FLOOD MODELING

UNIT 2

RMS® CCRA® Training Program

Certified Catastrophe Risk Analyst

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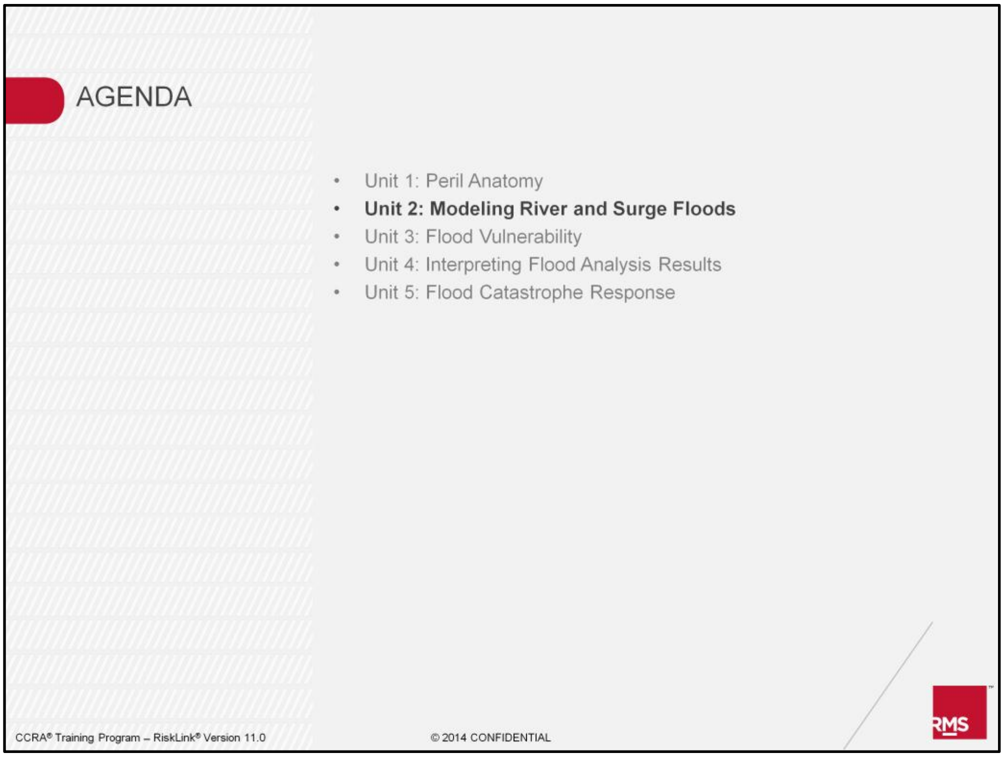

This unit discusses the vulnerability module of the Europe windstorm model.

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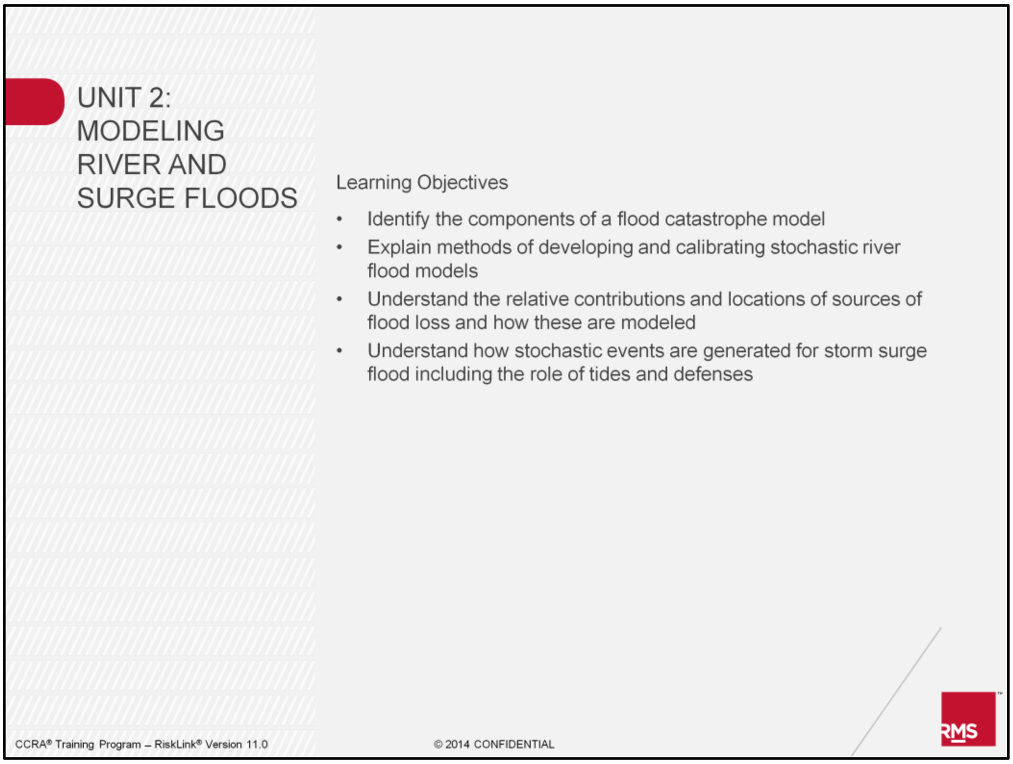
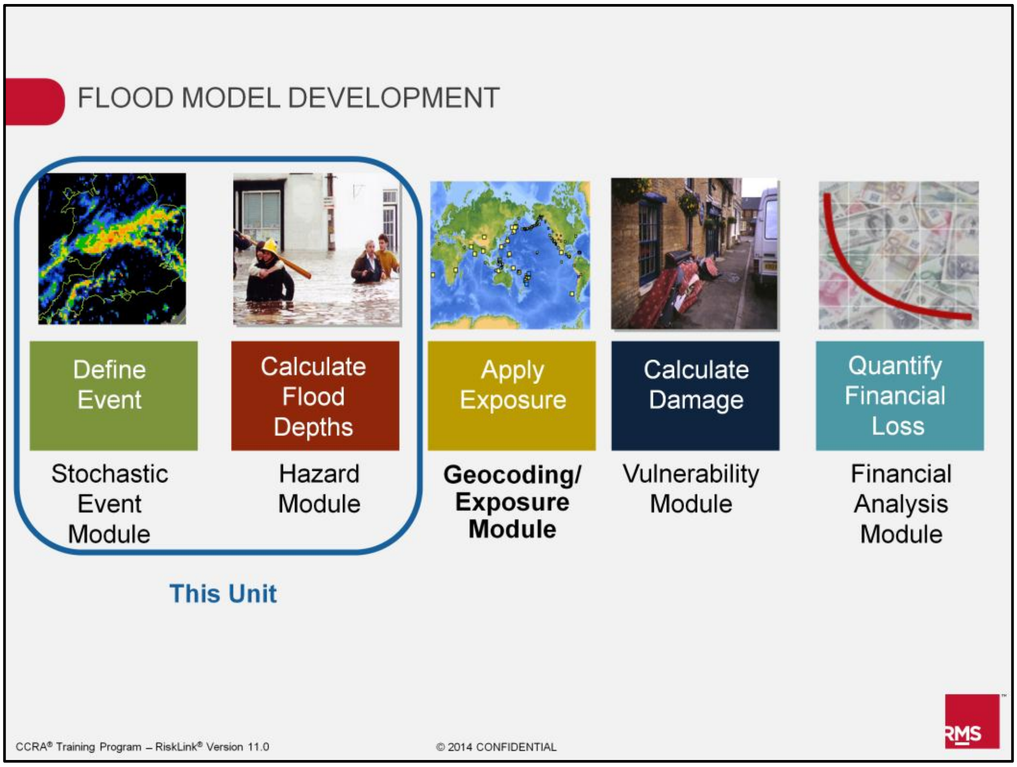
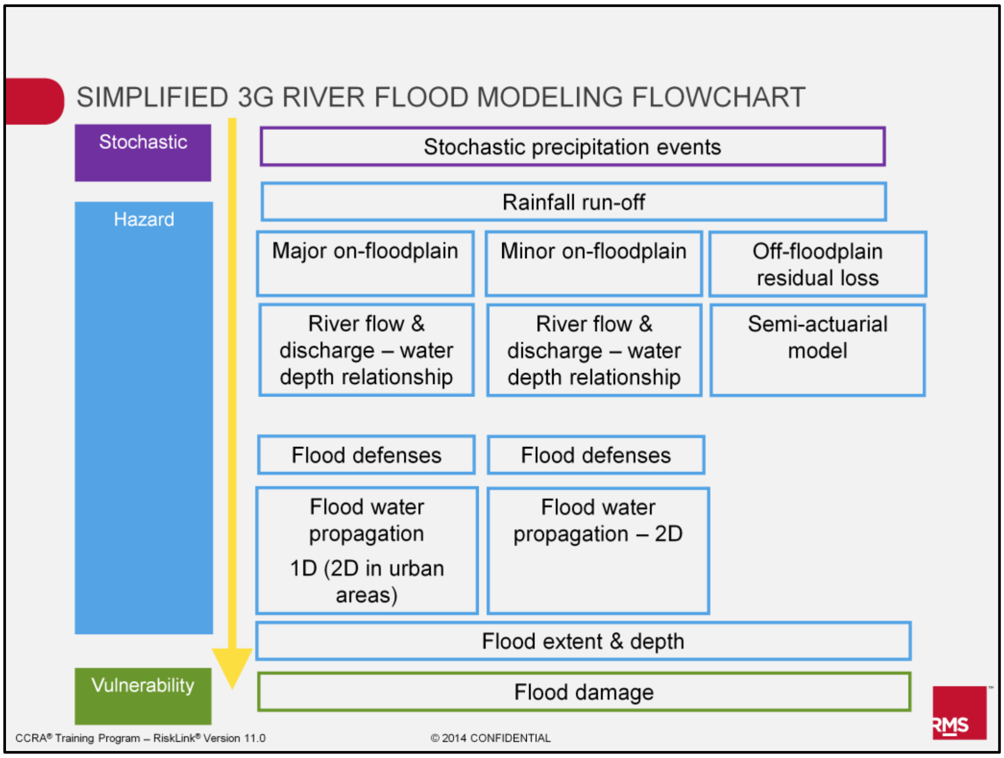


