Rapid Flood Mapping in Delft-FEWS

Combine 1D water level simulations with DEMs or offline flood maps to generate real-time 2D flood inundation maps

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9-11-2022

Rationale

- Having real-time flood inundation forecasts available in operational forecasting system may help support decision-making before, during, and after flood events
- Most Delft-FEWS applications for flow or flood forecasting include hydrological or 1D-hydraulic models, simulating water levels at select river stations
- Those 1D models usually don’t simulate or visualize flood inundations and extents outside the river bed, for example in the flood plains or urbanized areas
- Running 2D hydraulic models in the operational system, which do provide that information, is often too complex, expensive, time consuming or simply not available
- However, high resolution Digital Elevation Maps (DEMs) or Flood (Risk) Maps associated with a certain return period or other index are often available as part of offline desk studies
- Those DEMs and offline Flood Inundation maps can be used in Delft-FEWS in combination with the real-time 1D flood forecasts to create real-time flood inundation forecasting and mapping

Rapid flood mapping in Delft-FEWS

Several approaches possible:

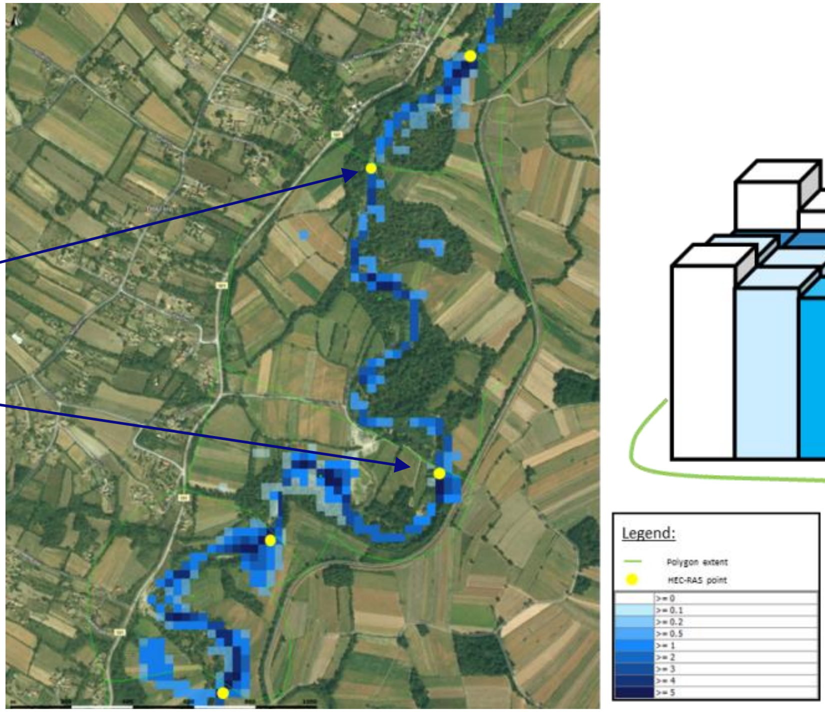
- Combine 1D water level simulations along the river with DEM to generate 2D floodmaps
  - with existing functionality
  - with improved functionality to be developed (10 - 15d)
- Import (references to) Flood Maps per water depth for specific locations to generate 2D floodmaps
  - Combine those maps with 1D water level simulations at specific forecasting locations
  - Visualize in Spatial Display using vertical slider, without time dimension
- Use Remote Sensing data for rapid flood mapping (observed only)
  - Use WMS layers in Spatial Display

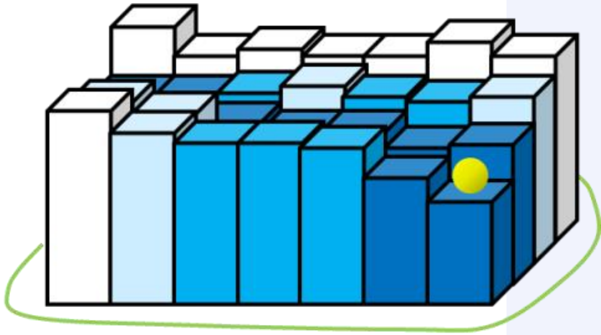
Other flood mapping alternatives in Delft-FEWS not discussed further as they are a bit more complex or too data intense:

- Use a reduced-complexity model like SFINCS, designed for super-fast modelling of (compound) flooding events

Combine 1D water level simulations along the river with DEM - principle

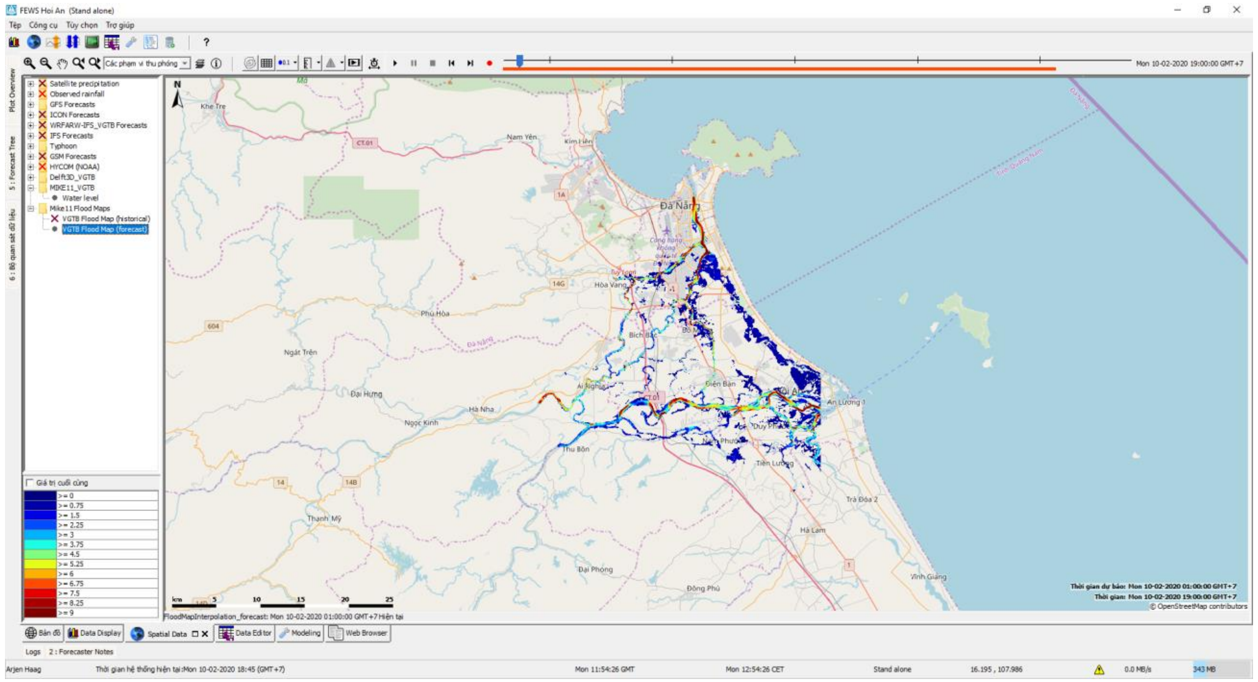
- Use 1D results to generate 2D flood maps for forecasts
- Works on the fly when visualizing the FEWS Spatial Display using a .cta file that FEWS generates
- Scales at different zoom levels
- Required for flood maps:
  - DEM
  - Points to link results to DEM
  - Polygons or Grids to define areas of the DEM





