, CNE10, CNE14, CNE02,
CNE09, CNW02, CNW06, CNW07, CNW08, CSE11, CSE07, CSW14,
NE18, NW10, NW11, NW12, NW07, SEF01 and SEF03

Legend

Iowa_Tiles
What is LiDAR?
Contours/DEM
LiDAR Tools

• UNI GeoTREE
  – http://www.geotree.uni.edu/lidarProject.aspx

• Quick Terrain Modeler

• ESRI ArcGIS
  – Spatial Analyst Extension
  – 3d Analyst Extension
1D Hydraulic Model (HEC-RAS)

- 1D – HEC-RAS – widely accepted – predicts average velocity in cross section and water surface elevation

- Very challenging to model in 1D, Ineffective Flow Areas, Losses from channel bends, Overtopping levee systems

Sections from USACE – Des Moines River Model
2D Hydraulic Models

- 2D Models—predicts depth-averaged two-dimensional velocity and water surface elevation

- Combines channel bathymetry + LiDAR (floodplains) + Surface Roughness into a velocity field
U.S. 69 over Iowa River – Belmond, IA
EXISTING CONDITION - 100 YR WATER SURFACE CONTOURS 0.1 FT INTERVAL

INUNDATION LIMITS

IOWA RIVER

BUILDINGS MODELED AS INEFFECTIVE FLOW AREAS

FLOW TO ROAD OVERTOP CONTROLLED BY OVERLAND FLOW

0.7 FT WATER SURFACE DIFFERENTIAL WEST TO EAST BRIDGE ABUTMENTS

EXAMPLE OF COMPLEX FLOW / ENERGY GRADIENT PATTERNS. 1D ASSUMPTION THAT STREAM CROSS SECTIONS REPRESENT A COMMON WATER SURFACE IS PROBLEMATIC AT LOCATIONS WITH COMPLEX FLOW PATTERNS

BELMOND MAIN STREET CROSSING
US 69 CROSSING MP 75.3 NORTH OF BELMOND - EXISTING

Example of significant change to floodplain with high damage potential. Numerous buildings in upstream floodplain. Existing/pre-development conveyance pattern to be significantly altered by improvements to reduce overtopping frequency.
IA 330 over Iowa River Near Albion
EXISTING CONDITION - 100 YR EVENT WATER SURFACE
CONTOURS 0.2 FT INTERVAL

IOWA RIVER NEAR ALBION IOWA - MARSHALL COUNTY

NUMEROUS DIKES AND EMBANKMENTS THAT ACT AS HYDRAULIC CONTROLS. RAILROAD WITH MULTIPLE OVERFLOW BRIDGES. 2D MODEL SIMPLIFIES ANALYSIS OF A COMPLEX FLOODPLAIN.
IA 330 CROSSING PROPOSED IMPROVEMENTS

- Mitigate Alt 30 - 100 Yr Water Surface Contours (0.2 ft interval)
- 564 ft Bridge Built 2000 (57% of Flow)
- 150 ft Bridge (12% of Flow)
- 2.0 ft Drop Across Dike
- 1.0 ft Drop Across Dike
- Iowa River
- Main Channel Bridge
- Bridge
- Iowa RR
- IA 330
- IA 330 Reloc. Highway in Service up to 100 Yr. Event
- 320 ft Bridge (23% of Flow)
- TR 12x12 RCB (8% of Flow)
- Albion Water Facility 0.68 ft increase from existing; to be protected by levee. Internal drainage piped to S side of IA 330, 1.4 ft lower HGL

Model results indicate that main channel bridge length beyond 350 ft results in minimal backwater reduction. Funds for extra 200 ft of bridge could have been diverted to overflow bridge construction.
ELECTRIC SUBSTATION

EXISTING CONDITION - 100 YR WATER SURFACE CONTOURS 0.2 FT INTERVAL

EXAMPLE OF A TYPICAL ROAD CROSSING. EXPECTATION WOULD BE THAT A 1D MODEL COULD PROVIDE A REASONABLE WATER SURFACE ESTIMATE AT SUBSTATION

120 FT OVERFLOW BRIDGE

STANLEY MILL ROAD

380 FT MAIN CHANNEL BRIDGE

2.0 FT WATER SURFACE DIFFERENTIAL ACROSS D/S 'SECTION'

LOCAL ROAD CROSSING EXISTING CONDITION
I-35 over South Skunk River
Domain split into three models as follows:

Lower - Domain extends to upstream of US 30. Developed to provide realistic head boundaries for 'production' models.

Center - Truncated lower model to provide a more responsive (smaller) model for design analysis at I-35 crossing.

Upper - Model with 30% smaller cell size to better capture urban effects in Ames area.

Tuflow model domain:
Skunk River / Squaw Creek near Ames, Iowa - Story County
Numerous dikes and embankments that act as hydraulic controls. TUFLOW approach that allows insertion of break lines to map controls provides for rapid modeling of a complex floodplain.

(A) Model vs. observed differential at this location probably due to dike/levée breach upstream. Model developed based on restored levee.
VERY FEW LOCATIONS WHERE A TYPICAL 1D MODEL SECTION WOULD BE APPLICABLE.

(A) MODEL UP SQUAW CREEK IS SYSTEMATICALLY LOWER THAN OBSERVATIONS. INCREASING SQUAW CREEK DISCHARGE TO 1993 EVENT PEAK FLOW RATE RAISES MODEL 0.25 FT UP SQUAW CREEK. HIGHER DISCHARGE IS CONSISTENT WITH STREAM GAGE HYDROGRAPHS.