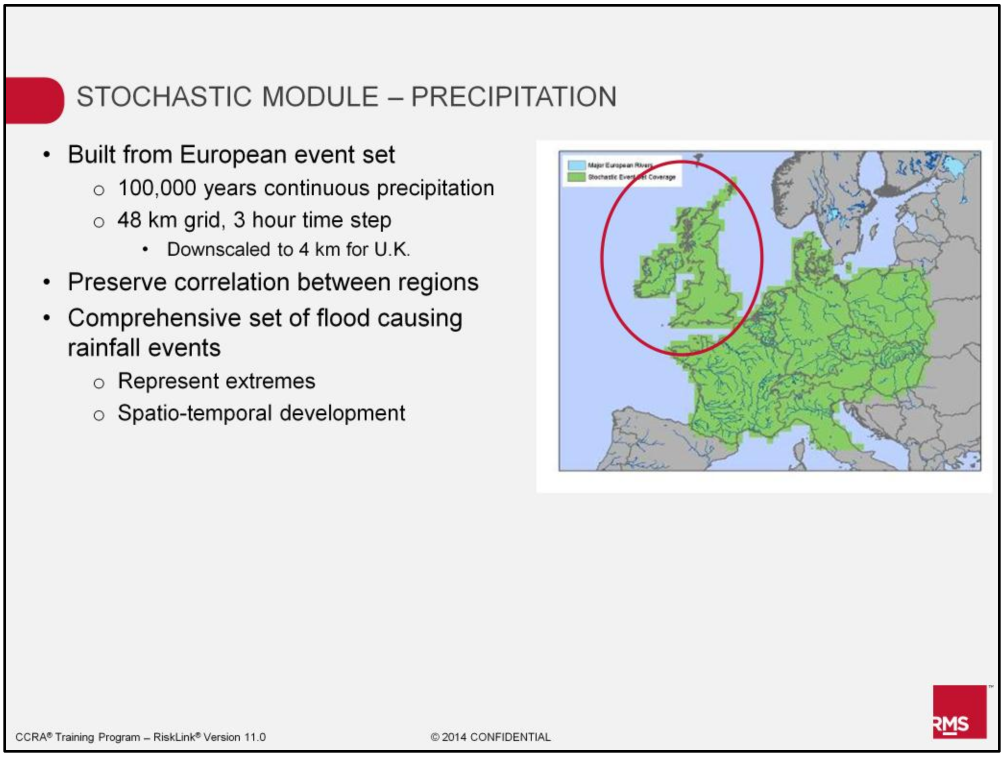
At the end of this unit you should have a good understanding of each of the five learning objectives listed on this slide.



There are four modules that comprise a catastrophe risk model. The stochastic module involves the creation of the event set. The hazard module determines the flood depth at each location. This information is then used by the vulnerability module to assess damage, which lastly, is input into the financial module from which we compute the losses. In this unit we are going to focus on the first two - the creation of the stochastic event set and the hazard module.



This graph shows how RMS models flood using a third generation (3G) river flood modeling flowchart. Every model that describes geophysical phenomena in space and time needs boundary conditions, initial conditions, and model parameters. These are then used to calculate a rainfall runoff model that also includes snow water equivalent as one of its stated variables. The water that is created as runoff is then routed through a river network where it can potentially flow above the river bed and flood property. The off-floodplain component in our modeling approach (e.g. the potential for flood risk outside of defined floodplains) is accounted for, and will be explained later in this presentation. Output from this model is stored on a variable resolution grid (VRG) from 50 m to 5 km.



As was shown in Unit 1, the causes of river and surge flooding can be regional in scale. In order to compute losses on a continental scale, it is necessary to create scenarios with the correct spatial and temporal evolution over the area of interest. This image shows the coverage of the current Europe-wide event set. For the green area we have to create spatial and temporal developments of precipitation that have never been observed, but that are realistic. This method should also include the effects of possible climate change scenarios. The blue circle represents Great Britain, where RMS has implemented the latest technology for the U.K flood model. Large scale precipitation was modeled on a 48 km grid and later statistically scaled down to 4 km.

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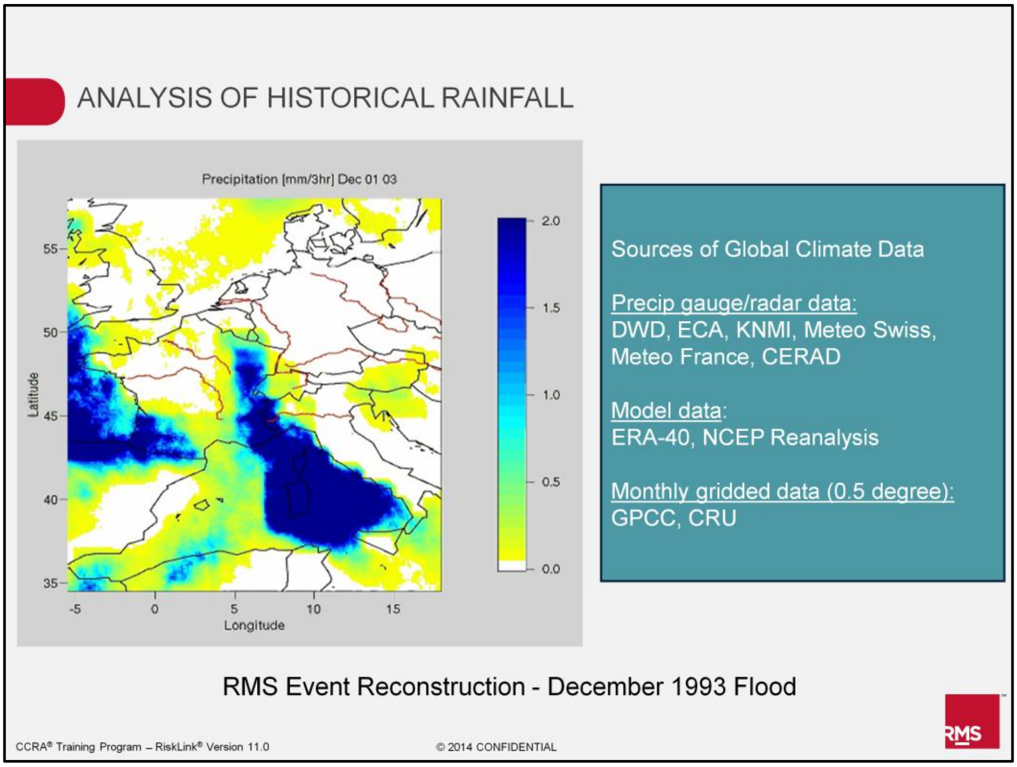

One technique for developing a stochastic precipitation model is to use measured precipitation data. This is the most complicated method when it comes to data gathering and processing. There are only about 100 years of measured data in Europe. Furthermore, the station density and the data quality/availability vary widely from country to country. It was therefore necessary to first recreate 45 years (1958 – 2002) of three-hourly precipitation from a blend of modeled data (ERA-40, NCEP reanalysis), station and radar data (see sources above), and the CRU and Global Precipitation Climatology Centre (GPCC) monthly data sets. This was accomplished using a “3D-var” analysis that optimally combines the measured and the modeled data. Based on this analysis, RMS now has a precipitation data set that covers all of Europe and has the correct spatial and temporal evolution. This data set in itself does not give us any new extremes beyond the 100-year return period.

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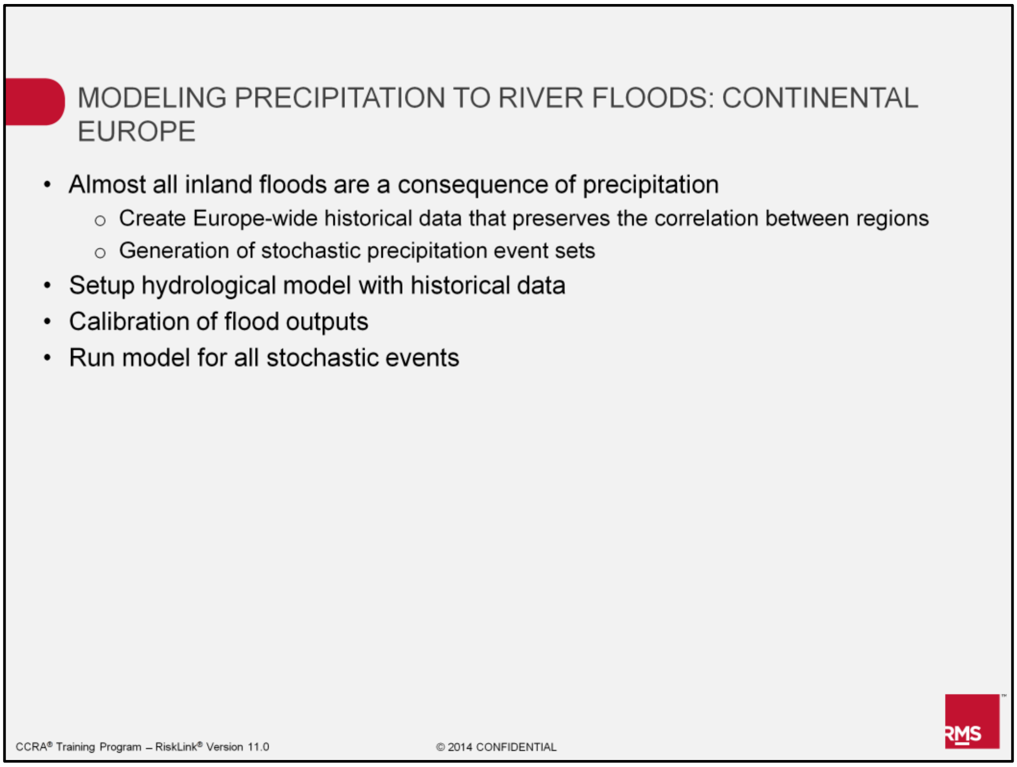

Inland floods are almost always a consequence of precipitation, the majority of which is rainfall; however, snowfall can also be significant in some classes of floods. In order to build a model of such river flood events, we need first to understand the precipitation characteristics of specific historical floods. Having understood the characteristics, the spatial scale, and geographic distribution of the rainfall associated with historical floods, we can use one of several techniques to develop a stochastic precipitation model which is the basis for generating the floods themselves. The rainfall which generates the flood will fall on the ground which may already be fairly saturated along rivers with high levels of run-off. In many situations it is important that antecedent conditions, such as ground saturation and the level of flow in the rivers, be captured before a specific precipitation event occurs.

Based on the amount of precipitation, it is possible to trace how the water moves into the rivers and ultimately contributes to flooding. This is the development of the hydrological model.

Throughout the process of building this model, it is important to calibrate the modeling procedure both for precipitation and for the flow in the rivers against historical data sets. The model results for all stochastic events are also calibrated against historical events.

SCALE OF PRECIPITATION EVENTS IN EUROPE

Scale	Size (km^2)	Duration	Example
Synoptic	25,000 - 1,000,000	Several Days	Oder Floods 1997 (580 mm in 4 days)
Large Mesoscale	> 50,000	6-24 hr	Easter Floods 1998 (76 mm in 22 hrs)
Mesoscale	< 2500	1-12 hr	Lynmouth 1952 (228 mm in 12 hrs)
Small Mesoscale	< 750	0.5-3 hr	Hampstead 1975 (175 mm in 3 hrs)
Microscale	< 10	< 0.5 hr	“April shower” (up to 30 mm)

U.K.