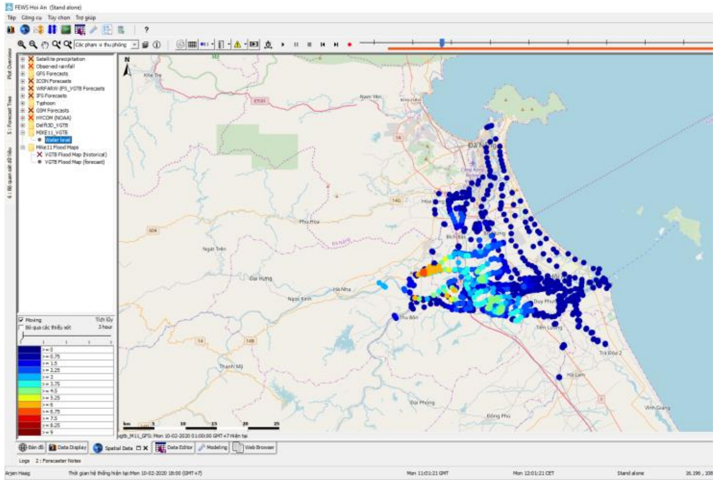
Combine 1D water level simulations along the river with DEM – existing functionality

1. Generate real-time water level results in 1D / point locations
2. Interpolate water levels to a:
   a) 2D grid and clip to flood prone areas
   b) or to polygons along the river
3. Convert a local DEM to a Coverage Tile Archive (CTA) file using a Delft-FEWS F12 option
4. Configure a CTA layer in the Delft-FEWS Spatial Display to overlay the water level results on this DEM to create flood inundation maps

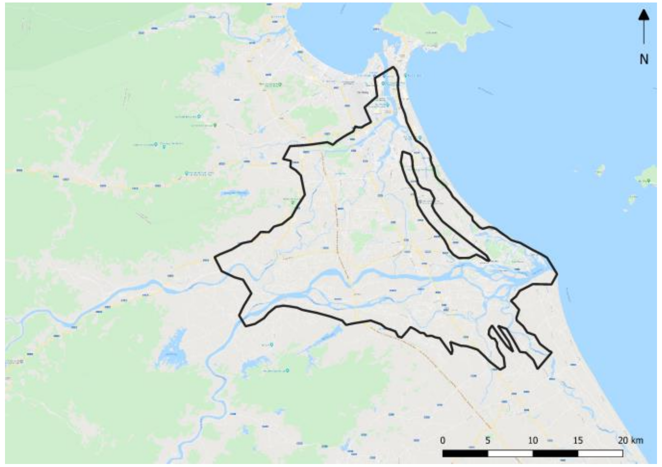


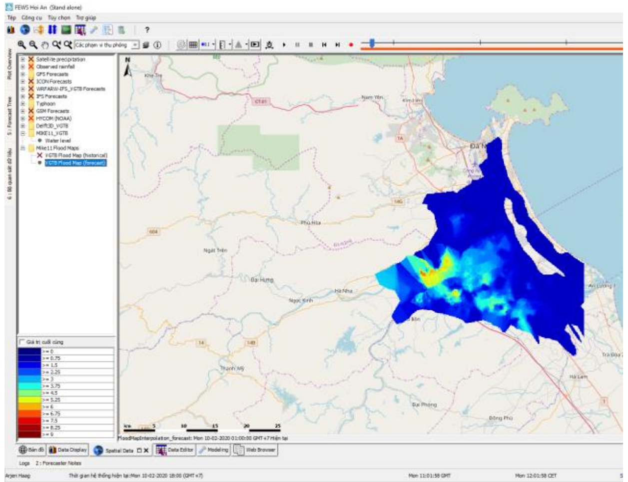
Combine 1D water level simulations along the river with DEM – Example with grids

