Regional Infrastructure Issues, Applied Hydraulics & Other Solutions

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Topography, Climate and Geology create common infrastructure issues for many Eastern Caribbean Nations.
Heavy rainfall and steep terrain create flash flooding and mudslides
The impact of tropical storms result in beach erosion....
causes in urban flooding...
undermines of infrastructure such as roadway bridges, culverts and pavement.
destroys agricultural production.....
Groundwater saturation can lead to slope instability creating roadway embankment failures
Sedimentation reduces hydraulic conveyance below bridges and culverts contributing to additional flooding
Sedimentation reduces navigation depths in ports and harbors requiring dredging...
Sedimentation reduces reservoir capacity and water supply
To prevent natural disasters, such as hurricanes from damaging or destroying infrastructure vital to a nation’s economy they must be designed to have adequate hydraulic conveyance for an appropriate level of risk.

Vital infrastructure, such as critical bridges or water supply structures, should be designed to a minimum of 100 year storm events. (some dams should have a order based on their hazard classification) Less important infrastructure can be designed to shorter return periods depending on the acceptability of economic loss and life safety.
Bridging the topics of hydrologic analysis and design of armoring to prevent channel erosion is the science of Hydraulics.

Hydraulics is the science that deals with practical applications of fluids in motion.
Hydraulic analysis one can determine the volume and velocity of water carried by a channel or conduit to determine:

- Embankment Armoring
- Culvert dimensions
- Bridge elevations and spans
- Flood wall and embankment elevations
- Channel cross sections
- Sediment load / yield
- Scour and/or Erosion
Water Resource - River Mechanics Modeling Applications Overview

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“Oh, there goes Lenny again — draining off the goldfish bowl. . . . He wants to one day work for the Army Corps of Engineers, you know.”
“Those who cannot remember the past are condemned to repeat it.”

- George Santayana

Popularized the Law of Unintended Consequences

- Robert K. Merton
What are we doing to ourselves?

Factors that influence our sustainability

“Whiskey’s for drinking, water’s for fighting over”
- Attributed to Mark Twain
Getting The Water Right

Q: How do we know if we can get the water “right”? 
A: Models!
Why Use Models?

- Integration of data (visualization and use)
- More complete understanding of study area and sensitive parameters
- Guide future data collection
- Simulate specified scenarios (design/prediction)
  - Hydrologic/hydraulic stresses (rainfall, GW pumping, etc)
  - Effects of land use changes etc.
  - Project alternative comparisons
- Presentation of outputs and associated evaluations
Why Use Models?

• Provides best estimate of represented system given data limitations

• Model results are only as reliable as the accuracy and completeness of the field data, i.e. the ability of the data to represent the hydrologic and hydraulic system being modeled

• Simply stated – the outputs (results) are only as good as the worst piece of input (data)!!!!!!!!!!!!!
The Rainfall Runoff Process

- Precipitation
- Infiltration
- Surface runoff
- Groundwater flow
- Water table
- Lake
- River
- Spring
- Condensation
- Transpiration
- Evaporation
- Ocean
- Groundwater
Orographic Effects on Rainfall

- Topography of foothills/mountains causing air mass to rise, drop in temperature, exceed dew point, and precipitate.
- Orographic effects are observed on many Caribbean Islands – with prevailing moist, easterly winds and central mountain ridges.
- Maximum rainfall tends to occur on windward (north and east) side and near peak of mountains.
- Rainfall is lower on the landward (south and west) side of the mountains due to rainshadow effect.
Orographic Effects on Puerto Rico Rainfall

- Majority of Puerto Rico’s rainfall is orographic in nature.
- Cordillera Central mountains run east-west over island.
- Due to pronounced orographic effect of these mountains, rainfall is distributed rather unevenly over the island.
- Annual rainfall ranges from 55-67” in northern coastal plains, 157-197” in northeast tropical rainforest, to less than 39” in the southwest.
HEC-HMS
GeoHMS – Hydrologic Parameters

Define modeling methods
Parameterize
model using
GIS data
Develop a
distributed
model
Input files generated by HEC-GeoHMS include the basin model file, which contains the physical description of the study area and parameter data estimated using GIS datasets, and background maps.
Streamflow Hydrograph

(a) Rainfall → Saturated overland flow → Interflow → Separation line → Falling limb → Baseflow

(b) Water table → Stream Flow → Baseflow → Return flow

(c) Interflow → Saturated overland flow → Stream Flow → Baseflow → Return flow
Energy Principles

\[
Z_2 + Y_2 + \frac{\alpha_2 V_2^2}{2g} = Z_1 + Y_1 + \frac{\alpha_1 V_1^2}{2g} + h_e
\]
Critical Depth / Flow Regime

- Specific energy “E” equal to the sum of the depth of water and the velocity head (for a small slope)
- State of minimal “E” corresponds to critical state of flow (i.e., critical depth)
- Two possible depths bound critical depth which will define the flow regime

Subcritical Flow - Mild Slope
\[ y_o > y_c \ ; \ S < S_c \ ; \ V < V_c \]

Supercritical Flow - Steep Slope
\[ y_o < y_c \ ; \ S > S_c \ ; \ V > V_c \]

Critical Flow - Critical Slope
\[ y_o = y_c \ ; \ S = S_c \ ; \ V = V_c \]
Open Channel Flow - Manning’s Equation

Manning’s Equation Example

Hydraulic radius \( R = \frac{\text{Area}}{\text{wetted perimeter}} = \frac{162.5 \text{ ft}^2}{45 \text{ ft}} = 3.6 \)