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It is worth recognizing that there is a very strong relationship between the rainfall extreme over a given time period, and the area over which that rainfall extreme was experienced. For example, the top of the table on this slide shows very large scale precipitation events where the total area affected could be up to or even in excess of 100,000 square kilometers, and the rainfall occurs over a series of days. An example of this are the floods in central Europe, both in 1997 and in 2002, when nearly 600 millimeters of rainfall occurred in a span of a few days. These large scale synoptic events impact very large river systems or several large river systems in the same event.

The large mesoscale event is typically up to about 50,000 square kilometers of area. An example was the 1998 U.K. Easter floods where about 80 millimeters of rainfall occurred in about 24 hours. On a smaller scale, mesoscale convective complexes may cover 2,000 square kilometers over half a day – as when more than 200 millimeters fell in the summer of 1952 in northern Devon. In the smaller-scale thunderstorm flash floods, as in North London and Hampstead in 1975 when 175 millimeters fell in three hours within the area of a few hundred square kilometers.

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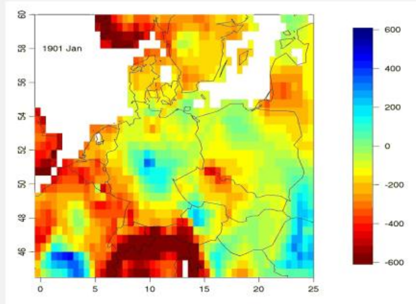
CREATION OF PRECIPITATION SCENARIOS

- Develop 102-year monthly precipitation dataset – 0.5º grid
- Analyze principal component patterns of rainfall anomalies
- Develop new monthly precipitation scenarios using Monte Carlo approach
- Break down monthly precipitation fields into 3 hourly fields



RESULT: 100,000 years of continuous modeled rainfall statistically similar in frequency, intensity, and correlation to observed precipitation

Validated against independent benchmarks (KOSTRA atlas, UK Flood Estimation Handbook)

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Since inland flood is almost always a consequence of precipitation, we must create a series of precipitation scenarios. From monthly precipitation data, for each 0.5 x 0.5 degree grid cell, we measure how much a particular month's precipitation (e.g. July 2002) deviates from the mean for the month (July) over the whole time period. The result is a time series of 102 years of gridded monthly precipitation anomalies for further analysis for each 0.5 degree grid cell.

The next step is to transform the precipitation in each grid cell into normal distributions and then generate principal component analysis (PCA) patterns and the associated time series. Using a Monte Carlo sampling of the principal components time series, RMS developed new anomalies that are statistically similar to those observed historically over the last 102 years. The new monthly data was then spatially and temporally disaggregated with observed data from a 45-year reconstructed time series.

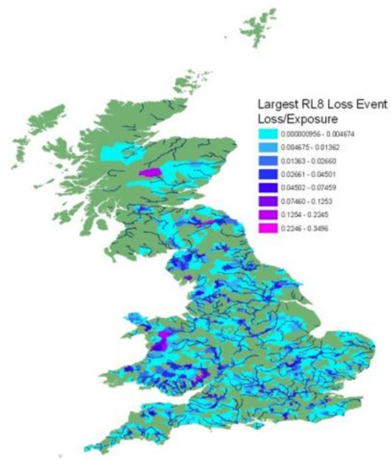
To account for small scale and short duration-type rainfall phenomena and the flood events that these can trigger, the existing 0.5 degree precipitation field was modified by overlaying it with a 4 km correlated noise field. The resulting downscaled precipitation field changes the precipitation locally over short time spans while conserving the mean precipitation over a longer period of time based on the original 0.5 degree data. The hydrological effect is that the local flood events with a short duration are more pronounced, whereas the effect of the larger scale events is marginal.

After creating 100,000 years of simulated rainfall, the next step is to translate rainfall into runoff, which is the amount of water available to flow over the ground and into the river network.

FROM PRECIPITATION TO FLOW TO FLOOD

MODEL FEATURES (UK FLOOD)

- Approximately 2 billion 10 m grid cells for distributed hydrological modeling
- 821 catchments (each ~ 500 km^2)
- Atmospheric forcing with 3 hour time steps for rainfall – runoff model
- Snow modeling with elevation bands (every 0.5 km interval)
- Minor and major floodplain
- 1-d routing model with 5 mn steps on 500 m segments
- 2-d routing with hydraulic model with seconds time step
- Continuous multi-100-year periods
- Calibration of model parameters
- EA defense data



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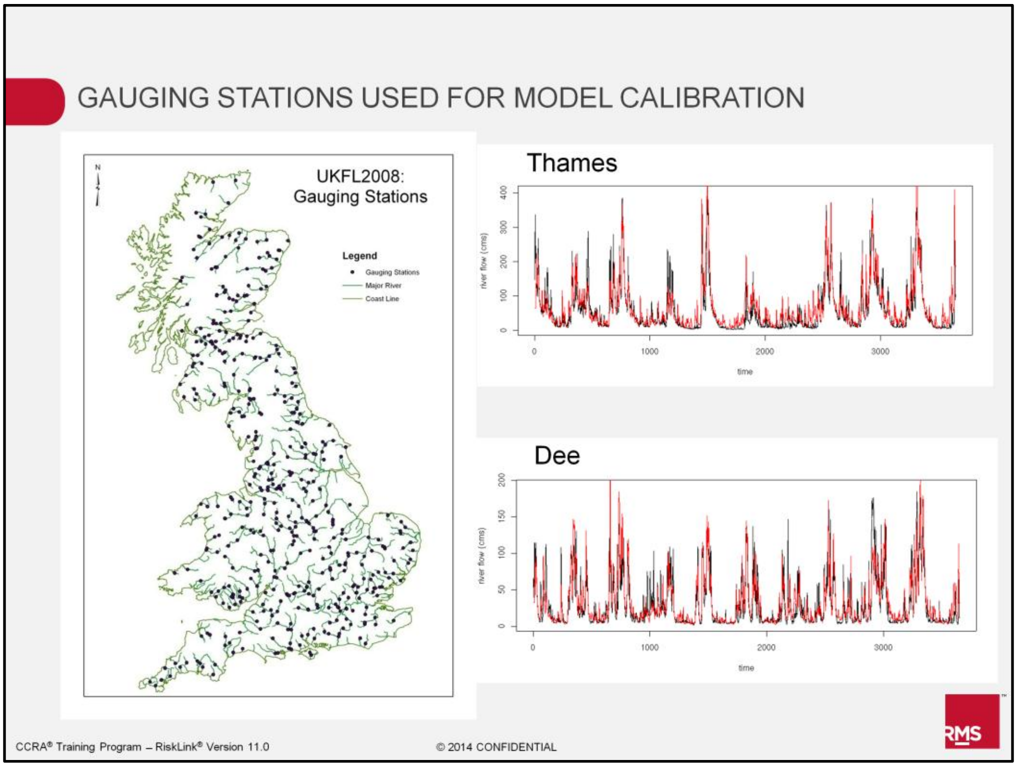
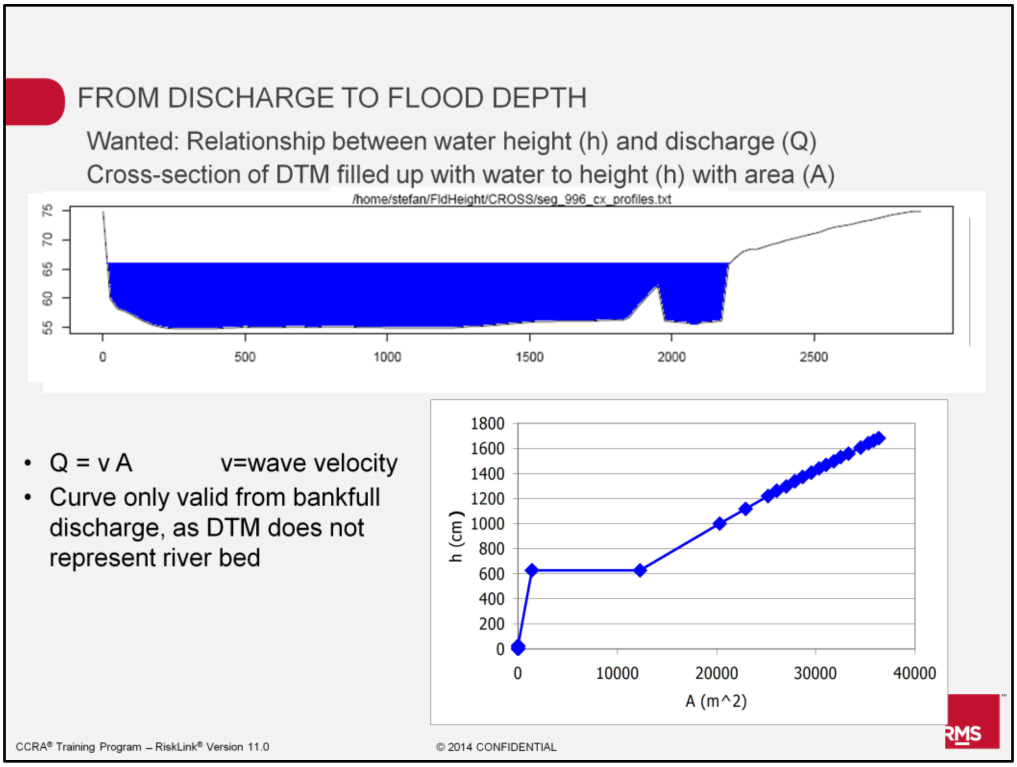
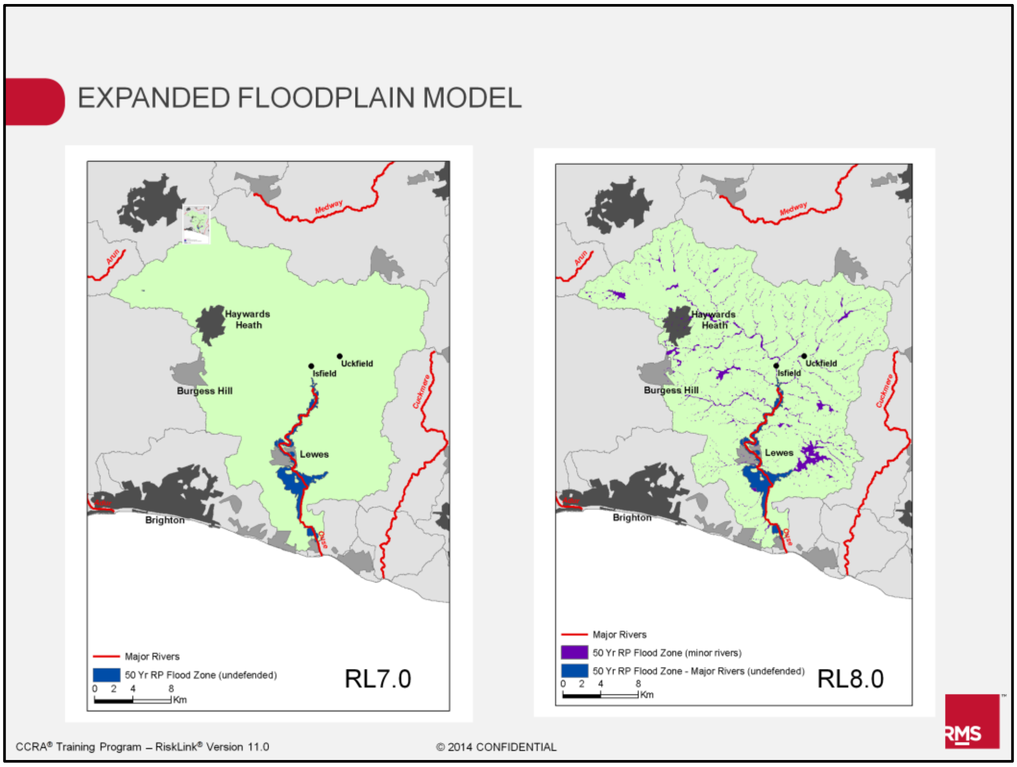
Using the results from the precipitation model analyses, river discharge models and flood depths are calculated. First, we compute the amount of precipitation that falls as snow. Second, we calculate the amount of rain plus snow melt-water that contributes to surface runoff and to infiltration. At that time the model also computes the groundwater discharge. Both runoff components are then fed into a one-dimensional river routing model with five minute time steps on 500 meter length river segments. This is performed over continuous multi-100-year time periods. In order to make observed streamflow and modeled streamflow agree, a complete multi-objective, multi-parameter calibration is performed on most model parameters. Input from the rainfall runoff model is also input for the two-dimensional minor floodplain model.



