FMA Modeling Challenge 2019

1. Rural flood modeling
   • Flood model calibration: FMA 2
   • Design event modeling: FMA 4

2. Urban modeling: FMA 5

We will use the ‘Challenge Models’ to prompt discussion on 2D modeling best practice
Case Studies
FMA Challenge 2

- Rural catchment
- External inflows
- Flood model calibration (1 event only)
Case Studies
FMA Challenge Model 4

- Rural catchment
- External inflows
- Design event model sensitivity testing
Case Studies
FMA Challenge Model 5

- Integrated 1D/2D urban scenario
- Direct rainfall
Flood Model Calibration
Flood Model Calibration Overview

1. Data Preparation
2. Model Development
3. Calibration Results
Building a Flood Model
General Principles

A flood model aims to be a digital twin of the real world

Building a Flood Model
General Principles

Continuity of Quality Equation
Building a Flood Model
General Principles

Check data quality before entering it into a model!

Scepticism is a valuable quality in a modeler

I WANT TO BELIEVE

TRUST NO ONE
Data Preparation
Topography Data

Confirm topography data accuracy by validation using secondary datasets

Accuracy calculated by subtracting ALS elevation from benchmark survey data (429 samples)
Common Airborne Laser Data (ALS or LIDAR) survey limitations

- Poor ability to penetrate water
Any thoughts on the quality of this data?
Hillshade symbology is useful for spotting ALS data errors.
Data Preparation
Topography Data

Common Airborne Laser Data (ALS or LIDAR) survey limitations

- Filter algorithms required in areas of dense vegetation
Data Preparation
Topography Data

Common Airborne Laser Data (ALS or LIDAR) survey limitations

• Bridge openings missing or misrepresented
Data Preparation
Topography Data

Common Airborne Laser Data (ALS or LIDAR) survey limitations

- ALS tile datum error

Hillshade symbology is useful for spotting errors
Data Preparation
Landuse Data

DO NOT trust free online datasets

“Developed” Areas?
DO NOT trust free online datasets

“Open Water” Areas?
DO NOT trust free online datasets

“Vegetated” Areas?
Data Preparation
Landuse Data

DO NOT trust free online datasets
DO NOT trust free online datasets
Use industry standard resistance values.

Data Preparation
Landuse Data

Make site visits to help define landuse categorisation and associated resistance values

**DO NOT** blindly use values from other studies

Can you spot the ‘unusual’ values?

<table>
<thead>
<tr>
<th>Land Cover Description</th>
<th>Manning’s n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waterbody</td>
<td>0.035</td>
</tr>
<tr>
<td>Developed, open space</td>
<td>0.040</td>
</tr>
<tr>
<td>Developed, low intensity</td>
<td>0.068</td>
</tr>
<tr>
<td>Developed, medium intensity</td>
<td>0.068</td>
</tr>
<tr>
<td>Developed, high intensity</td>
<td>0.040</td>
</tr>
<tr>
<td>Evergreen forest</td>
<td>0.320</td>
</tr>
<tr>
<td>Deciduous forest</td>
<td>0.360</td>
</tr>
<tr>
<td>Mixed forest</td>
<td>0.400</td>
</tr>
<tr>
<td>Shrub</td>
<td>0.400</td>
</tr>
<tr>
<td>Grassland/herbaceous</td>
<td>0.368</td>
</tr>
<tr>
<td>Pasture/hay</td>
<td>0.325</td>
</tr>
<tr>
<td>Crop/vegetation</td>
<td>0.323</td>
</tr>
<tr>
<td>Woody wetlands</td>
<td>0.086</td>
</tr>
<tr>
<td>Emergent herbaceous wetlands</td>
<td>0.183</td>
</tr>
</tbody>
</table>

Tidal data

• Correct the water level datum to match the model elevation datum
Data Preparation
Boundary Condition Data

Tidal data
• Correct the water level datum to match the model elevation datum

Historic rainfall data
• Verify recorded data quality
• Operational for the whole event?
• Compare daily / tip bucket / hourly totals