1. Water level results in point locations

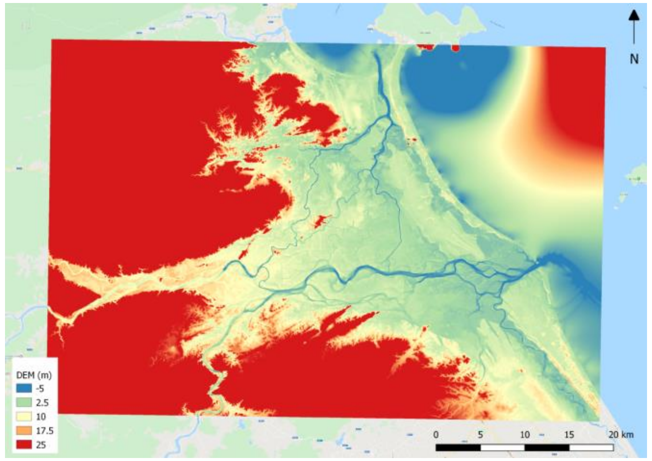


2a. Interpolate water levels to 2D grid and clip to flood prone areas

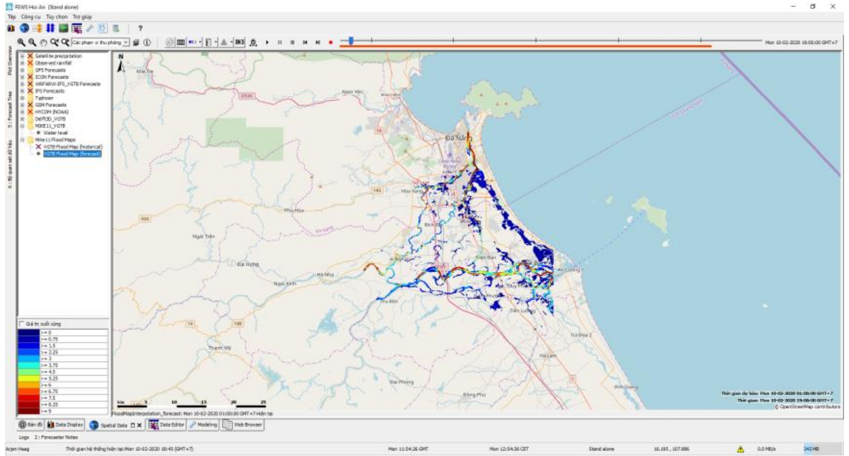




3. Convert a local DEM to a CTA file

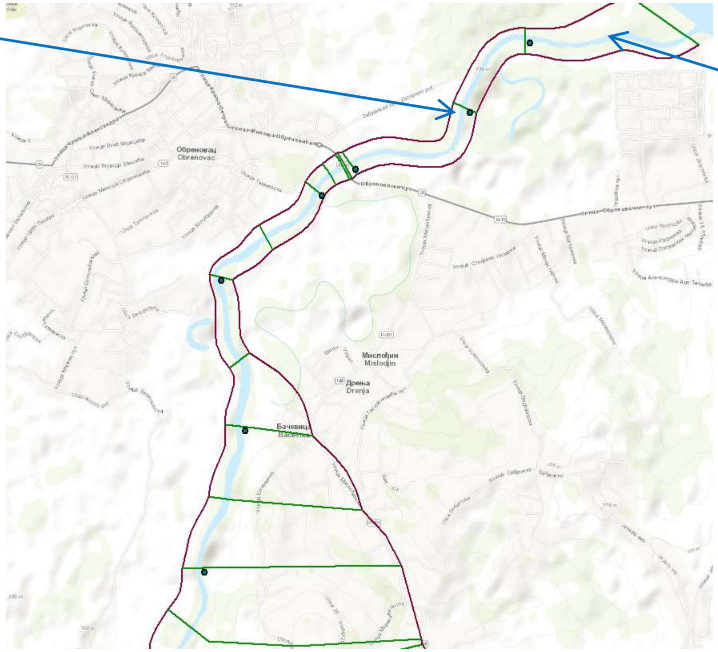


Configure a CTA layer in Delft-FEWS



Combine 1D water level simulations along the river with DEM – Example with polygons

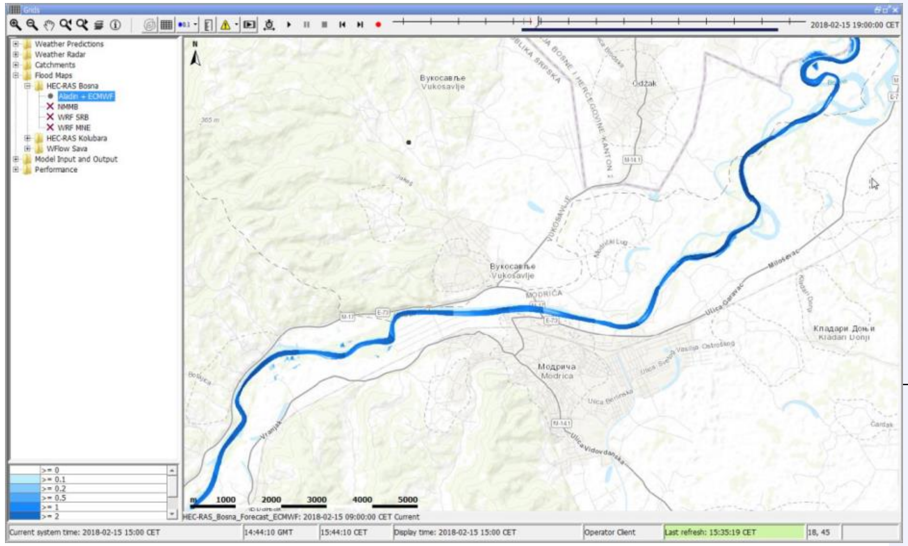
1. Water level results in 1D / point locations at cross sections, say every 1km



2b. Interpolate water levels to polygons

- use the cross sections, river and river edge line to define the polygons
- Link point between cross section and polygon
- Polygons get one water level assigned
- Within the polygons you should have a DEM

Configure a CTA layer in Delft-FEWS



3. Convert a local DEM to a CTA file

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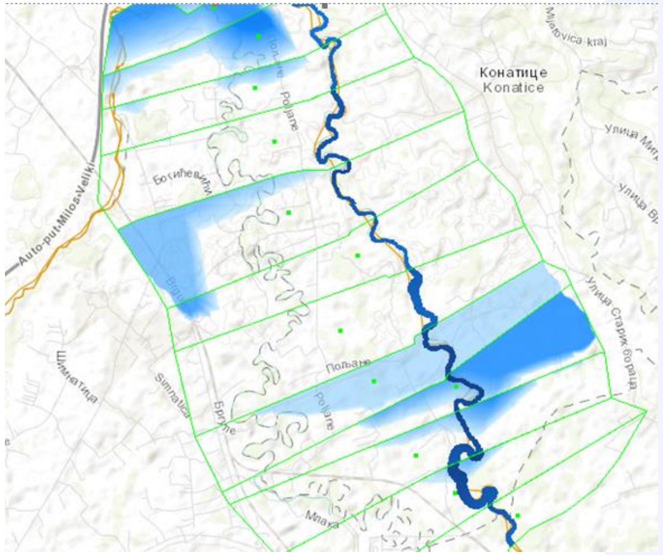
Combine 1D water level simulations along the river with DEM – design for improved functionality

The coverageTileArchiveLayer is very easy to configure and gives more intuitive modeling results by presenting inundation maps.

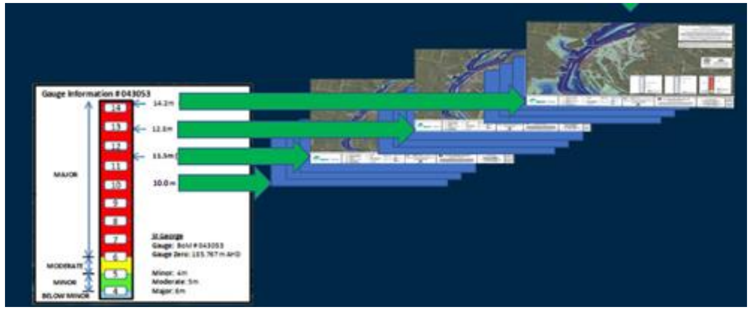
- However, the grid or polygon size of the 1D based water levels is often much larger than the DEM (for example 1km versus 5m). As a result, the inundation maps can get an unrealistic stair case pattern along the river profile.
- To improve this visualization, and to significantly reduce the time to generate the river polygons, we like to develop two enhancements to Delft-FEWS:
  - a feature which generates on the fly a longitudinal profile with the detailed grid size, and apply this profile to the inundation map.
  - The global water level datum for a screen pixel is currently based on the cell the pixel belongs to. In fact, the cell value only applies to the pixel at the cell center. The other pixel values should be calculated using an inverse distance to the nearest cell centers
- Estimated level of effort for development and testing: 15 days



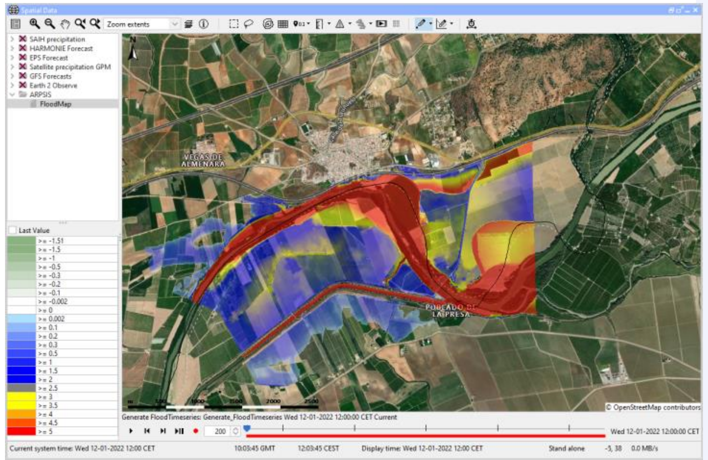
Import Flood Maps per water depth for specific locations to generate 2D floodmaps - principle