The map of the U.K. on the left shows all locations of river gauges that were used to calibrate the rainfall runoff and one-dimensional river routing model in the U.K. Inland Flood Model. Results of that calibration are shown on the right side of the slide for two rivers (the Thames and the Dee) from 1986 to 1995. The black lines show the observed streamflow while the red curve is the modeled result.



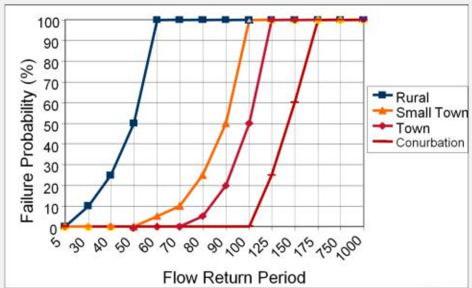
Once the river water volume is assessed, it is then possible to compute the river flood height. The easiest way to see the relationship between modeled flow (Q) and the corresponding river height (h) is by viewing a cross-section of a digital terrain model (DTM) and fill it up with water. The wave velocity (v) can be calibrated from observed data, so that after we compute Q, we can determine A and then have a simple look-up table that relates A with h. One element that introduces uncertainty is that the elevation of the river bed (bathymetry) is normally not known, and must therefore be estimated.



The images on this slide compare the expanded floodplain in RiskLink 8.0 to that of 7.0. The advances in computational fluid mechanics allowed us to compute the flood risk in far more detail. Beginning in RiskLink 8.0, RMS was able to quantify the flood risk in approximately 1,000,000 km of rivers in the U.K. This slide shows the increase in coverage of the floodplain in RiskLink 8.0.

INCORPORATION OF FLOOD DEFENSES AND OTHER FLOOD CONTROL MEASURES

- Flood defense performance is modeled probabilistically
- Strong correlation in the U.K. and Germany found between return period of flood defense protection and value at risk
- High correlation of “uncertainty in flood outcome” for properties protected by the same flood defense



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One complexity of modeling flood is that in many locations, defenses or levees have been created to try and prevent the flow from passing into protected land that often have buildings. Available information on flood defenses is often incomplete. We may not know exactly how high the flood defense is at every location. There may be gates in the flood defense, holes may have been cut in the flood defense, and they may be of variable quality. It is hard to model the performance of flood defenses deterministically. Instead, it is better to model their performance probabilistically. That means that we assume there is some relationship between the probability that the defense will fail and the return period of the flow on the river.

We have found in the U.K. there is quite a good correlation between the value at risk that is protected by a given flood defense and the return period to which the flood defense will offer protection. And we can use this in developing ‘fragility functions’ which reflect the probability that the defense fails relative to the return period of extreme flow.

For example, if the flood defense is only protecting agricultural land, typically it may fail at a flood of ten or 20 years. But if the flood defense is protecting a high value concentration associated with a town, then typically the flood defense may be built to withstand flows with 50- or 100-year return periods. This is something that can be incorporated in the modeling. We can test this assumption from defense performance in actual floods.

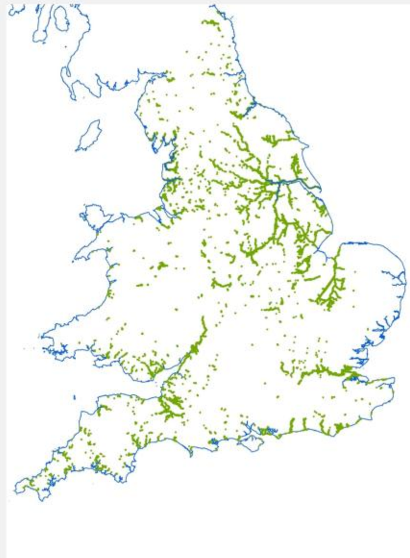
For a town with many properties in the protected floodplain, there is a high correlation of the uncertainty of the flood outcome; i.e. whether the property is flooded or not. If one flood defense is protecting a large number of properties in a town, and it fails, they may all be flooded; if it does not fail, then they may all have no loss. So, clearly, this localized correlation is quite significant.

IMPROVED DEFENSE MODELING

Environment Agency Defense Database

- 15,000 fluvial defense structures
- Total length: 7,125 km
- Design return period up to 1,000 years

Design Return Period	Fraction
1 – 15	16%
20 – 40	19%
50 – 70	16%
75 – 100	32 %
150 – 200	6 %
200 – 1,000	6 %



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RMS incorporates information form the Environment Agency's (EA) National Flood Defense Database, which contains information about the height and the standard protection against river flooding for approximately 15,000 fluvial defense structures with a total river length of over 7,100 km. The information from this database is used as input parameters for the defense model, and to estimate parameters of the defense failure model across the U.K. where no detailed defense data is available. Defense failure is modeled using a probabilistic approach to model the envelope of uncertainty around the defense failure.

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STORM SURGE FLOOD CATASTROPHE MODELING

- Tropical cyclone storm surge
  - Mainland
  - Island
- Temperate storm surge
- Role of tide vs. storm surge
- Defended vs. undefended coastline

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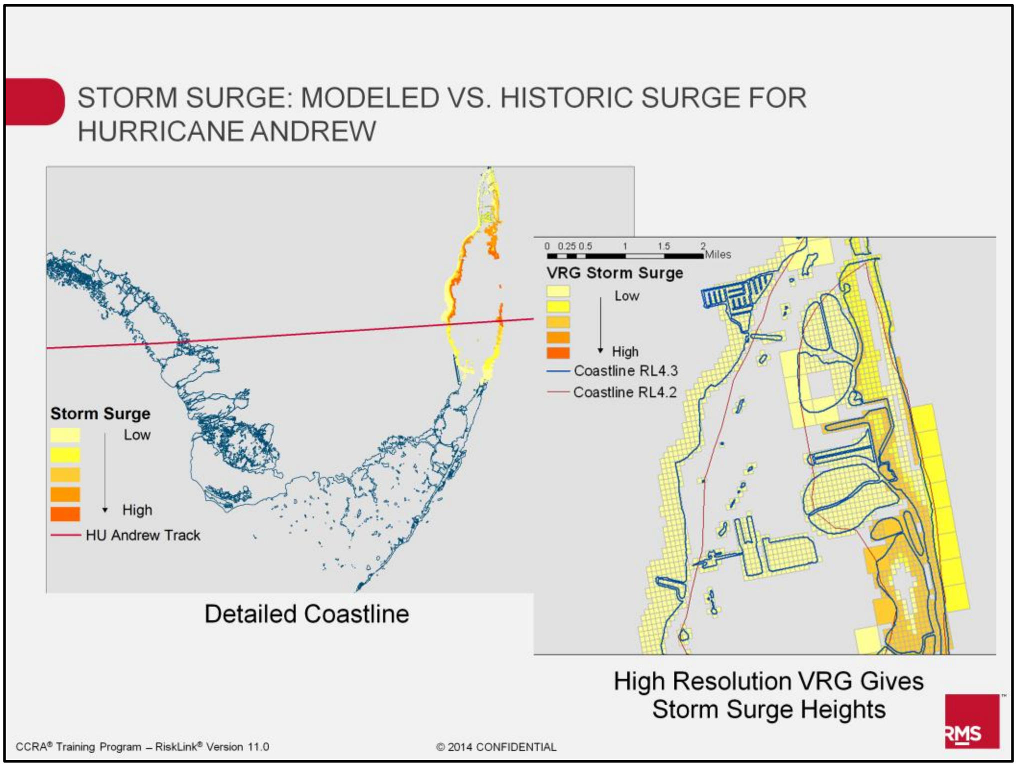
Next we will talk about storm surge flood catastrophe modeling.

Storm surge is simply a rise in sea level principally forced by the wind, but also by the low pressure at the center of a deep storm. As there is less load on the ocean, the water levels rise. For a tropical cyclone, the impact of the storm surge can be very different between a mainland location and an island. For a mainland location ,the water becomes banked up against the coast and may reach five, six, or seven meters in height.

However on a small island, five to 20 kilometers long, much of the raised water levels may go around the island instead of banking up against one shoreline. Typically for storm surges on islands, heights might reach two to three meters.

Outside the tropics, the winds of extra-tropical cyclone storms are typically not as high as in tropical cyclones, therefore, storm surges tend to be lower. The storm surge will typically be two or three meters on open coastlines reaching four to five meters where the surge becomes concentrated or has a funnel shaped inlet, as in the southeast corner of the North Sea around Hamburg.