BOUNDARY
UPPER MODEL
APPROX. EL 875.8
WS CONTOUR

EXISTING CONDITION - 2010
EVENT WATER SURFACE
CONTOURS 0.2 FT INTERVAL
NUMBER IN RECTANGLE IS MODEL
WATER SURFACE DIFFERENCE
FROM OBSERVATION IN FEET

UPPER REACH - SKUNK RIVER / SQUAW CREEK
FOR 25 YR EVENT SITE APPEARS TO HAVE A CONVEYANCE PATTERN THAT COULD BE REASONABLY MODELED BY 1D METHODS. ONLY PROBLEMATIC AREA IS THE DIFFERENTIAL ACROSS THE DIKE SYSTEM DOWNSTREAM OF I-35.
FOR 100 YR EVENT S'TE HAS A SIMILAR CONVEYANCE PATTERN TO 25 YR EVENT. VARIABLE WATER SURFACE ALONG I-35 OVERTOP SECTION COULD PROVIDE A MINOR CHALLENGE FOR 1D MODEL DEVELOPMENT.
CONVEYANCE PATTERNS COMPLETELY CHANGED FROM EXISTING TO PRE-DEVELOPMENT CONDITION. A SEPARATE 1D MODEL WOULD HAVE TO BE DEVELOPED.
2D model accommodates shifting conveyance patterns with minimal effort. Revising model from existing to pre-development to proposed required a minimal amount of effort compared to a 1D model. In addition, a 2D model provides a better comparison between model scenarios. 1D model development for a complex floodplain is subjective. 2D model development is primarily mechanistic regardless of the floodplain complexity.
I-35 Skunk River Crossing - 2010 Event
U.S. 65 over Des Moines River

Des Moines River near Pleasant Hill Iowa - Polk County
US 65 Des Moines River Crossing - 2008 Event
US 65 relocation resulted in a significant portion of the conveyance being relocated to the main channel in the bridge area. Result was excessive backwater and a 24 ft deep scour hole in the area of the bridges (measured after 2008 event).

2.2 ft drop over 5000 ft of channel (2.3 ft/mi)

Flood Wall

Levee

Great Ape Trust

16 ft to 28 ft deep scour hole meas. after 2008 event

Electric Substation

Des Moines River

Four Mile Creek

24 ft deep scour hole meas. after 2008 event

915 ft main channel bridges

1.2 ft drop across bridge waterway

Existing condition - 100 yr water surface contours 0.2 ft interval

US 65 crossing area existing condition

SE 45th St

Old RR Grade

South FP Flow Pre-HWY 27% Existing 10%

MIDDLE FP FLOW PRE-HWY 27%

Existent 1%
PROPOSED US 65 IMPROVEMENTS REDUCE BACKWATER TO ACCEPTABLE LEVEL.
HYDRAULIC GRADIENT UPSTREAM OF SE 45TH ST ALIGNMENT IS
PRIMARILY DUE TO LOSSES FROM CHANNEL BEND IN FLOODWALL AREA.
FOR COMPARISON LEVEE REACH NEAR SE 14TH ST HAS GRADIENT
APPROX. 2.0 FT/MI. SCOUR HOLE DEPTH MEAS. FOLLOWING 2008
FLOOD WAS 28 FT AT A 2.2 FT/MI GRADIENT.
2D MODELS PROVIDE ABILITY TO CAPTURE BEND LOSSES.

3.6 FT DROP OVER 5000 FT OF CHANNEL (3.8 FT/MI)

580 FT WIDTH, 720 FT WIDTH TYP IN LEVEE SECT U/S SE 14 TH ST

0.7 FT DROP ACROSS BRIDGE WATERWAY

915 FT MAIN CHANNEL BRIDGES

MIDDLE FP FLOW PRE-HWY 27% PROPOSED 0%

1.9 FT DROP ACROSS US 65

MITIGATE ALT 36 - 100 YR WATER SURFACE CONTOURS 0.2 FT INTERVAL

US 65 CROSSING AREA PROPOSED IMPROVEMENTS

0.8 FT WS DROP FROM EXISTING

UPRR

LEVEE

GREAT APE TRUST

ELECTRIC SUBSTATION

DES MOINES RIVER

DES MOINES RIVER OVERFLOW

SE 45TH ST

466 FT OVERFLOW BRIDGES

US 65

0.9 FT DROP ACROSS US 65

SOUTH FP FLOW PRE-HWY 27% PROPOSED 36%

700 FT OVERFLOW BRIDGES

LEVEE

LEVEE
466’ Overflow Bridge
City of Dumont – Flood Mitigation
City of Dumont – Flood Inundation
Raise Cedar Ave. w/Closures
1950’s
Early 1960’s
1970’s
Current Aerial
Looking D.S. at I-80 Bridge

I-80 over South Raccoon River
Dallas County
Looking U.S. from East Bank

I-80 over South Raccoon River
Dallas County
Bendway Weir & Stone Toe Design
Verification of Bendway Weir Design
When Should 2-D Hydraulic Modeling Be Used?

- Overflow Bridges
- Flood Plains with Flank/Lateral Levees
- Roadways Significantly Skewed to the Flood Plain/River
- Locations that are Hydraulically Complex
Questions?

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