Real-time 1D forecast at specific station

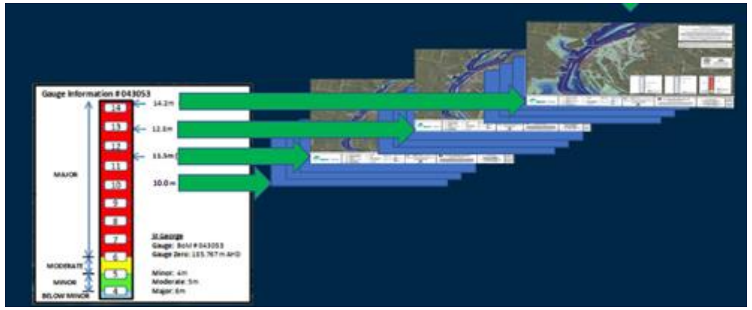
Offline library of flood maps

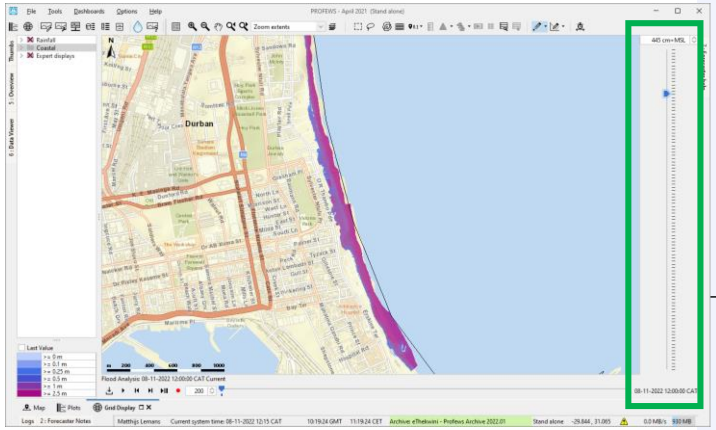


Real-time 2D flood map in FEWS



or





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Combine 1D simulations at specific forecasting locations with offline Flood Maps

1. Import 2D simulations (or their references) from static offline flood maps
2. link the real-time 1D simulation value at a particular station to an index value using a lookup transformation in FEWS
3. retrieve the associated 2D flood map belonging to the index value using a gridEnsembleMemberByIndex transformation.
4. Configure a grid display to visualize the 2D inundation forecast

Combine 1D simulations at specific forecasting locations with offline Flood Maps

1. Import 2D results from different flood maps
   - The different maps usually have just one value at a random time step
   - Import the different maps as ensemble members

Database Lister

..	..	..	T0	Dispatch time	Workflow	What-if scena...	Description	FDO	FSS ID	FSS Group ID	Runtime	Output Time ...	...
			Wed 12-01-2022 12:00:00	Tue 20-09-2022 14:21:49	Generate FloodTimeseries GE014		Generate_Flood...	Matthijs Lemans	none		0 s	1 d	2
			Wed 12-01-2022 12:00:00	Tue 20-09-2022 14:19:17	Import FloodMaps GE014		Import FloodMa...	Matthijs Lemans	none		22 s	2 d	3

Filter by Selection

Filter by Branch

Location Id	Location Name	Parameter Group	Parameter Id	Parameter Name	Module Instance	X	Y	Time Series Type	Ensemble	Ensemble Member	Value Type	Time Step	Start	End	Time Span	Timestamp Count	Stored Timestamp C	Unit	Min Value	Max Value
1	1	1	1	1	1			1	1	3	1	1	Sat 01-01-200	Mon 03-01-20	0 s	3	3	1	0.010	8.480
GE014	ARPSI GE014	Nivel	H.sim	Nivel Simulacion	Import_Flo...	-3.818	37.209	external hi...	FloodMaps	1	grid	hour	Sat 01-01-2...	Sat 01-01-2...	0 s	1	1	m.l.a	0.010	4.450
GE014	ARPSI GE014	Nivel	H.sim	Nivel Simulacion	Import_Flo...	-3.818	37.209	external hi...	FloodMaps	2	grid	hour	Sun 02-01-...	Sun 02-01-...	0 s	1	1	m.l.a	0.010	8.040
GE014	ARPSI GE014	Nivel	H.sim	Nivel Simulacion	Import_Flo...	-3.818	37.209	external hi...	FloodMaps	3	grid	hour	Mon 03-01...	Mon 03-01...	0 s	1	1	m.l.a	0.010	8.480

Time Series 3

Combine 1D simulations at specific forecasting locations with offline Flood Maps

2. link the real-time 1D simulation value at a particular station to an index value using a lookup transformation in FEWS

```xml
<transformation id="EnsembleIndices">
    <lookup>
        <simple>
            <input>
                <variableId>WaterLevels</variableId>
            </input>
            <coefficientSetId>FloodMaps</coefficientSetId>
            <coefficientSetFile>FloodMaps</coefficientSetFile>
            <output>
                <variableId>EnsembleIndices</variableId>
            </output>
        </simple>
    </lookup>
</transformation>
```

```xml
<coefficientSet id="FloodMaps">
  <lookup>
    <simple>
        <interpolationType>class</interpolationType>
        <extrapolationType>maxmin</extrapolationType>
        <inputUnit>m.l.a</inputUnit>
        <outputUnit>-</outputUnit>
        <lookupTable>
            <lookupTableRow input="3.960" output="1"/>
            <lookupTableRow input="7.655" output="2"/>
            <lookupTableRow input="10.835" output="3"/>
        </lookupTable>
    </simple>
  </lookup>
</coefficientSet>
```

Combine 1D simulations at specific forecasting locations with offline Flood Maps

3. retrieve the associated 2D flood map belonging to the index value using a gridEnsembleMemberByIndex transformation.