Use real recorded data. **DO NOT** use design event rainfall as an input for calibration!
Data Preparation
Calibration Data

- Surveyed peak flood / debris marks

Check for consistency with surrounding levels
Check against DEM elevations
Data Preparation Calibration Data

• Surveyed peak flood / debris marks
• Gauge water level recordings

Check for consistency with surrounding gauge levels, shape and timing

Confirm location and gauge datum
Data Preparation
Calibration Data

• Surveyed peak flood / debris marks
• Gauge water level recordings
• Gauge flow estimate

Check for consistency with surrounding gauges
Confirm how the gauge rating been derived?
Data Preparation Calibration Data

- Surveyed peak flood / debris marks
- Gauge water level recordings
- Gauge flow estimate

Check for consistency with surrounding gauges

Confirm how the gauge rating been derived?
Data Preparation
Calibration Data

- Surveyed peak flood / debris marks
- Gauge water level recordings
- Gauge flow estimates
- Don’t discount anecdotal evidence. All validation data is valuable.

Check for consistency with surrounding gauges

Confirm how has the gauge rating been derived?
Flood Model Calibration
Model Build
Case Studies
FMA Challenge 2

- Rural catchment
- External inflows
- Flood model calibration (1 Event only)
Factors to consider:

- The scale of topographic and flow phenomena
- The desired level of output detail
- The length of event time and model run time
- The size of the area of interest

Recommendations:

<table>
<thead>
<tr>
<th>Modelling Case</th>
<th>Typical 2D Cell Resolution</th>
</tr>
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<tbody>
<tr>
<td>Flow in Channel</td>
<td>≥ 5 grid/mesh elements laterally across the channel</td>
</tr>
<tr>
<td>Urban Overland</td>
<td>6ft to 15ft</td>
</tr>
<tr>
<td>Flow in Floodplain</td>
<td>30ft to 150ft</td>
</tr>
<tr>
<td>Lakes and Estuaries</td>
<td>Flexible mesh – range of cell sizes</td>
</tr>
</tbody>
</table>
Model Build
Cell Size Selection

Cell Size Convergence

Inaccurate

Accurate

Simulation Accuracy

Small

Cell Size

Large
## Model Build
### Cell Size Selection

**FMA Challenge Model 2**

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### Key Learnings From Exercise

1. *Is the model extent sufficient (refine and repeat)*
Glass-wall or open boundary? Neither approach is recommended
## Model Build
### Cell Size Selection

### FMA Challenge Model 2

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**Key Learnings From Exercise**

1. Is the model extent sufficient (refine and repeat)
2. Simulation efficiency / model health (eg. timestep performance)
# Model Build

## Simulation Timestep Review

### TUFLOW

- **Classic (Finite Difference Implicit Scheme)**
  - US Units = 0.15 to 0.05
  - cell size = Courant number < 10 e.g. 30ft resolution = 5 to 2 seconds

- **HPC (Finite Volume Explicit Scheme)**
  - Automatic adaptive timestep = Unconditionally stable
  - Courant number < 1
  - Celerity number < 1.0
  - Diffusion number < 0.3

### HECRAS

- Can someone provide comment from the audience?

```plaintext
<table>
<thead>
<tr>
<th>iStep</th>
<th>tEnd</th>
<th>dtStar</th>
<th>dt</th>
<th>Nu</th>
<th>Nc</th>
<th>Nd</th>
<th>Eff</th>
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<tbody>
<tr>
<td>264</td>
<td>329.833</td>
<td>1.3369</td>
<td>1.336</td>
<td>0.41953</td>
<td>0.8</td>
<td>0.15498</td>
<td>95.8%</td>
</tr>
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<td>331.169</td>
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<td>1.336</td>
<td>0.41913</td>
<td>0.8</td>
<td>0.15466</td>
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<td>332.505</td>
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<td>1.336</td>
<td>0.41873</td>
<td>0.8</td>
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<td>0.41844</td>
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<td>0.14984</td>
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<tr>
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<td>0.14958</td>
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<td>1.336</td>
<td>0.41432</td>
<td>0.8</td>
<td>0.14905</td>
<td>96.0%</td>
</tr>
</tbody>
</table>
```