In modeling storm surge floods the tides can be very significant. Tides vary as the ultimate water level may be very dependent on how the tide and the surge interact. We also need to consider the difference between defended and undefended coastlines. If they are defended, we need to also include in the modeling how we anticipate the defense to perform.



This is an example of the storm surge for Hurricane Andrew. The red line on the left map marks the track of the storm as it passed across southern Florida. Above the track is shown the height of the storm surge where it reached the coastline. The height of the storm surge is concentrated in a band about 10 to 20 kilometers north of the storm track, which was the area impacted by the highest winds.

On the right we have blown up our reconstruction of the flood depths in this event using our high resolution VRG system, driven off the resolution of a digital terrain model.

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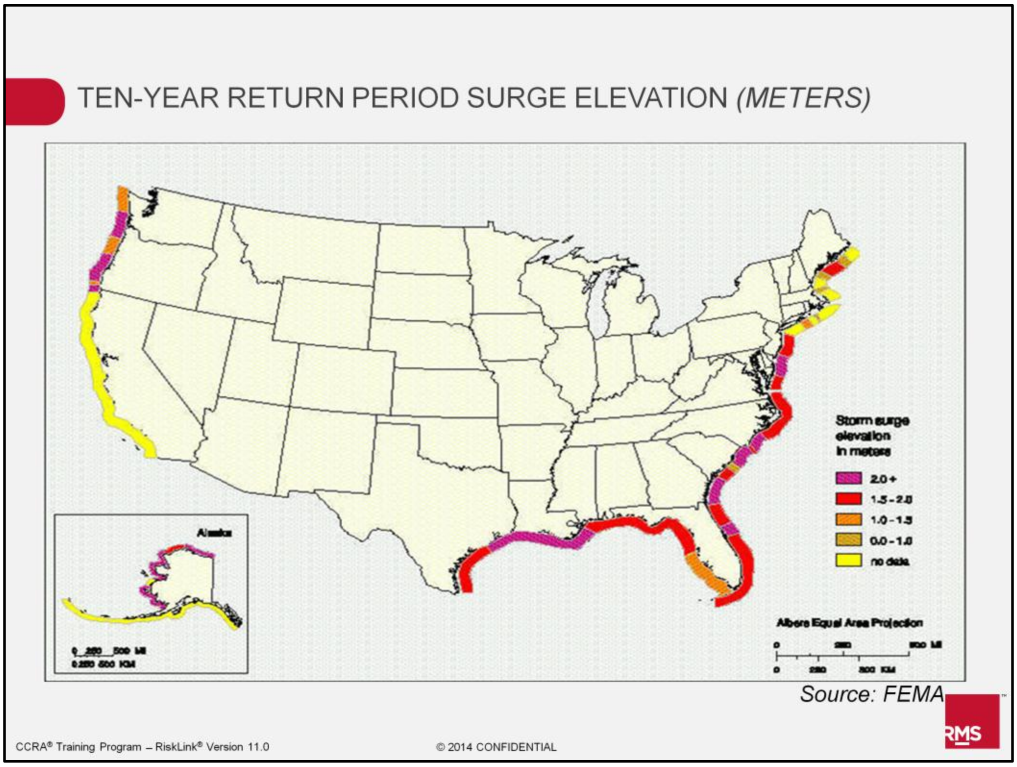
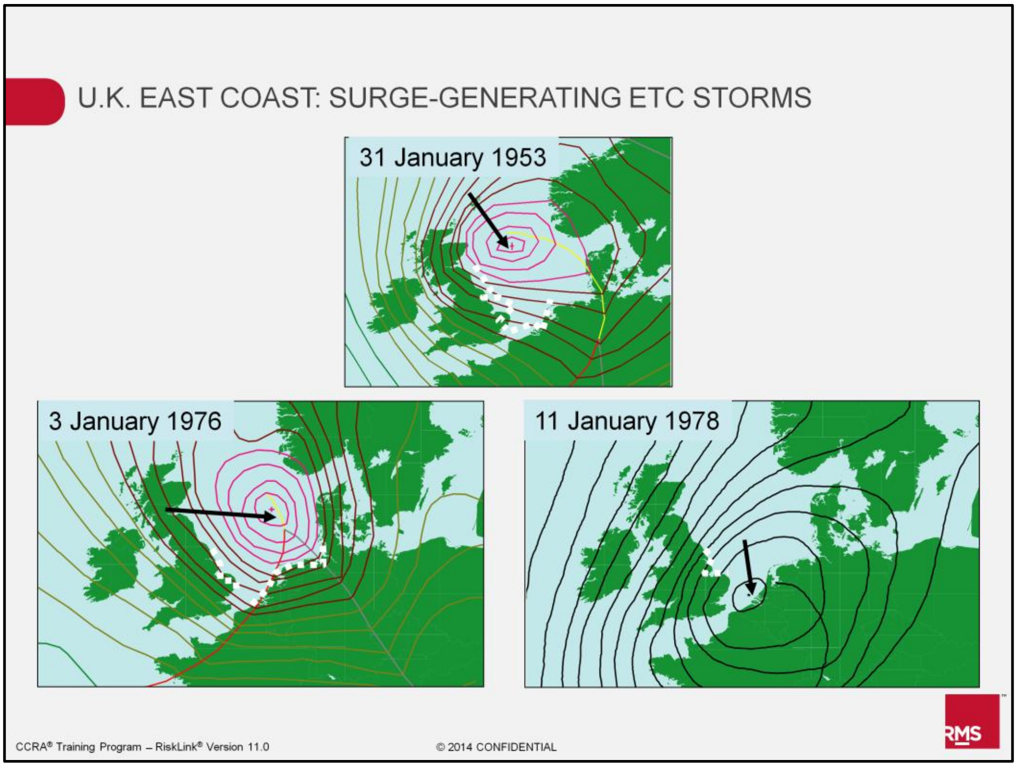


This map illustrates the various contributions to significant storm surge heights for all of the U.S. for a 10-year return period. These storm surges are predominantly generated by hurricanes along the south and east coast of the U.S. Some of the highest storm surge heights occur around the central Gulf coast and up along the coast of northern Florida into Georgia and North and South Carolina.

This is a function of the strength and intensity of hurricanes likely to be found in these regions. Further north, the hurricanes become less frequent and weaker, so the height of the storm surge is reduced. On the U.S. west coast, storm surge is generated by extra-tropical cyclones in the winter. The height of the storm surge is higher as you move to the north, because intense storms close to the Canadian border are more likely than they are in northern California.



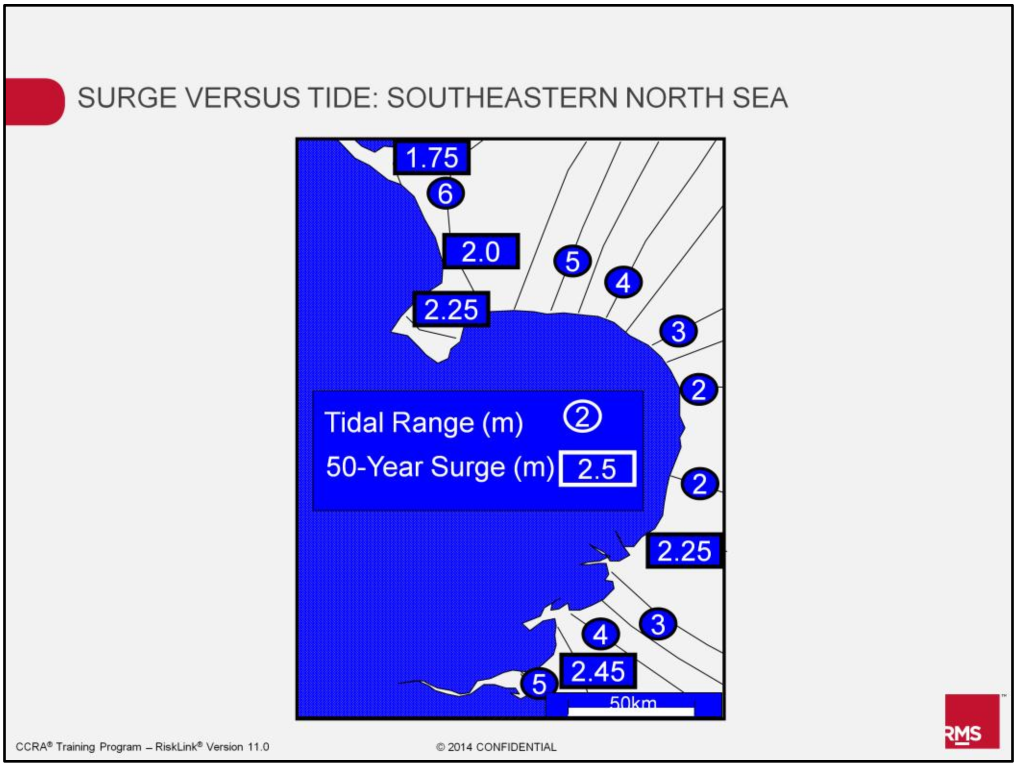
In developing an RMS storm surge model for the east coast of the U.K, we first identified the different classes of storms that generated major storm surges. We identified three different classes of storms, which we modeled separately.

On the top is the 31st of January 1953 event, which was an intense extra-tropical cyclone that moved rapidly to the southeast across the North Sea, bringing very strong winds over the western North Sea, pushing the water onto the east coast of the U.K. and also onto the coast of southern Netherlands.

On the bottom left is the January 1976 event, which involved a very deep, very large, intense storm that moved rapidly eastwards across the North Sea driving a large storm surge into the region around Hamburg, where the surge reached four to five meters in height. A storm surge of at least two meters covered a wide section of coastline ,including northern Holland, and along parts of the east coast of the U.K, where the surge was driven by strong northerly winds that came around the back of the storm.

The highest wind speeds for both these classes of storms in 1953 and 1976 were to the right-hand side of the track.

On the bottom right we have a separate and less common class of storms that can cause a storm surge in the east coast of the U.K. This is a low pressure system with a very large area of high pressure sitting out to the west of it that squeezed the isobars, the lines of equal pressure, and therefore developed strong easterly winds to the north of the storm center. The wind pushed a surge onto the coastline of eastern England causing a storm surge that was far more localized than the other two classes.