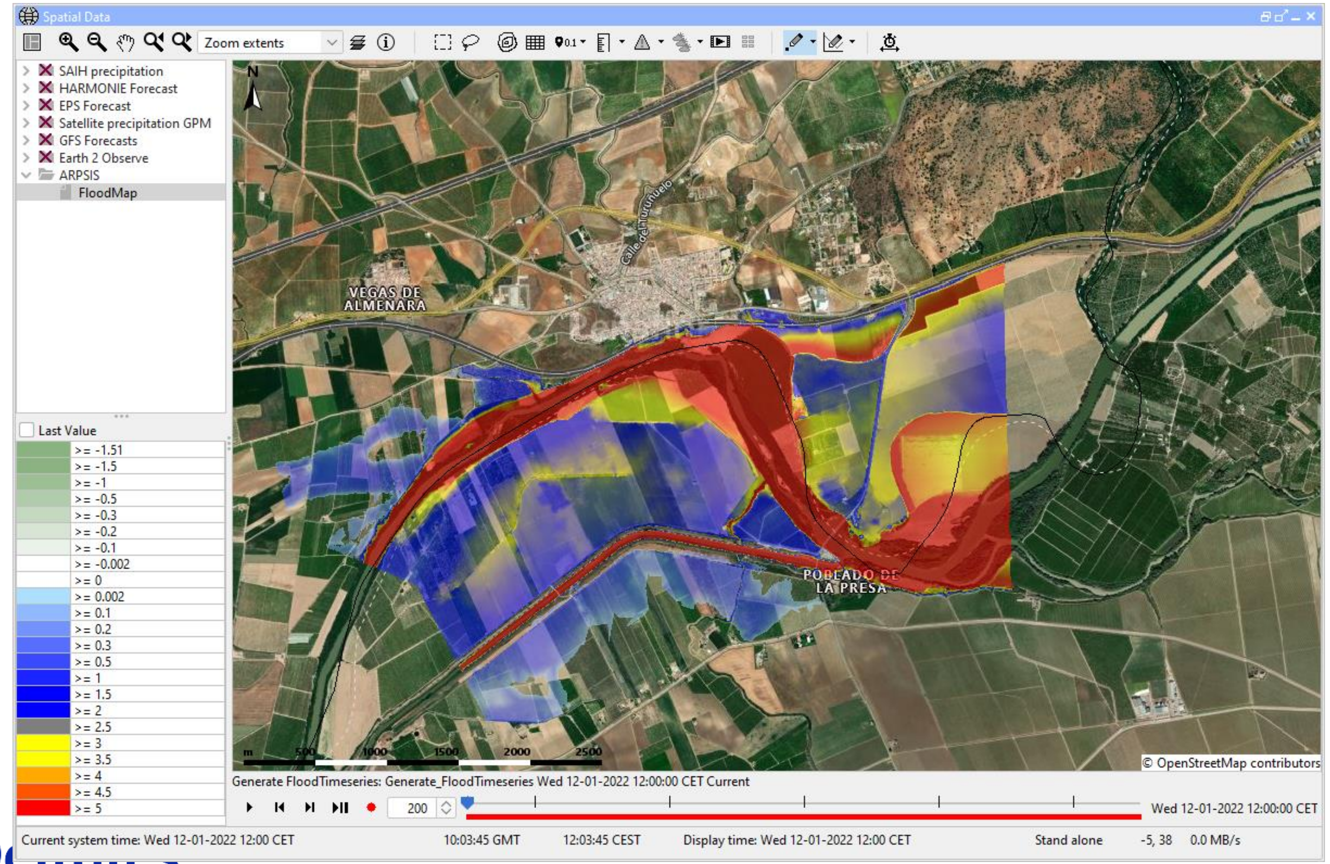
- The flood map selection should be based on a single timeseries, with the different flood maps configured as ensemble members in the Delft-FEWS application.

```
<transformation id="ensembleLookup">
	<selection>
		<gridEnsembleMemberByIndex>
			<inputEnsembleIndices>
				<variableId>EnsembleIndices</variableId>
			</inputEnsembleIndices>
			<inputTimeSeriesGrids>
				<variableId>InputGrids</variableId>
			</inputTimeSeriesGrids>
			<output>
				<variableId>Output</variableId>
			</output>
		<matchInputAndOutputGridTimes>false</matchInputAndOutputGridTimes>
		</gridEnsembleMemberByIndex>
	</selection>
</transformation
```

This allows the transformation to fill the forecast period of the output time series with the last non-missing 2D value of the gridded input series

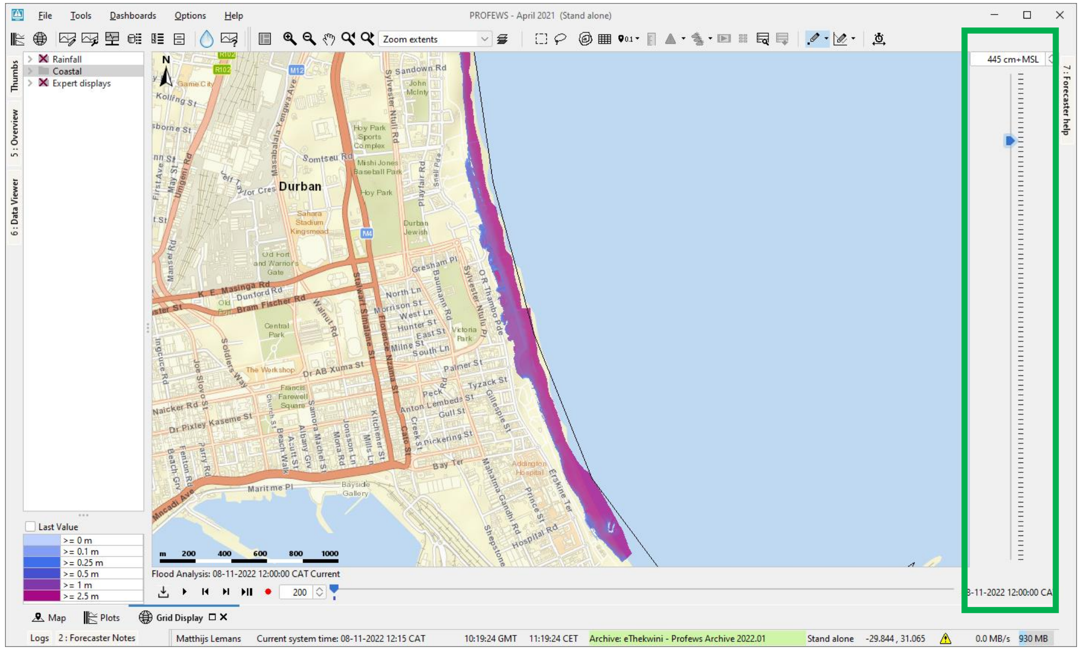
Combine 1D simulations at specific forecasting locations with offline Flood Maps

4. Configure a grid display to visualize the 2D inundation forecast



Visualize imported Flood maps in Spatial Display using vertical slider, without time dimension

1. Import 2D simulations (or their references) from static offline flood maps, each water depth as separate ensemble
2. Process the ensemble time series to a ‘normal’ time series with the water depth as unique locationId’s
3. Configure a grid display with vertical slider to visualize the 2D inundation forecast



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Visualize imported Flood maps in Spatial Display using vertical slider