**Min dt**

- 1.4
- 1.5
- 1.6
- 1.7
- 1.8
- 1.9
- 2
## FMA Challenge Model 2

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</table>

### Key Learnings From Exercise

1. **Is the model extent sufficient** (refine and repeat)
2. **Simulation efficiency / model health** (e.g. timestep performance)
3. **Identification of hydraulically sensitive areas** (the significant locations you want to make sure you get correct)
4. **Model resolution selection for further calibration efforts**
Model Build
Cell Size Selection

Model resolution selection for further calibration efforts

How?

1. Subtract modeled from recorded
2. Take absolute value
3. Create exceedance plot
4. Compare plots from different resolution simulation to test for convergence
5. Use zone filtering if needed (learn Excel pivot tables)
Model Build
Cell Size Selection

Flood Level Difference Comparison (Modeled vs Recorded)

- Cell Resolution
- 328 ft

Peak Flood Level Difference (abs. Modeled minus Recorded) (ft)

Percent Occurrence

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
Model Build
Cell Size Selection

Flood Level Difference Comparison (Modeled vs Recorded)

- Cell Resolution
  - 328ft
  - 165ft

Percent Occurrence vs Peak Flood Level Difference (abs. Modeled minus Recorded) (ft)
Model Build
Cell Size Selection

Flood Level Difference Comparison (Modeled vs Recorded)

Cell Resolution
- 328ft
- 165ft
- 98ft

Peak Flood Level Difference (abs. Modeled minus Recorded) vs Percent Occurrence
Model Build
Cell Size Selection

Flood Level Difference Comparison (Modeled vs Recorded)

Cell Resolution
- 328ft
- 165ft
- 98ft
- 65ft

Peak Flood Level Difference (abs. Modeled minus Recorded) (ft)

Percent Occurrence

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
Model Build
Cell Size Selection

Flood Level Difference Comparison (Modeled vs Recorded)

- Cell Resolution
  - 328ft
  - 165ft
  - 98ft
  - 65ft
  - 50ft

Peak Flood Level Difference
(abs. Modeled minus Recorded) (ft)

Percent Occurrence

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
Model Build
Cell Size Selection

Filter GIS point data to inspect whether these points are related.
Model Build
Broad-scale Calibration Approach

After cell size selection calibrate to multiple events

1. Small in-bank event or tide (conveyance dominated)
   • Refine channel resistance (manning n)
   • Refine additional form losses (e.g. bridges, bends)

2. Large out-of-bank event (conveyance + storage dominated)
   • Refine floodplain hydraulic control features (levees, roads, rail embankments etc.)
   • Refine floodplain resistance (manning n)

3. Extreme out-of-bank event (conveyance + storage dominated)
   • Model parameter verification

Magnitude sequence helps workflow efficient
Don’t make the mistake of

- Using values outside “industry standard” to achieve a good calibration.
- Make changes to the model that aren’t evidence based just to match a recorded level.
- Fall into the trap of focusing on microscale aspects. Work out what is significant hydraulically and focus on sensitivity testing those features. (Hint: don’t just focus on Manning’s n)
- Involve other colleagues to review results and brainstorm solutions.
Model Build
Broad-scale Calibration Approach

After cell size selection calibrate to multiple events

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3. Extreme out-of-bank event (conveyance + storage dominated)
   - Model parameter verification
Model Build
Step 1: In-bank Calibration Example

Hillshade symbology is useful for spotting ALS data errors
Model Build
Step 1: In-bank Calibration Example

- In-bank data is critical!! If not available…
- It’s the modeler’s responsibility to inform the client of possible over estimation of the water surface elevations in the floodplain!