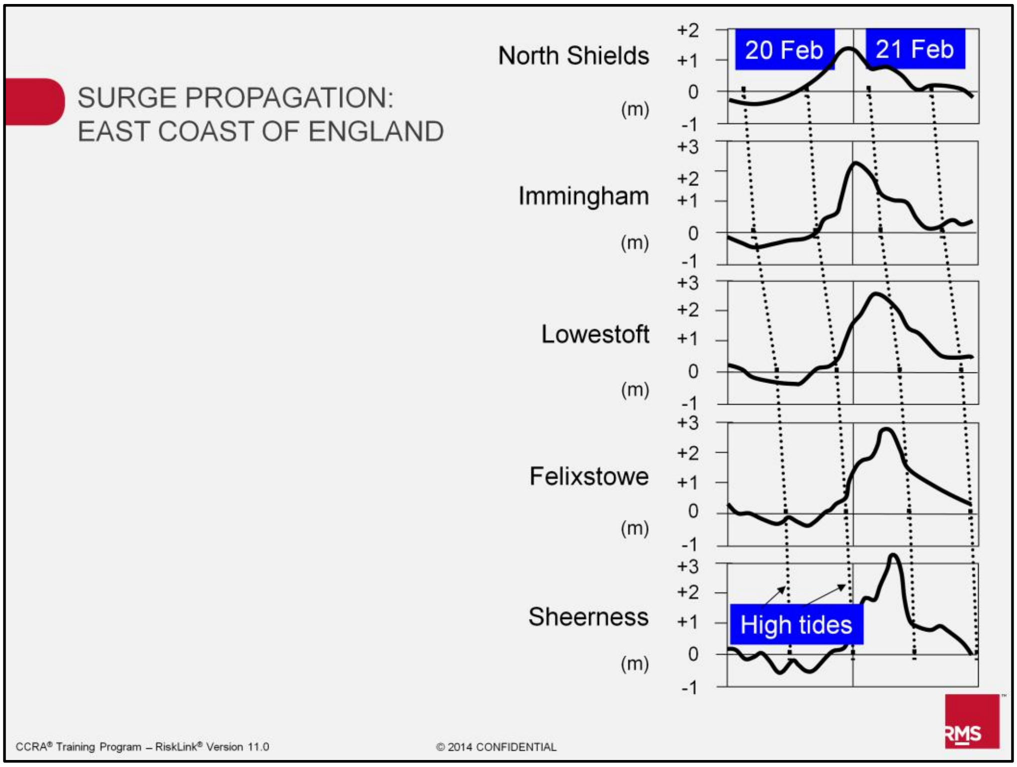


We mentioned the importance of including the tide in how we define the sea level heights. This illustrates the difference between the tidal range in meters, (the numbers in the circles), and the height of the 50-year return period storm surge (the numbers in the rectangles).

Immediately to the right of the caption you can see that the tidal range is only two meters on the northeast corner of East Anglia in England. This is the only area in the whole region where the tidal range is actually lower than the height of the 50-year storm surge. Both to the north and the south, the height of the tidal range moves up to five meters, twice the height of a 50-year storm surge. To the north the tidal range is six meters, three times as high as the 50-year storm surge in that same region.

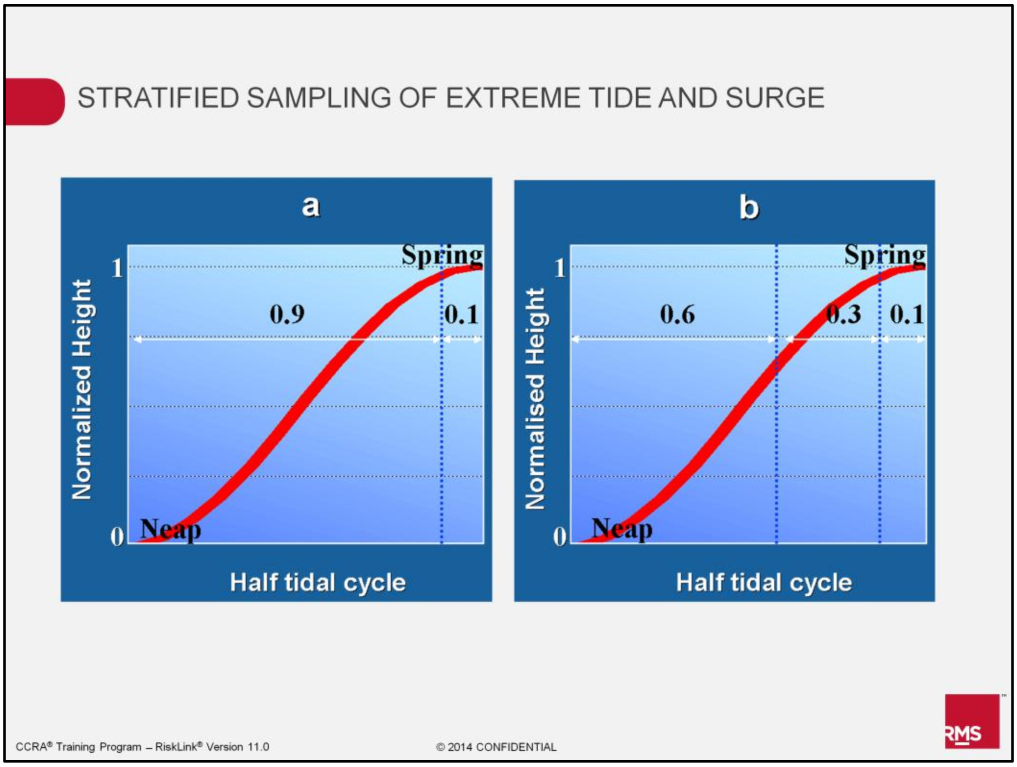
So, clearly, if we are thinking about extreme water levels, it is important to model the height of the tide, because the tide can be contributing more to an extreme water level than the height of the surge. Ultimately we are concerned with how tide and surge interact.

The tidal range varies at different states of the tide through the lunar month from the highest springs to the lowest neaps. You could have an extreme tide and not a very extreme storm surge giving you the same water levels as would be found with a moderate tide and a very extreme storm surge.



On the east coast of the U.K. the surges typically arrive from the north. As they move south, the surge and the tide tend to get in phase, with the surge arriving on the rising tides. The effect of the surge is to bring the time of the high tide forward.

This is a storm surge in January 1993. If we deduct the measured water levels from those that were expected for this day, we get the residuals, which were greatest immediately before the high tide. The high tide is indicated as one of these dotted lines connecting the individual ports which run down the east coast of the U.K. North Shields is in the far northeast corner of England, and Sheerness is close to London. You can see here that as we go further south, the height of the surge residual gets bigger, but it stays in advance of the high tide.



Modeling the possible surge and tide combinations is very challenging so we use stratified sampling when considering the role of the tide to ensure we concentrate our sampling on the most extreme events. These are most likely when we have had a very high tide. Therefore, we sample more events that combine the wind driven surge with an extreme tide than we will for a more ordinary tide. Here the sampling is focused in the top ten percent of the heights of the tide, adjusting the probabilities of the events we generate as part of the stratified sampling process.

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SEA DEFENSE FAILURE MODEL

- Failure before overtopping
- Impact of waves
- Failure following overtopping
- Failure progression
- Quantifying failure probabilities
- Stochastic sampling combinations of defense failures (extremely non-linear impacts)

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For storm surges, sea defenses are typically critical in protecting concentrations of value. Defenses are likely to be most damaged by waves superimposed on the surge. Sea defenses can start to fail before the water overtops it. Once water is flowing over the top of a defense, then failure typically follows and we need to track how this failure is likely to progress. We need to put all these factors together to quantify the probability that a particular defense fails given a specific combination of surge and tide.

As part of the stochastic modeling, we include different combinations of defenses failing at different locations because the impact of these can be very non-linear in terms of the implications for flood loss. There will be a large number of properties that have no loss if the defense holds; but if the defense fails, we may get a significant concentration of flood loss.

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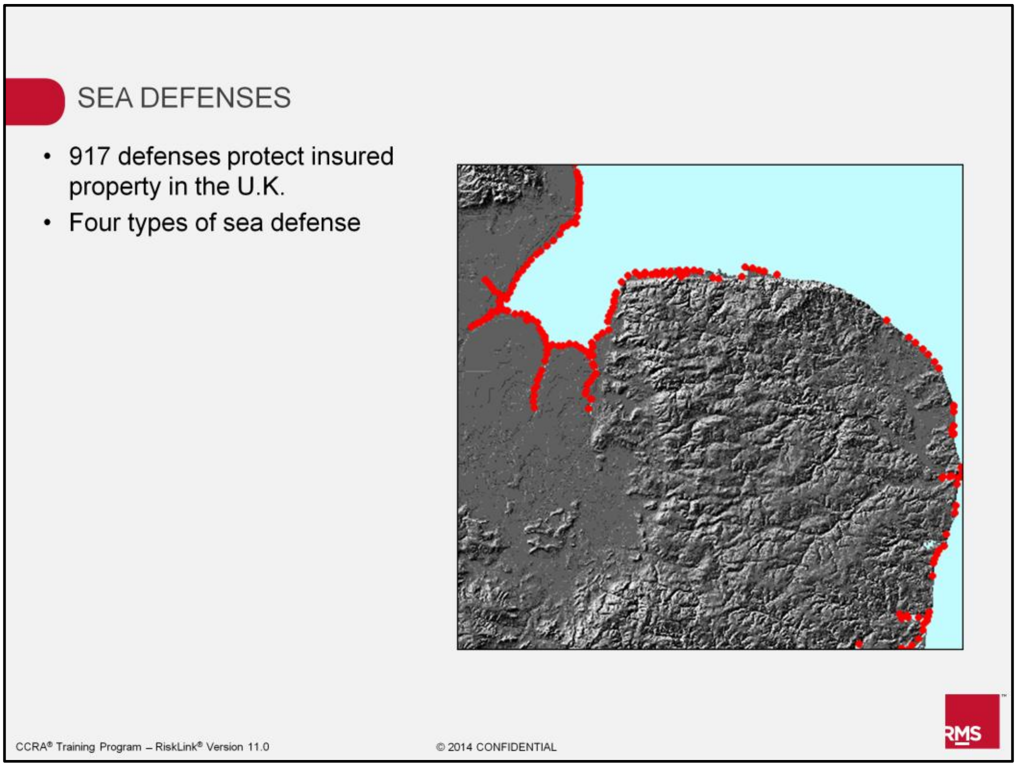
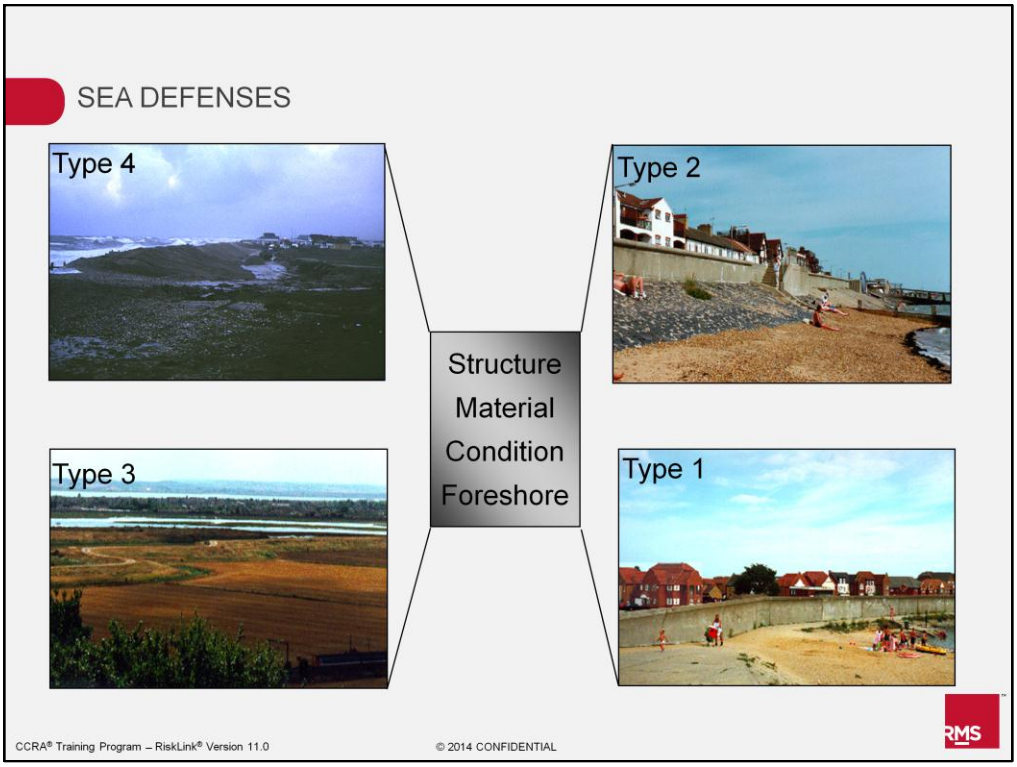