1. Import references of 2D simulations grid files from static offline flood maps, each water depth as separate ensemble
   - The different maps usually have just one value at a random time step
   - Import the different maps as ensemble members

```xml
<import>
  <general>
    <importType>NETCDF-CF_GRID_REFERENCES</importType>
    <folder>$IMPORT_FOLDER_INUNDATION$</folder>
    <fileNamePatternFilter>$LOOP_LOCATION_ID$*</fileNamePatternFilter>
    <fileNameEnsembleMemberIndexPattern>$LOOP_LOCATION_ID$_???.nc</fileNameEnsembleMemberIndexPattern>
    <deleteImportedFiles>false</deleteImportedFiles>
    <idMapId>IdImportInundationDepth</idMapId>
    <unitConversionsId>ImportUnitConversions</unitConversionsId>
    <dataFeedId>FloodMaps</dataFeedId>
  </general>
  <timeSeriesSet>
    <moduleInstanceId>Import_InundationDepthGrids</moduleInstanceId>
    <valueType>grid</valueType>
    <parameterId>WD.simulated</parameterId>
    <locationId>$LOOP_LOCATION_ID$</locationId>
    <timeSeriesType>temporary</timeSeriesType>
    <timeStep multiplier="1" unit="hour"/>
    <readWriteMode>add originals</readWriteMode>
    <ensembleId>FloodMaps</ensembleId>
  </timeSeriesSet>
</import>
```

c:\FEWS\FEWS_Durban\PROFEWS-SA\Import\inundation_grids*.*

Name	Ext	Size	Date	Attr
[..]		<DIR>	08-11-2022 11:07	----
a00_500	nc	4.811.531	14-12-2021 18:44	-a--
a00_495	nc	4.811.531	14-12-2021 18:44	-a--
a00_490	nc	4.811.531	14-12-2021 18:44	-a--
a00_485	nc	4.811.531	14-12-2021 18:44	-a--
a00_480	nc	4.811.531	14-12-2021 18:44	-a--
a00_475	nc	4.811.531	14-12-2021 18:44	-a--
a00_470	nc	4.811.531	14-12-2021 18:44	-a--
a00_465	nc	4.811.531	14-12-2021 18:44	-a--
a00_460	nc	4.811.531	14-12-2021 18:44	-a--
a00_455	nc	4.811.531	14-12-2021 18:44	-a--
a00_450	nc	4.811.531	14-12-2021 18:44	-a--
a00_445	nc	4.811.531	14-12-2021 18:44	-a--
a00_440	nc	4.811.531	14-12-2021 18:44	-a--
a00_435	nc	4.811.531	14-12-2021 18:44	-a--
a00_430	nc	4.811.531	14-12-2021 18:44	-a--
a00_425	nc	4.811.531	14-12-2021 18:44	-a--
a00_420	nc	4.811.531	14-12-2021 18:44	-a--
a00_415	nc	4.811.531	14-12-2021 18:44	-a--
a00_410	nc	4.811.531	14-12-2021 18:44	-a--

Visualize imported Flood maps in Spatial Display using vertical slider

2. Process the ensemble time series to a ‘normal’ time series with the water depth as unique locationId’s

workflow

```xml
<workflow xmlns="http://www.wldelft.nl/fews" xmlns:xsi="http://www.w3.org/2001/XMLSche
  <activity>
    <runIndependent>false</runIndependent>
    <moduleInstanceId>Import_InundationDepthGrids</moduleInstanceId>
    <moduleConfigFileName>Import_InundationDepthGrids</moduleConfigFileName>
    <loopLocationSetId>Inundation.grids</loopLocationSetId>
  </activity>
  <activity>
    <properties>
      <string key="ENS_ID" value="100"/>
    </properties>
    <runIndependent>false</runIndependent>
    <moduleInstanceId>InundationEnsemble</moduleInstanceId>
    <moduleConfigFileName>Template_InundationEnsemble</moduleConfigFileName>
    <loopLocationSetId>Inundation.grids</loopLocationSetId>
  </activity>
  <activity>
    <properties>
      <string key="ENS_ID" value="105"/>
    </properties>
    <runIndependent>false</runIndependent>
    <moduleInstanceId>InundationEnsemble</moduleInstanceId>
    <moduleConfigFileName>Template_InundationEnsemble</moduleConfigFileName>
    <loopLocationSetId>Inundation.grids</loopLocationSetId>
  </activity>
  <activity>
    <properties>
      <string key="ENS_ID" value="110"/>
    </properties>
    <runIndependent>false</runIndependent>
    <moduleInstanceId>InundationEnsemble</moduleInstanceId>
    <moduleConfigFileName>Template_InundationEnsemble</moduleConfigFileName>
    <loopLocationSetId>Inundation.grids</loopLocationSetId>
  </activity>
  <activity>
    <properties>
```

transformation

```xml
<variable>
  <variableId>Input_$LOOP_LOCATION_ID$</variableId>
  <timeSeriesSet>
    <moduleInstanceId>Import_InundationDepthGrids</moduleInstanceId>
    <valueType>grid</valueType>
    <parameterId>WD.simulated</parameterId>
    <locationId>$LOOP_LOCATION_ID$</locationId>
    <timeSeriesType>temporary</timeSeriesType>
    <timeStep multiplier="1" unit="hour"/>
    <relativeViewPeriod unit="hour" start="0" end="0"/>
    <readWriteMode>read only</readWriteMode>
    <ensembleId>FloodMaps</ensembleId>
    <ensembleMemberId>$ENS_ID$</ensembleMemberId>
  </timeSeriesSet>
</variable>
<variable>
  <variableId>Output_$LOOP_LOCATION_ID$</variableId>
  <timeSeriesSet>
    <moduleInstanceId>InundationEnsemble</moduleInstanceId>
    <valueType>grid</valueType>
    <parameterId>WD.simulated</parameterId>
    <locationId>Inundation_$LOOP_LOCATION_ID$_L$ENS_ID$</locationId>
    <timeSeriesType>simulated historical</timeSeriesType>
    <timeStep multiplier="1" unit="hour"/>
    <relativeViewPeriod unit="hour" start="0" end="0" startOverrulable="true"/>
    <readWriteMode>add originals</readWriteMode>
    <synchLevel>41</synchLevel>
    <expiryTime unit="day" multiplier="365"/>
    <ensembleId>main</ensembleId>
  </timeSeriesSet>
</variable>
<transformation id="L$ENS_ID$">
  <user>
    <simple>
      <expression>Input_$LOOP_LOCATION_ID$</expression>
      <outputVariable>
        <variableId>Output_$LOOP_LOCATION_ID$</variableId>
      </outputVariable>
    </simple>
  </user>
</transformation>
```