Don’t be fooled by (or fool others with) convincing pretty pictures
Model Build

Step 1: In-bank Calibration Example

How much can in-bank data impact a result?

Clarence River Flood Study (2012)
Model Build
Step 1: In-bank Calibration Example

How much can in-bank data impact a result?

No Bathymetry
Flood Level Difference (feet)
(Model – Recorded)
Model Build
Step 1: In-bank Calibration Example

How much can in-bank data impact a result?

**With Bathymetry**

Flood Level Difference (feet)  
(Model – Recorded)
Model Build
Broad-scale Calibration Approach

After cell size selection calibrate to multiple events

1. Small in-bank event or tide (conveyance dominated)
   - Refine channel resistance (manning n)
   - Refine additional form losses (e.g. bridges, bends)

2. Large out-of-bank event (conveyance + storage dominated)
   - Refine floodplain hydraulic control features (levees, roads, rail embankments etc.)
   - Refine floodplain resistance (manning n)

3. Extreme out-of-bank event (conveyance + storage dominated)
   - Model parameter verification
Model Build
Step 2: Refine Floodplain Geometry

Legend

Label Symbology
○ 0.0 Recorded Peak Level (ft)
○ 0.0 Modeled Peak Flood Level (ft)
○ 0.0 Difference (ft)

Flood Mark Symbology
Flood Level Difference (Recorded min Modeled)
- Red: -5ft to -3ft
- Orange: -3ft to -1ft
- Yellow: -1ft to 1ft
- Green: 1ft to 3ft
- Blue: 3ft to 5ft

No opening through bridge
Model Build
Step 2: Refine Floodplain Geometry

Legend

Label Symbology
- 0.0 Recorded Peak Level (ft)
- 0.0 Modeled Peak Flood Level (ft)
- 0.0 Difference (ft)

Flood Mark Symbology
Flood Level Difference (Recorded min Modeled)
- 5ft to 3ft
- 3ft to 1ft
- 1ft to 1ft
0ft to 3ft
3ft to 5ft

Opening added
Model Build
Step 2: Refine Floodplain Geometry

Legend
Change in Peak Water Level (ft)
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5

Flood Level Impact
Bridge Open vs Bridge Closed
Topography Updates
Step 2: Refine Floodplain Geometry

**TUFLOW Classic**

Cell Center (ZC) determines storage

Cell sides (ZU, ZV) determine when/how water moves between neighbouring cells

**TUFLOW HPC and HECRAS**

Cell storage curve

Cell Face Cross-section
Topography Updates
Step 2: Refine Floodplain Geometry

Z points do not fall exactly on the agricultural levee crest
Topography Updates
Step 2: Refine Floodplain Geometry

Water can flow through the embankment in this location using a model of this resolution

Using a finer cell resolution may not be practical due to increased simulation time 😞
Topography Updates
Step 2: Refine Floodplain Geometry

TUFLow: Break-line model inputs (Zshape) can be used to enforce Z elevations
Topography Updates
Step 2: Refine Floodplain Geometry

TUFLOW: Break-line model inputs (Zshape) can be used to enforce Z elevations
Topography Updates
Step 2: Refine Floodplain Geometry

TUFLOW: Break-line model inputs (Zshape) can be used to enforce Z elevations
Step 2: Refine Floodplain Geometry

Break-line model inputs (Zshape) can be used to enforce Z elevations.
Break-line model inputs (Zshape) for key hydraulic controls:
1. Improves accurate definition of topography
2. Improves result accuracy
3. Assists to achieve cell size convergence at a coarser cell resolution

Audience: Comment on other software approaches? FLO2D, HECRAS, MIKE, RiverFlow2D, SRH-2D.
Topography Updates
Step 2: Refine Floodplain Geometry
Topography Updates
Step 2: Refine Floodplain Geometry
Topography Updates

Step 2: Refine Floodplain Geometry

ASC_to_ASC = Free tool to automate break-line elevation extraction from DEM

https://wiki.tuflow.com
Flood Model Calibration Results
Mapping Discussion

- Approximately 20% of the recorded high water marks have been surveyed to have an elevation below ground level (as defined by the DEM).
- This is not physically possible.

Model results have been extracted from the closest wet cell on the flood fringe where the high DEM level is preventing the high water mark location from becoming wet in the flood model.
Model Calibration Results

Legend

Label Symbology
- 0.0 Recorded Peak Level (ft)
- 0.0 Modeled Peak Flood Level (ft)
- 0.0 Difference (ft)

Flood Mark Symbology
Flood Level Difference (Recorded min Modeled)
- -5ft to -3ft
- -3ft to -1ft
- -1ft to 1ft
- 1ft to 3ft
- 3ft to 5ft

Map showing modeled peak flood levels and differences compared to recorded levels.
Model Calibration Results

Legend

Label Symbology
- 0.0 Recorded Peak Level (ft)
- 0.0 Modeled Peak Flood Level (ft)
- 0.0 Difference (ft)

Flood Mark Symbology
Flood Level Difference (Recorded min Modeled)
- -5ft to -3ft
- -3ft to -1ft
- -1ft to 1ft
- 1ft to 3ft
- 3ft to 5ft
Model Calibration Results

Legend

Label Symbology
- 0.0 Recorded Peak Level (ft)
- 0.0 Modeled Peak Flood Level (ft)
- 0.0 Difference (ft)

Flood Mark Symbology
Flood Level Difference (Recorded min Modeled)
- -5ft to -3ft
- -3ft to -1ft
- -1ft to 1ft
- 1ft to 3ft
- 3ft to 5ft

Map showing flood levels and differences with various symbology symbols for different levels.
Model Calibration Results

Legend

Label Symbology
- 0.0 Recorded Peak Level (ft)
- 0.0 Modeled Peak Flood Level (ft)
- 0.0 Difference (ft)

Flood Mark Symbology
Flood Level Difference (Recorded min Modeled)
- -5ft to -3ft
- -3ft to -1ft
- -1ft to 1ft
- 1ft to 3ft
- 3ft to 5ft
Model Calibration
Discussion

Question  Answer  Comment
Design
Event
Modeling

4
Design Flood Estimation
Overview

1. Hydrology / Hydraulic Transformation Probability Neutrality?

2. 2D floodway calculation (Australia)
   If time permits

3. Interesting changes in hydrology assessment approach internationally
The calibrated model is ready to be used for design event simulation

**BUT...**

Critical design hydrology assumptions:

- Intensity, duration, temporal pattern, areal reduction factor, etc.

**Hydrology / Hydraulic Transformation**

**Probability Neutrality?**

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*Historic Flood Frequency Data*

*Flood Model Result*
Estimating Design Floods
Monte Carlo Statistical Approach

Same total rainfall

Annual Exceedance Probability of Catchment Rainfall (1 in Y)
Estimating Design Floods
Monte Carlo Statistical Approach

- Same total rainfall
- Wet antecedent conditions, Dams near full
- Dry antecedent conditions, Dams near empty
Irrespective of hydrology approach (USA or Australia)...

Comparison of design flood model estimate against flood frequency analysis of recorded data is the best practice method to confirm design event estimation accuracy.

Historic Flood Frequency Data

Flood Model Result
“I will present the 2D floodway calculation methodology I’ve used for the past (in Australia) at FMA 2019”.

Chris Huxley (Modeling and Mapping Panel discussion Reno 9/6/2018)
Objective: Define the area of preservation within the catchment using at 2D model.

Area of Preservation: Inside this area, development (filled with solid material) would cause peak flood levels to increase by more than 1ft.
1. Model design flood event and output peak flow hazard (ft$^2$/s) ($Z_0 = v^*d$)

$Z_0$ is an unbiased output for reporting 2D conveyance and storage.