In the East coast U.K. flood model, we model 917 separate defense lengths that protect all the areas at risk of being flooded in this area.



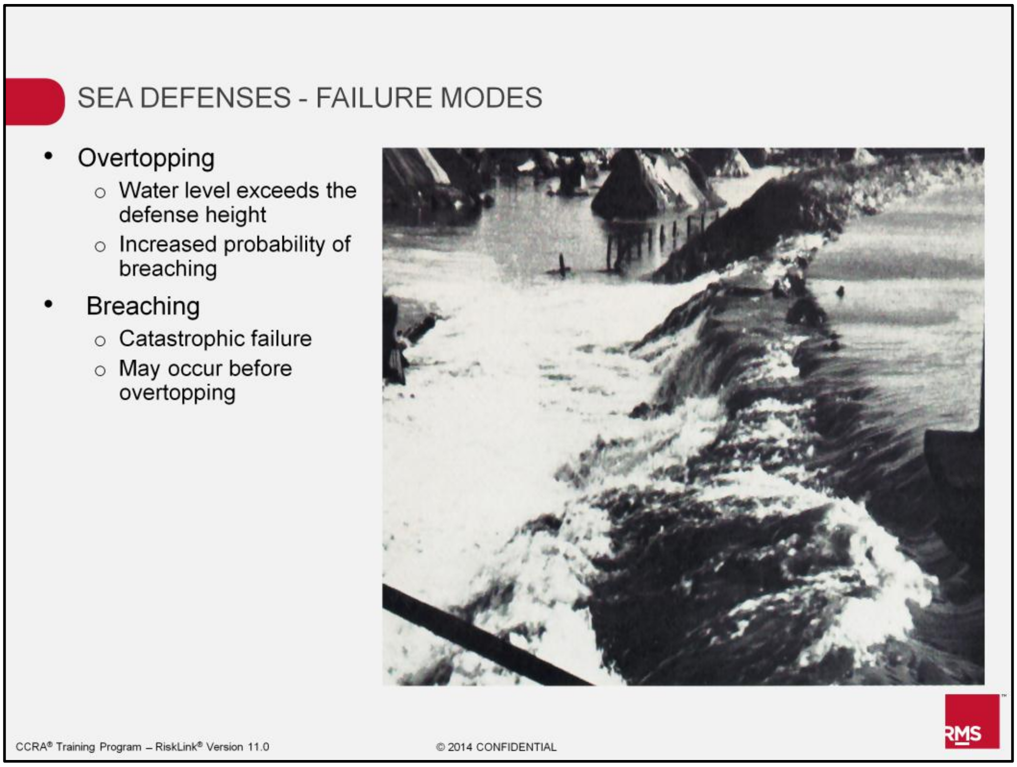
In building the RMS model, we classified sea defenses into four categories according to how they were built, what materials they were constructed out of, the underlying engineering structure of a flood defense, the condition of the flood defense, and the foreshore, including what is protecting that defense from the direct impact of waves under conditions of very high water levels.

The worst category of flood defense (Type 4), shown at the top left, is natural dunes or shingle ridges, which can be eroded in a big storm.

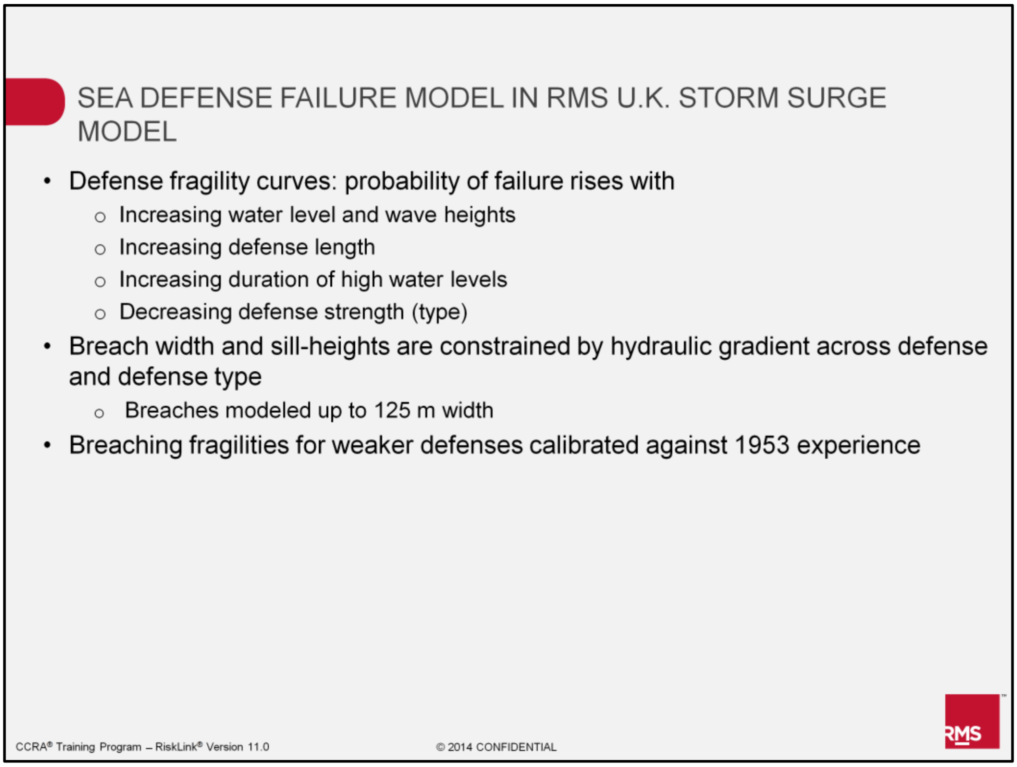
Next, on the bottom left (Type 3), are earth embankments typically used to protect estuaries where there was not an expectation of significant waves.

Where there are significant waves, then it is going to be necessary to increase the level of protection provided by the defenses. This is done by building them out of concrete (Type 2), or to protect an earth embankment by constructing a concrete apron at the base of the embankment.

The highest quality defenses of all (Type 1), are highly engineered defenses, which will have some foreshore protection as well as being built to high standards. These different defense types will have different potential for failure.

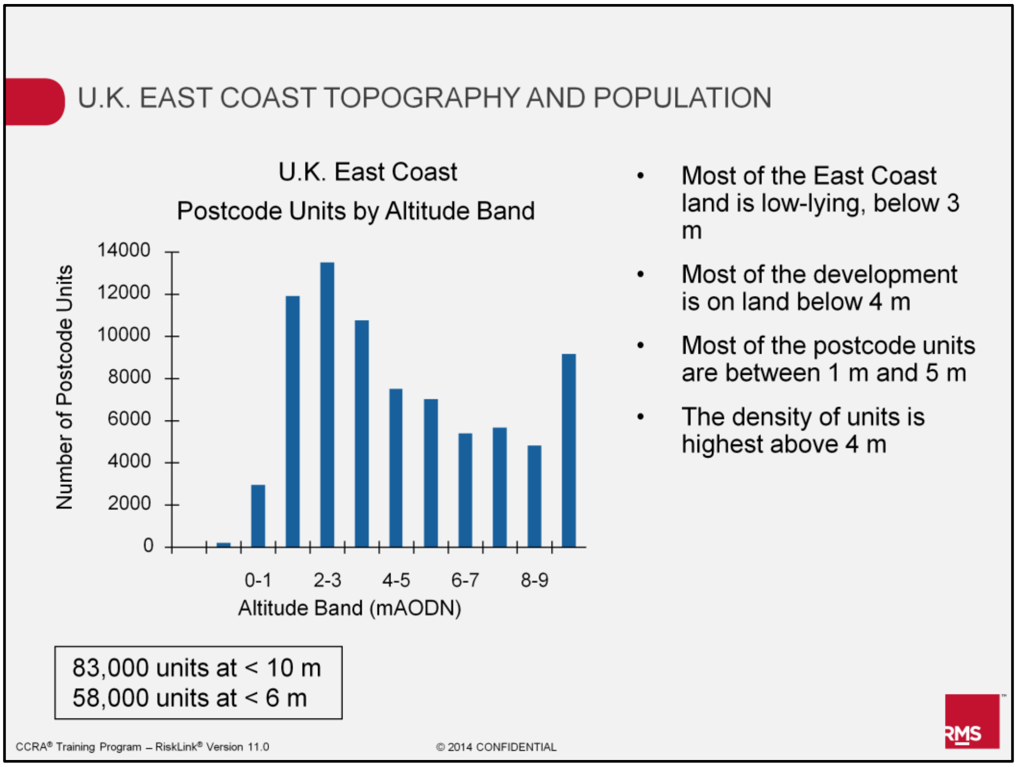


Sea defenses can be overtopped, or they can be breached. Once a defense is overtopped, even when it is well-made, there is an increased probability that it will end up breached. Breaching can also occur without the defense being overtopped, as happened in New Orleans following Hurricane Katrina.



Fragility curves express how the probability of the defense failing increases with an increased water level and the heights of the accompanying waves. The longer the water levels stay high around a defense, the more likely it is to fail. The better built and protected the defense the less likely it is to fail. So we use all this information to capture the probability that failure will occur.

Once we have a failure, we also have to model how big that failure becomes, as this will determine how much water can flow into the floodplain.



In the U.K. there are many properties situated between two and three meters above sea level. You can see the number of postcode units here by their elevation. There is a small number, about 3,000, located under one meter elevation, and a much larger number of postcodes at two to three meters. These are areas that all have the potential to be flooded in an extreme storm surge event.

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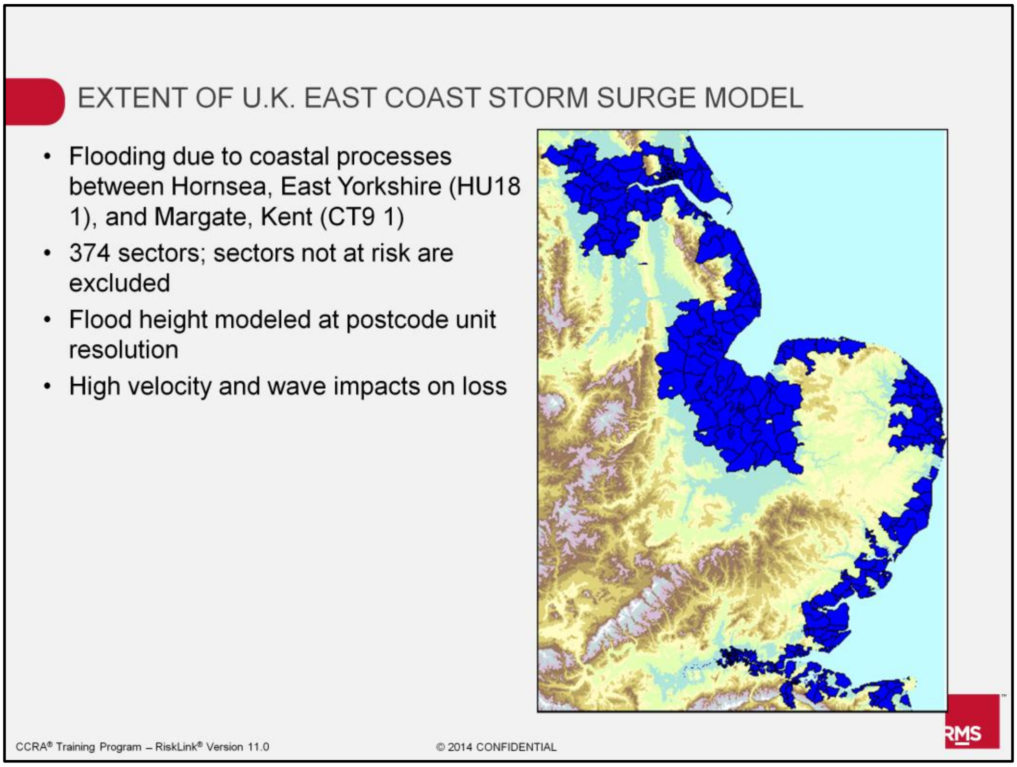

This map shows the areas covered by the U.K. Storm Surge Model. There are 374 postcode sectors as part of the model, and RMS only models the risk in these areas. In the RMS model released in spring 2006, we included the impact on London if the Thames Barrier were to fail. The Thames Barrier was designed to protect London against a one in 1,000-year flood. However, due to increases in sea level rise that were not sufficiently accounted for when the barrier was constructed, it is possible ,though highly unlikely, that the Thames barrier may be overtopped or breached by an event with a return period of less than 1,000 years.

EUROPEAN ETC STORMS AND U.K. STORM SURGE MODELS

- The surge events in the RMS U.K. east coast storm surge model are driven by the windstorms in the European extra-tropical cyclone model
- ETC storms have been split into as many as six alternative combinations of “state of the tide” and “defense failures” to create the different inland surge flood events
- Windstorms that correlate with surge floods may have their losses in the U.K., or other European territories (principally the Netherlands and Germany)

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These storm surge events in northern Europe are driven by the wind fields of extra-tropical cyclones passing over the North Sea. We have modeled these within our European extra-tropical cyclone windstorm model, which provides the event set for our U.K. east coast storm surge model.

Because the state of the tide on the day that a particular storm surge arrives makes a significant difference, we have to model the possibility that one wind-driven storm may turn into a range of different flood extents according to the state of the tide. To accomplish this, we split the stochastic events into as many as six alternatives. For each of these alternatives, we combine the windstorm with a different state of the tide to generate different flood outcomes.

In exploring event losses, you will find that there may be as many as six split Event IDs that all give identical windstorm losses. The windstorms that link with the highest storm surge flood losses may not even have their greatest impacts in the U.K, but may be associated with catastrophic losses in Germany or Holland.

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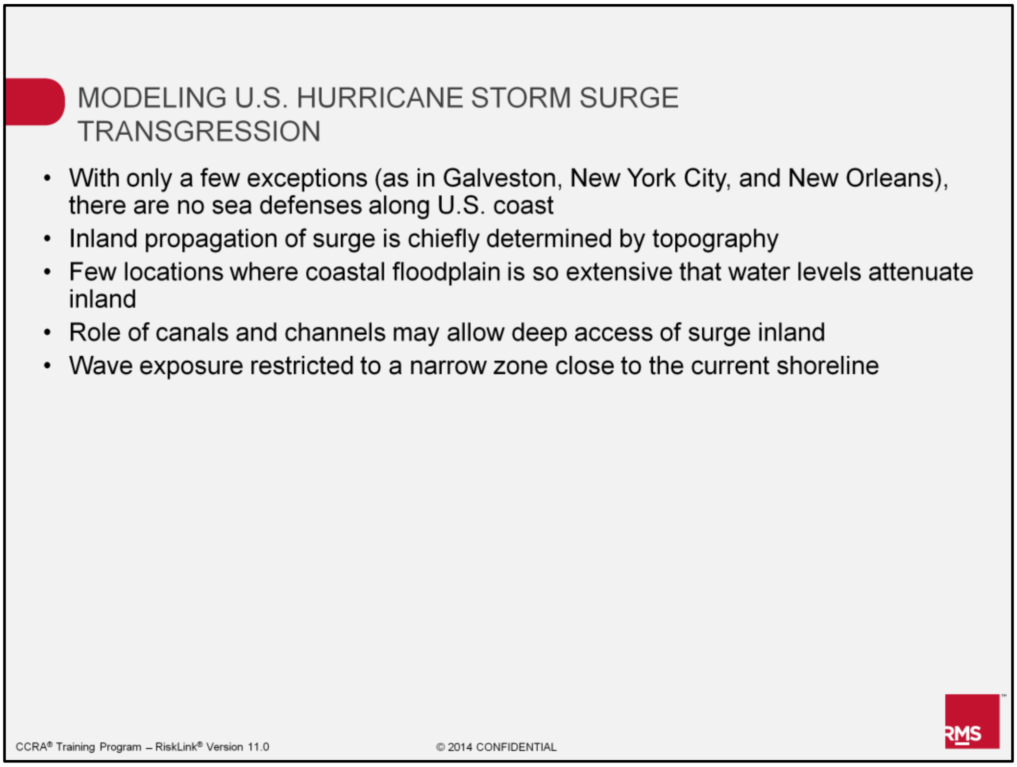
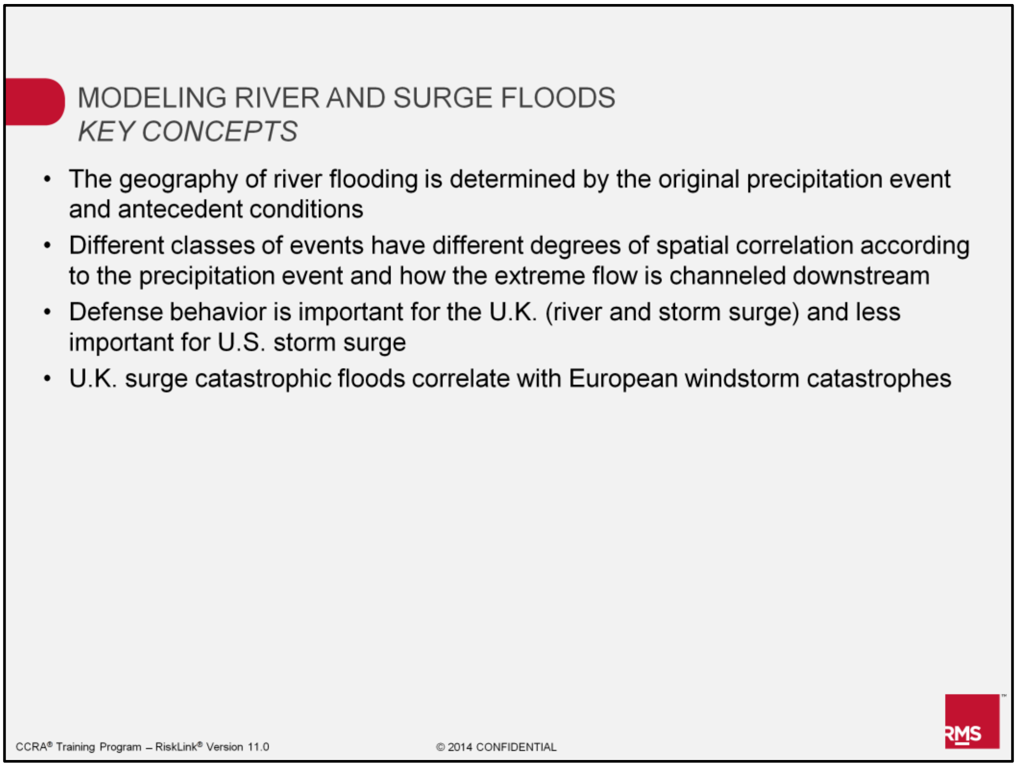


For U.S. hurricane storm surges, the main difference comes in the need to model the performance of sea defenses as there are only a small number of defended city locations in the U.S., although one of these happens to be New Orleans. For most sections of the coast, there are no artificial sea defenses, and therefore in modeling, we do not need to be concerned with how well they are built or the probability of failure. Along almost all the U.S. coast, tides are also lower than surges, so that is another complication that is less critical to the modeling. The way in which floods propagate inland is principally determined by the shape of the topography.

Artificial channels can be important for guiding water inland, especially along the southern U.S. coasts where they have been constructed as part of canal estate developments. We also need to be concerned with wave impacts associated with storm surges (i.e. damage inflicted by the force of the actual waves), both for properties that are located close to the coast and for situations where flood heights rise to the point that sea waves can pass inland.



This slide summarizes the key concepts from Unit 2. Review the summary to make sure all key concepts are clear to you before continuing on to Unit 3.