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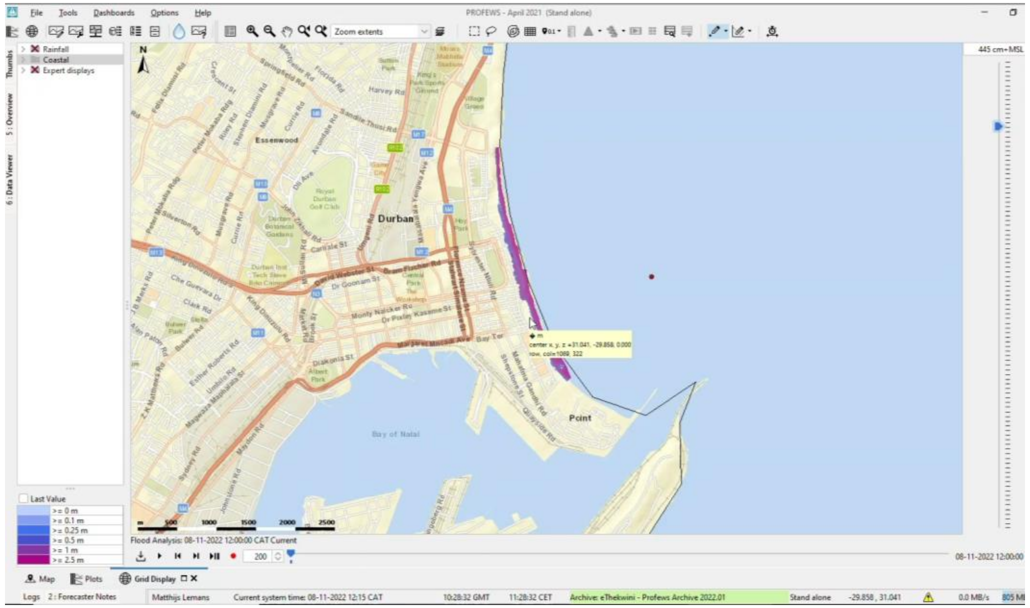
Visualize imported Flood maps in Spatial Display using vertical slider

3. Configure a grid display with vertical slider to visualize the 2D inundation forecast

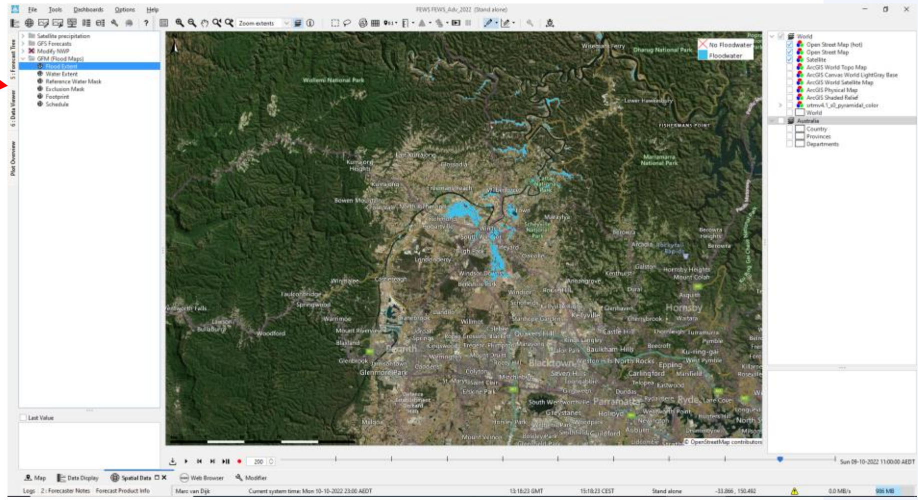
- Use a zParameterId in the datalayer to generate a vertical slider
- Only one (main)layer with specific locationId is configured
- The display interpolates between the available sibling layers

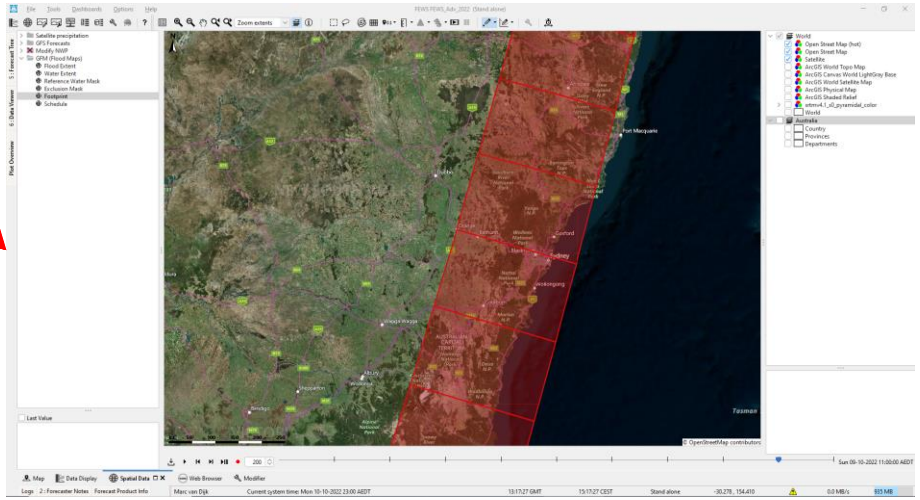
```xml
<gridPlot id="inundation_fa" name="Flood Analysis">
  <dataLayer>
    <timeSeriesSet>
      <moduleInstanceId>InundationEnsemble</moduleInstanceId>
      <valueType>grid</valueType>
      <parameterId>WD.simulated</parameterId>
      <locationId>Inundation_A00_L100</locationId>
      <timeSeriesType>simulated historical</timeSeriesType>
      <timeStep unit="hour"/>
      <relativeViewPeriod unit="day" start="-10000" end="10000"/>
      <readWriteMode>add originals</readWriteMode>
    </timeSeriesSet>
    <zParameterId>H.simulated.cm</zParameterId>
  </dataLayer>
  <classBreaksId>Class.Water.Depth</classBreaksId>
</gridPlot>
```



Use Remote Sensing data for rapid flood mapping

- In 2021, a new operational, near real-time global flood monitoring (GFM) was integrated into GloFAS. The new GFM provides a continuous monitoring of floods worldwide by immediately processing and analyzing all incoming Copernicus Sentinel-1 Synthetic Aperture Radar (SAR) satellite data
- GFM WMS-T is freely accessible at the following URL: **https://geoserver.gfm.eodc.eu/geoserver/gfm/wms**
- This WMS-T can be used in Delft-FEWS, to visualize the following data:
  - **Flood Extent**
  - Water Extent
  - Reference Water Mask
  - Exclusion Mask
  - **Footprint**
  - Schedule





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Use Remote Sensing data for rapid flood mapping

- Configuration of WMS layer in Spatial display xml file
  - URL of WMS Server
  - WMS layer Name
  - Date Time pattern
  - Timestep and period

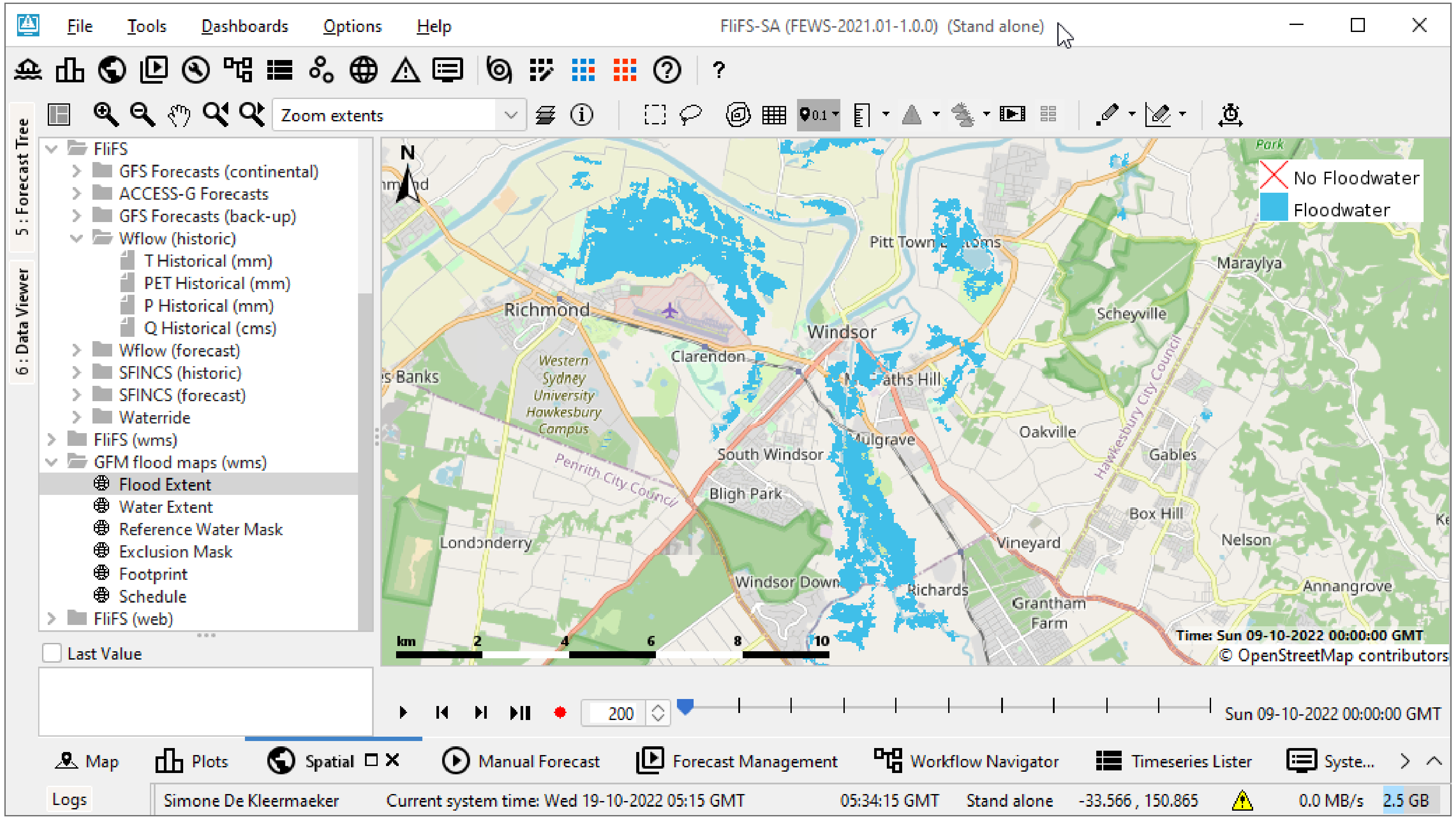
```xml
<gridPlot id="GFM_Flood_Extent" name="Flood Extent">
  <wmsLayer>
    <url>https://geoserver.gfm.geoville.com/geoserver/gfm/wms?</url>
    <wmsLayerName>observed_flood_extent</wmsLayerName>
    <imageFormat>png</imageFormat>
    <transparent>true</transparent>
    <dateTimeParameter name="time" format="yyyy-MM-dd'T00:00:00.00Z'" timeZone="GMT"/>
    <timeStep unit="day"/>
    <relativeViewPeriod unit="day" start="-10" end="0"/>
  </wmsLayer>
  <logo>
    <imageFile>GFM_legend_observed_flood_extent.png</imageFile>
    <position>topRight</position>
  </logo>
</gridPlot>
```

- Configuration of logo as legend

- Info in topology.xml for Web Viewer

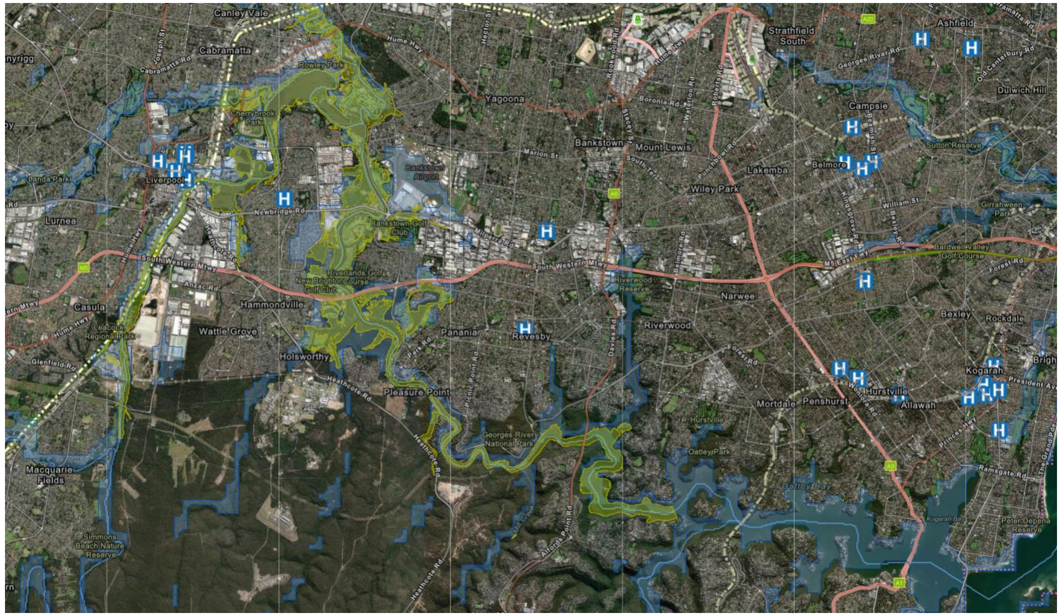
```xml
<node id="GFM_FloodMap" name="GloFAS Global Flood Monitoring (GFM)">
  <mainPanel>web browser display</mainPanel>
  <url>https://www.globalfloods.eu/technical-information/glofas-gfm/</url>
  <localRun>false</localRun>
  <showRunApprovedForecastButton>false</showRunApprovedForecastButton>
</node>
```

Use Remote Sensing data for rapid flood mapping



Future ideas?

- Apply the flood maps to a streamflow ensemble. This would allow one to draft probabilistic inundation maps showing the extend that is likely to be flooded with 10%, with 20%, ... with 90% certainty, et cetera.
- Combine the flood extents with the estimated consequences of that inundation – like locations with critical infrastructure or hospitals
- Or even further: combine the consequences with the probabilities: 90% probability that one hospital will be flooded, 80% probability that 3 hospitals will be flooded, ... 10% probability that 67 hospitals will be flooded: a map of flood risk!
- …
- …
- …



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