2. Contour peak $Z_0$ results from 0 up in regular increments (e.g. 0.5).
3. Create fill scenarios for each contour range.
4. Run the fill scenario models and compare peak water level results with base flood peak water levels.
   • Run 1 = Z0 (0 to 0.5)
   • Run 2 = Z0 (0 to 1.0)
   • Run 3 = Z0 (0 to 1.5)
3. Create fill scenarios for each contour range.

4. Run the fill scenario models and compare peak water level results with base flood peak water levels.

- Run 1 = Z0 (0 to 0.5)
- Run 2 = Z0 (0 to 1.0)
- Run 3 = Z0 (0 to 1.5)
3. Use cross-section approach to consolidate results for entire floodplain

4. Refine fill region to meet 1ft rise criteria. The area not filled represents the “floodway” zone.
Australian Floodway Calculation Example

Example:

Z0 Result

Maximum Z0 (ft²/s)

- 0
- 0.5
- 1
- 1.5
- 2
- 2.5

- 3
- 3.5
- 4
- 4.5
- 5
- 5.5

- 6
- 6.5
- 7
- 7.5
- 8
- 8.5

- 9
- 9.5
- 10
Australian Floodway Calculation Example

Example:

Fill Area Z0 = 0 to 3 ft$^2$/s

<table>
<thead>
<tr>
<th>Change in Flood Level (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-2</td>
</tr>
<tr>
<td>-1</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
</tbody>
</table>

- **Fill Area**
- $dH < 1ft$
- $dH > 1ft$
- $dH = 1ft$
Australian Floodway Calculation Example

Example:

Fill Area Z₀ = 0 to 6 ft²/s

Change in Flood Level (ft)

-2
-1
0
1
2

Fill Area

dH = 1ft

dH > 1ft
Australian Floodway Calculation Example

Example:
Fill Area = Z0 composite from previous results

- From Z0 = 0 to 6 ft²/s
- From Z0 = 0 to 5.5 ft²/s
- From Z0 = 0 to 3.5 ft²/s
- From Z0 = 0 to 2.5 ft²/s
- From Z0 = 0 to 2 ft²/s
- From Z0 = 0 to 1.5 ft²/s
- From Z0 = 0 to 1 ft²/s
- From Z0 = 0 to 0.5 ft²/s
Australian Floodway Calculation Example (Profile)

$dH \approx 1\text{ft}$
Note: Some recommend removal of flood storage zone “islands” if isolated by 100 Year ARI and inundated during PMF (i.e. “low flood islands”)

Australian Floodway Calculation Example Map

- Floodway
- Flood Storage Zone (100 Year Floodplain Limits)
- Flood Fringe (PMF Year Floodplain Limits)
Design Event Modeling Discussion

Question Answer Comment
Research found temporal pattern assumptions were the most dominant parameter influencing result sensitivity in 1987 hydrology.

1958: Peak flow or unit hydrograph per AEP. All inputs fixed. Q = ?

1977: Single hydrograph per magnitude & duration per AEP. All inputs fixed.

1987: Ensemble 10 hydrographs magnitude & duration per AEP. Vary temporal patterns.

2016: Monte Carlo Thousands of hydrographs per AEP. Vary all major factors.

Reducing uncertainty / Increasing defensibility
Estimating Design Floods
Reducing Temporal Pattern Uncertainty

1987
- 8 regions each 20 durations (10 min to 72 hr)
- 2 AEP bands
- 1 temporal pattern per duration per region

2016
- 12 regions each 24 durations (10 min to 7 days)
- 4 AEP bands
- 10 temporal patterns per duration per AEP band per region
- Resulting in 11,000 design temporal patterns sourced from 100,000’s recorded storm bursts
Australian H+H industry aims improve consideration and communication of uncertainty

Range of temporal patterns
- When no FFA, median temporal pattern represents “single event” result.
- Range of results helps quantify uncertainty
- Range of results help inform other flood risk metrics: e.g. warning time, duration of flooding, storage

Learn More: 4:00pm Thursday @ Marina 4