Water surface slope = 0.001

Channel roughness \( n = 0.045 \)

\[
V = \frac{1.49 \times R^{2/3} \times S^{1/2}}{n} \\
V = \frac{1.49 \times 3.6^{2/3} \times 0.001^{1/2}}{0.045} = 2.4 \text{ ft/s} \\
Q = V \times A \\
Q = 2.4 \times 162.5 = 390 \text{ cfs}
\]

\[ Q = \frac{K_n}{n} \left( \frac{2}{R^3} \right)^{1/2} \frac{1}{S_f^2} A \\
\text{where} \\
Q = \text{discharge} \\
K_n = \text{unit conversion factor, } K_n = 1.0 \text{ for SI units, } K_n = 1.49 \text{ for English units} \\
n = \text{Manning’s roughness coefficient} \\
R = \text{hydraulic radius, } R = A/P_w \\
A = \text{cross-sectional area} \\
P_w = \text{wetted perimeter} \\
S_f = \text{friction (i.e., energy grade line) slope} \]
Steady/Unsteady Flow

- This is a topic that could take an entire day or more but it is safe to say there are inherent differences........mainly timing and storage

- Specific project needs/application will determine the necessity for whether or not steady versus unsteady state is necessary

- Understanding the fundamentals; you have a choice........iterative evaluation or employ the usage of computer simulation

- 1-D versus 2-D is another topic to consider
Digital Elevation Model Development

- Aerial photography
- Field Survey
- Compilation of data
- TIN Generation
- Baseline DEM
- Incorporation of project features
- Modified DEM
Hydrologic & Hydraulic Numerical Evaluations

- HEC-HMS
- HEC-RAS
- XPSWMM
- HEC-6
- Mike-11
- Etc.......
Hydraulic Analysis of Structures
Specific Watersheds and Flooding

Cochiti Canyon/Dixon Orchard:
Post-Fire/Pre-Flood, 07 Aug 11
Specific Watersheds and Flooding

Cochiti Canyon
August 22, 2011
NEXRAD

1.5in/8hr
Specific Watersheds and Flooding

Cochiti Canyon Flood
Dixon's Apple Orchard

August 22, 2011
Specific Watersheds and Flooding

Peralta Creek, Culvert Crossing, July 21, 2011
Specific Watersheds and Flooding

Peralta Creek, Culvert Crossing, August 21, 2011

10'
Specific Watersheds and Flooding

Peralta Creek, Culvert Crossing, March 6, 2012
Specific Watersheds and Flooding

Peralta Creek, Culvert Crossing, August 19, 2014
Common Mistakes We Make

- Not properly evaluating outside the bounds of “normal”........ (if I were water what would I do?)
- Just enter some information to get the model running........ (oh look an answer, it must be correct)
- Not properly accounting for structures or other aspects of the hydraulic system (“just extend the culvert – what’s the big deal?”)
- Expecting a model to make up for lack of details just because it is a pretty visual tool........
Visualization
Animated Visualization

Existing Conditions

Proposed Project
The Watershed Analysis Tool (HEC-WAT)

Hydrology

Reservoir

Flood Damage

Hydraulics
Education is key.......to reducing risk

- Proper planning and outreach with inclusion of land use considerations, zoning, development, encroachment enforcement, infrastructure limitations........

- “Evidence” based (or risk-informed) decision making accounts enables us to learn from our past practices and evolve making better use of our science thereby providing resiliency........
Final Thought

A model is a tool to aid in our application of evolving science and founded engineering fundamentals. Any individual can generate a data set sufficient to “run” a model. Yet, understanding model strengths/limitations and the adequacy or appropriate range of sensitivities within modeling parameters is where the “engineer” plays the biggest role. Data is the driver in all modeling codes and modeling code applications. The biggest key point to understand is a model is only as good as its worst piece of data and must be properly applied.
Design is only as good as the data and assumptions

- Topographic survey
- Rainfall data
- Stream gage data
- Geology
Topographic survey

- Accurate Hydrologic Analysis requires topographic survey data.
Most Topographic data is gathered by aerial survey.
Mobilization is expensive making it far more cost effective to obtain topographic survey for an entire island than for individual watershed basins.

Surveying several islands further benefits from the economy of scale. There is much to gain from international cooperation.
RAINFALL DATA

- Rainfall data, typically obtained at the airport, does not generally reflect the precipitation in the mountains due to orographic effects is not always sufficient. Rainfall gages monitored upstream are useful for more accurate hydrologic models.
STREAM GAGE DATA – is needed to calibrate hydraulic models for more accurate predictions and in predictions for flood forecasting of real-time flood events.
The Corps of Engineers can offer assistance in the following manner:

- Perform engineering design reviews to insure work is performed in good practice in accordance with international standards.
- Perform value engineering consultation in the during conceptual design to optimize project construction costs.
- Provide technology transfer and training to assist countries build internal capacity.
USACE can perform or consult in all aspects of civil infrastructure planning engineering and construction including:

- Geomatics (GIS & Surveying)
- Navigation (including Ports & Harbors)
- Highways & Highway Structures
- Hydrologic & Hydraulic Analysis
- Flood Control (including Dams)
- Water Supply
- Geology & Geotechnical Engineering
- Structural Engineering
- Mechanical & Electrical Engineering
- Construction Management
- Contracting
- Cost Engineering
Over 600 free Engineering Design Manuals are available covering civil works infrastructure design at the following website: