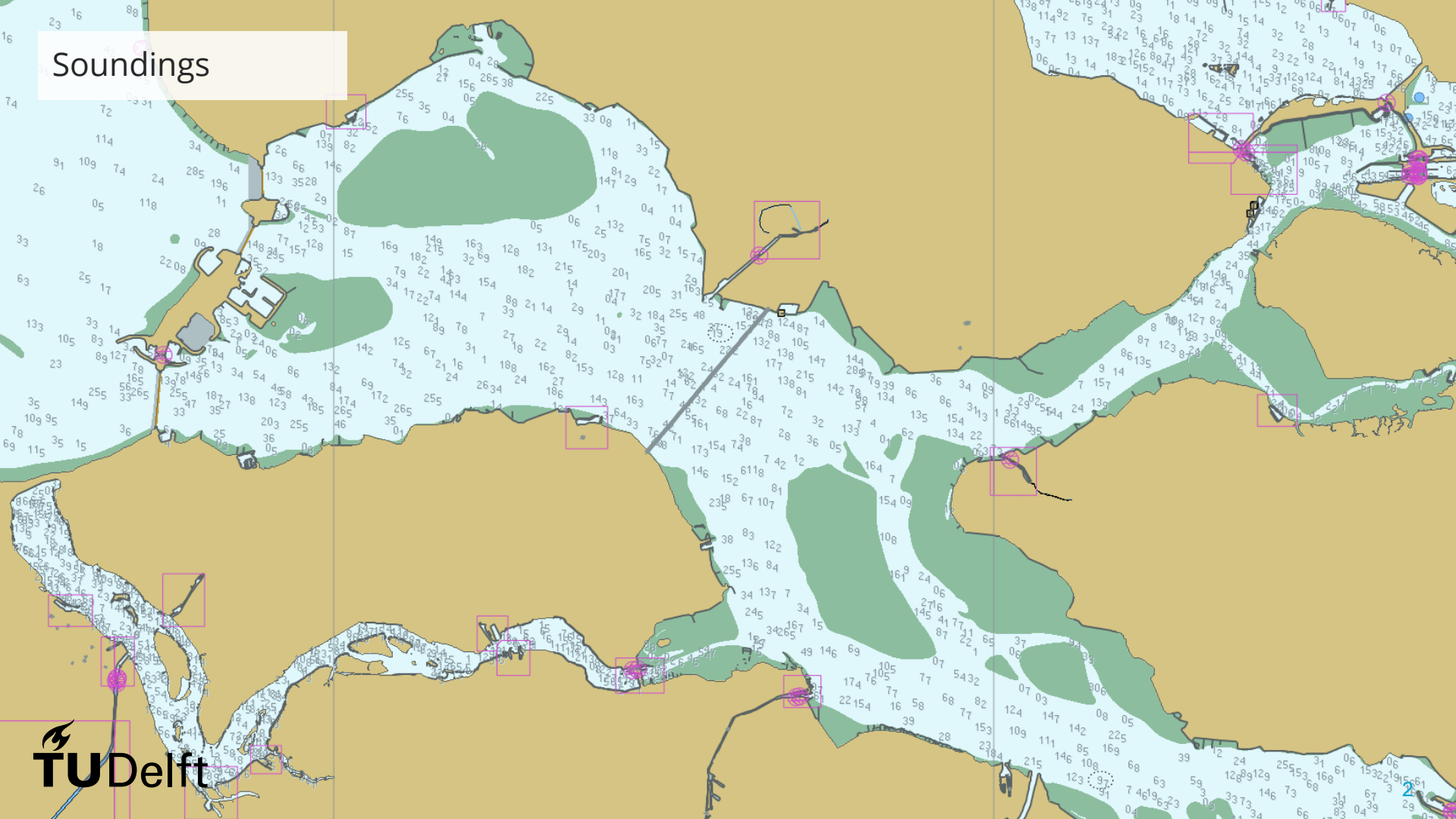
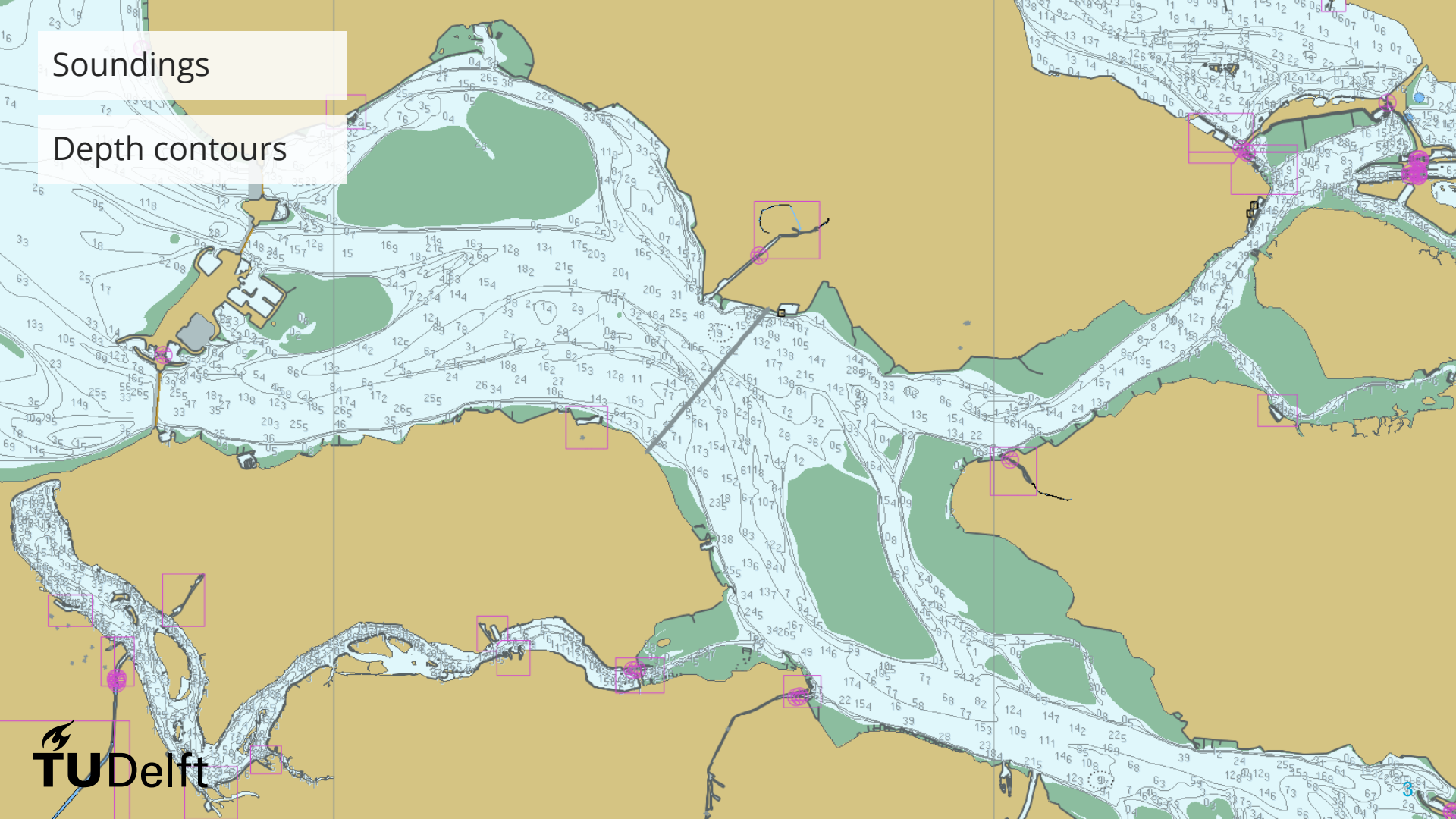
# Automatic isobath generalisation for navigational charts

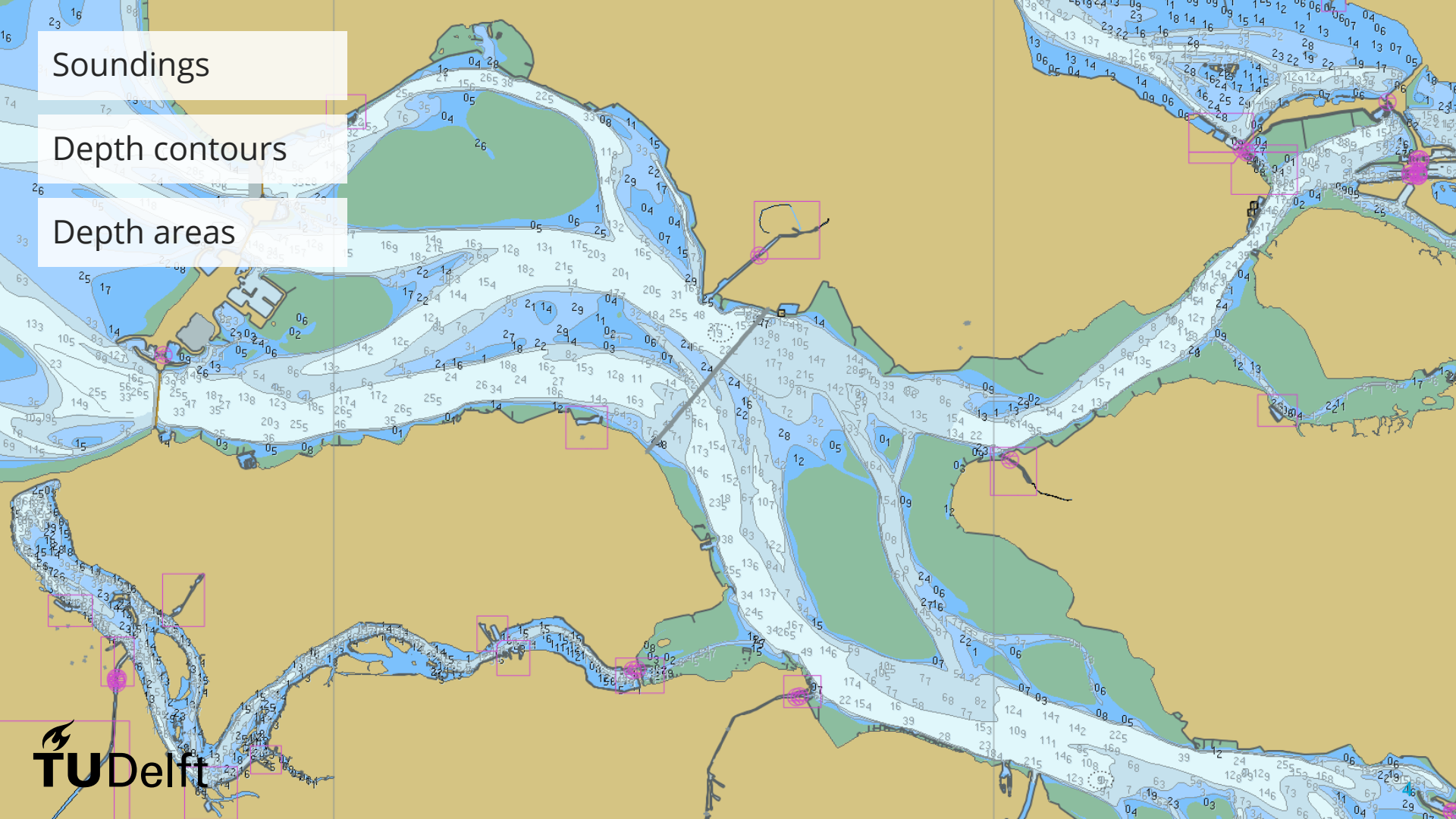
**Willem van Opstal**
Martijn Meijers (1st mentor)
Ravi Peters (2nd mentor)

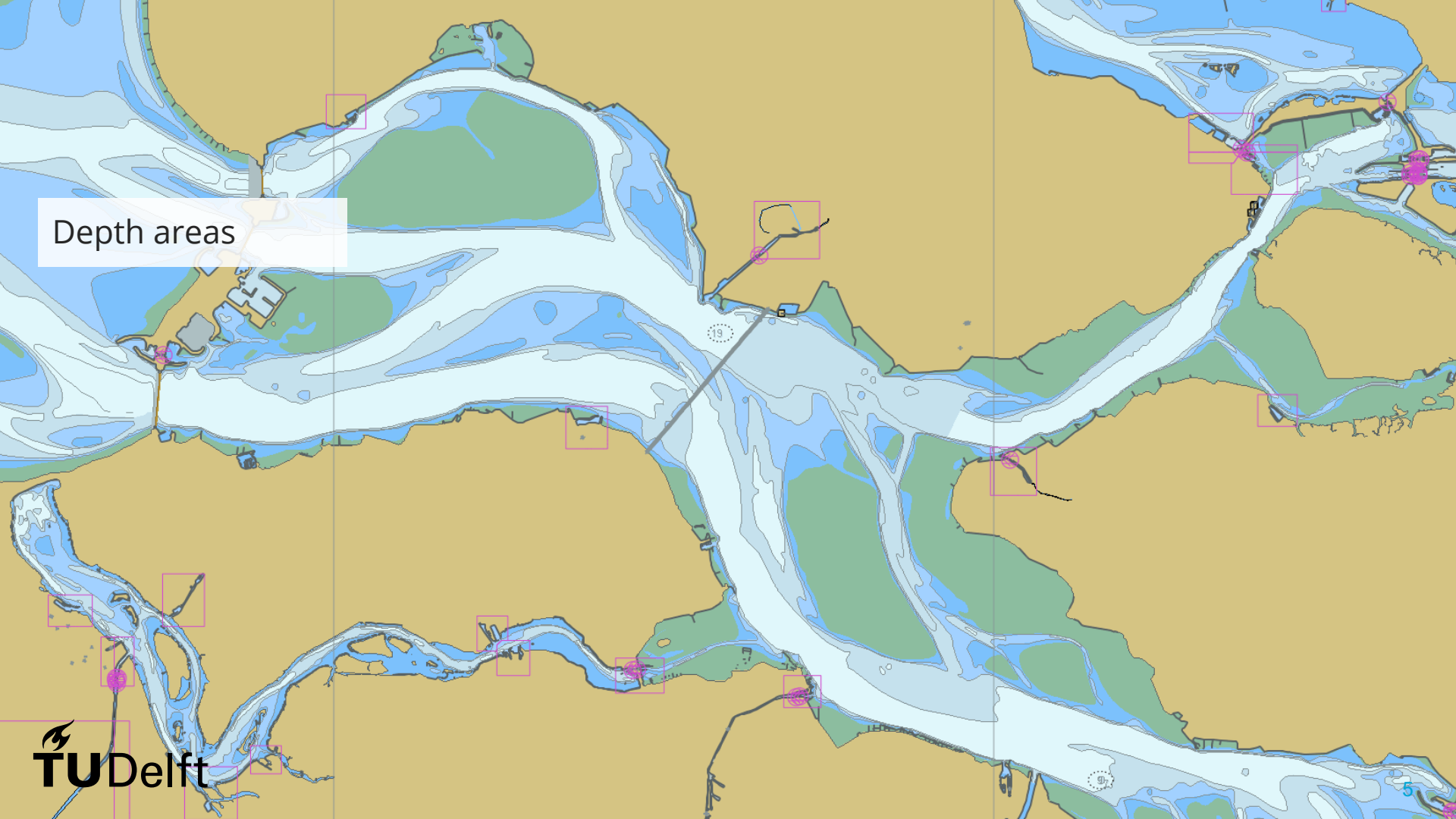
July 9th 2020


Soundings

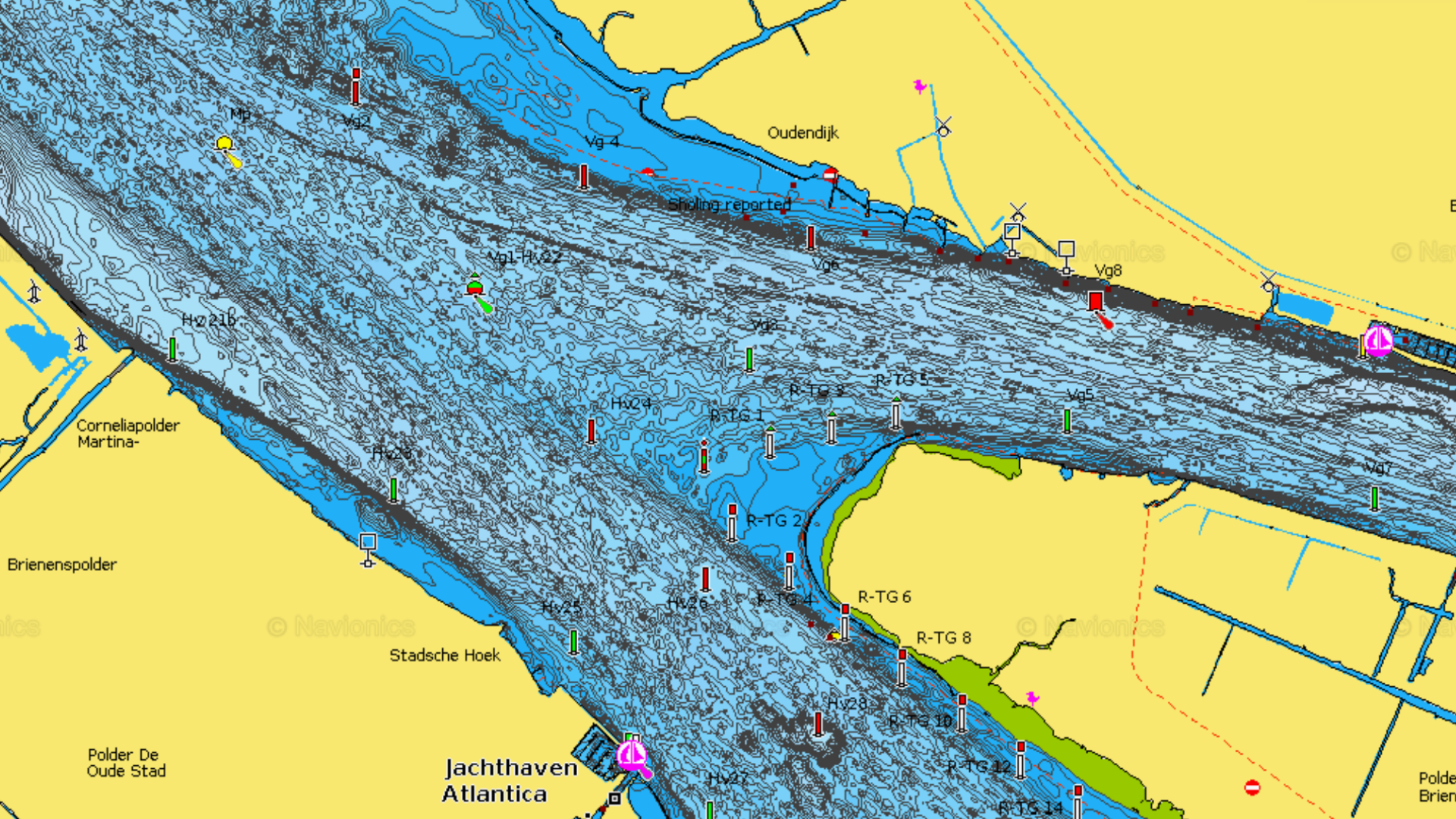


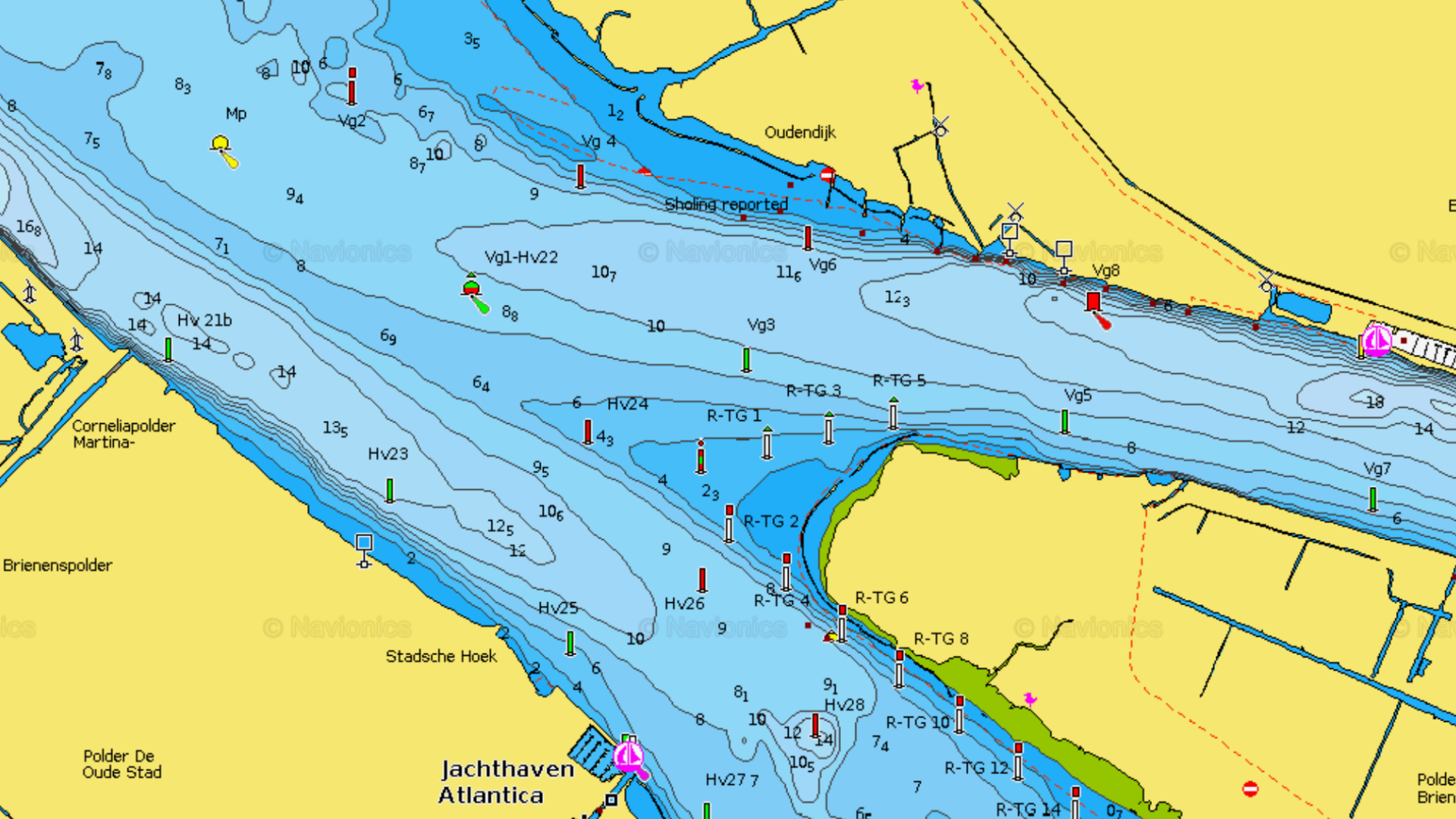

TU Delft


Soundings
Depth contours
Depth areas


Depth areas

# Contents

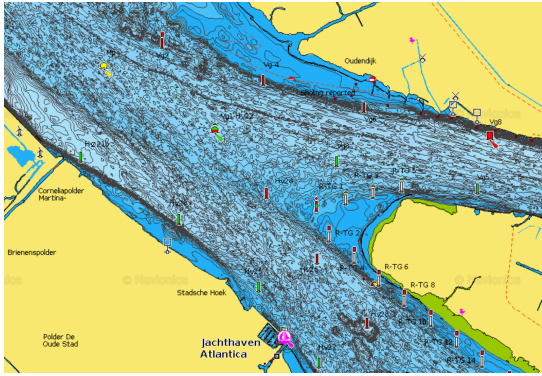

Mp
Vg2
Vg 4
Oudendijk
Sholing reported
Vg1 Hv22
Vg6
Vg8
Hv21b
Vg3
R-TG 3
R-TG 5
Vg5
Hv24
R-TG 1
Corneliapolder
Martina-
Hv23
Vg7
R-TG 2
Brienenspolder
Hv25
Hv26
R-TG 4
R-TG 6
R-TG 8
Stadsche Hoek
Hv28
R-TG 10
Polder De
Oude Stad
Jachthaven
Atlantica
Hv27
R-TG 12
R-TG 14
Polde
Brien

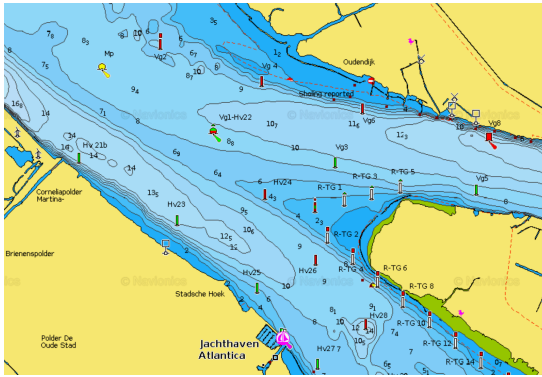

Mp
Vg2
Vg 4
Oudendijk
Sholing reported
Vg1-Hv22
Vg6
Vg8
Vg3
Hv 21b
R-TG 5
R-TG 3
R-TG 1
Hv24
Vg5
Vg7
Corneliapolder
Martina-
Hv23
R-TG 2
Brienenspolder
Hv25
Hv26
R-TG 4
R-TG 6
R-TG 8
Stadsche Hoek
Hv28
R-TG 10
R-TG 12
R-TG 14
Polder De
Oude Stad
Jachthaven
Atlantica
Hv27
Polde
Brien

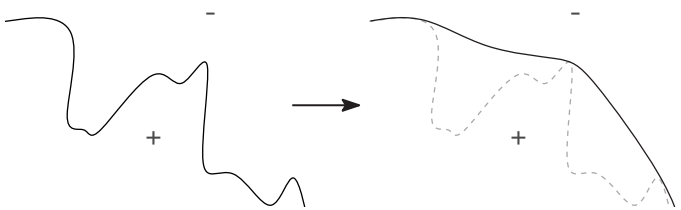
# Isobath generalisation

- Omitting details
- Making a readable chart

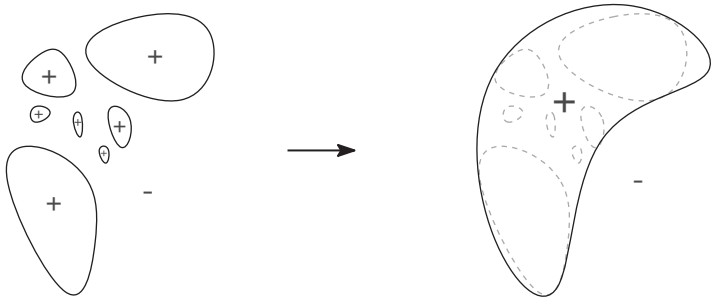
- Cartographic constraints
  - Morphology — Seabed shape
  - Legibility — Readability
  - Functional — Safety
  - Topology — Topology



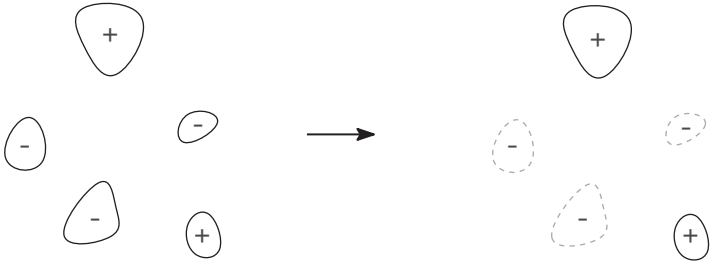





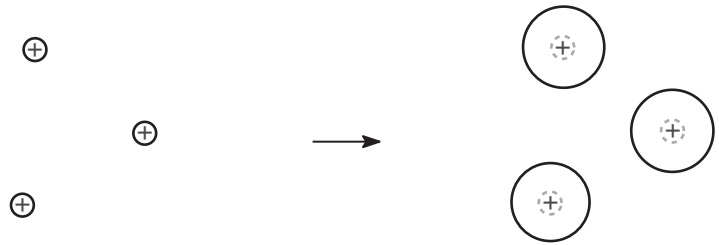
Simplification



Aggregation



Omission

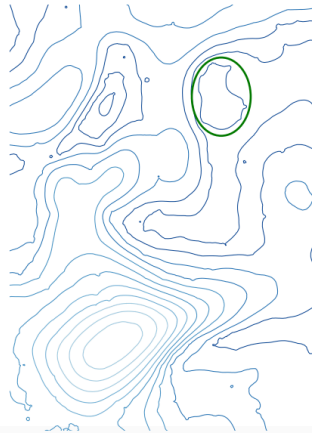


Enlargement

# Isobath generalisation

- Currently done manually
  - Complex decisions
  - Cartographers insight
  - Different purposes, in different areas
  - Liability

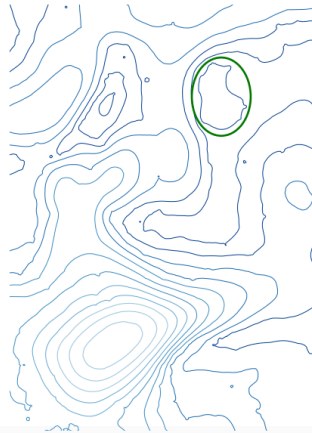
- Automation brings:
  - Economic benefits
  - Safety benefits

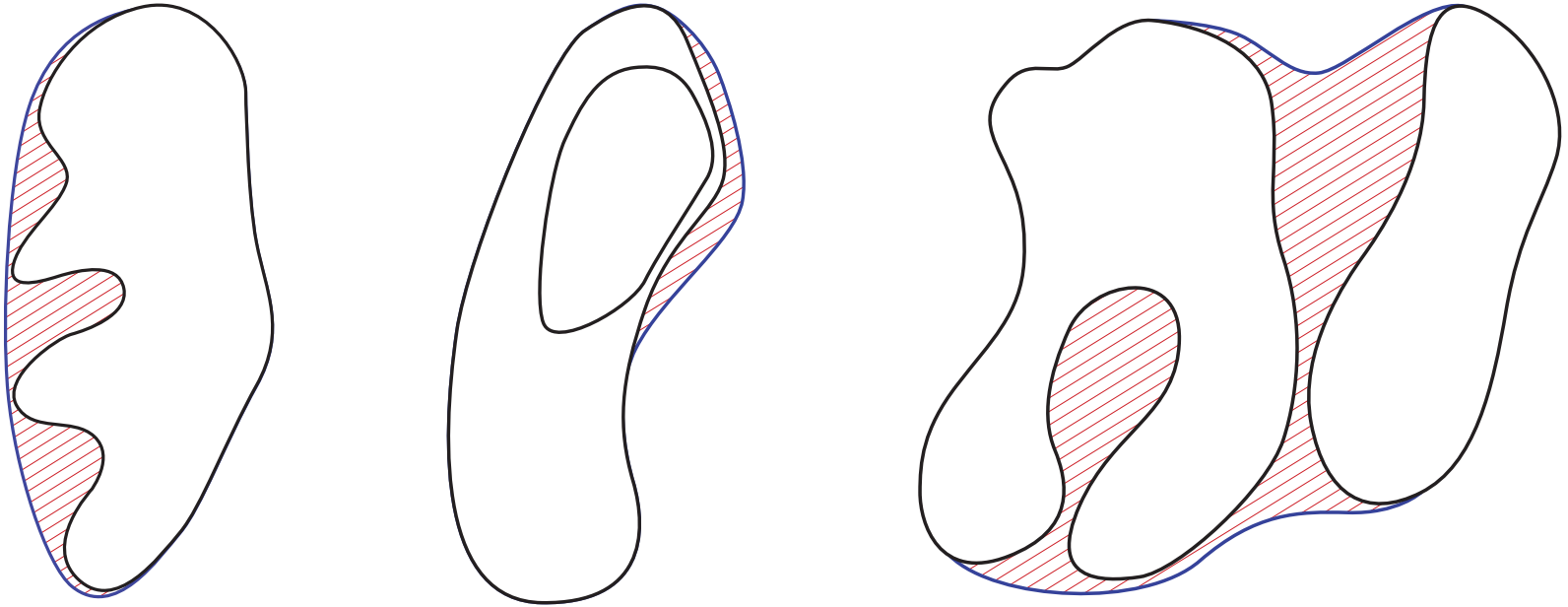


# Problem statement

- Incompatible constraints
  - Chart scales and purposes
  - Smoother lines > less morphology
  - Increasing line separation > less morphology
  - Masking safe waters

- Relation with data is destroyed





# Research objectives

- An automated generalisation process
- Integrate *all* constraints
- Not to over-generalize

- Apply operators locally, where needed

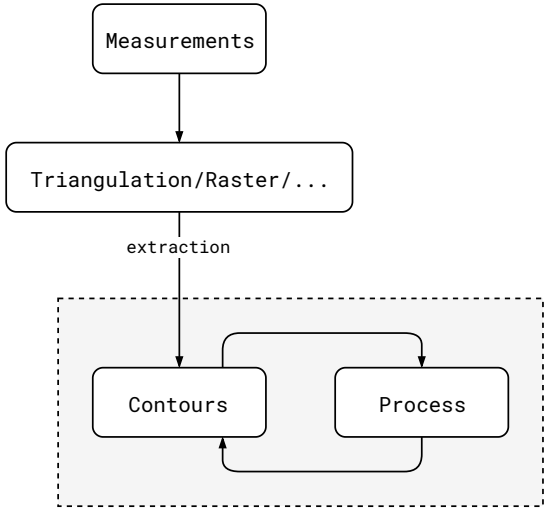
# Contents

# Line-based generalisation

- First extracts lines
- Alters the lines, and only the lines

- Multi-agent system
  - Makes choices, based on requirements for the lines
  - Rules and operators

- Complex
- No connection with survey data

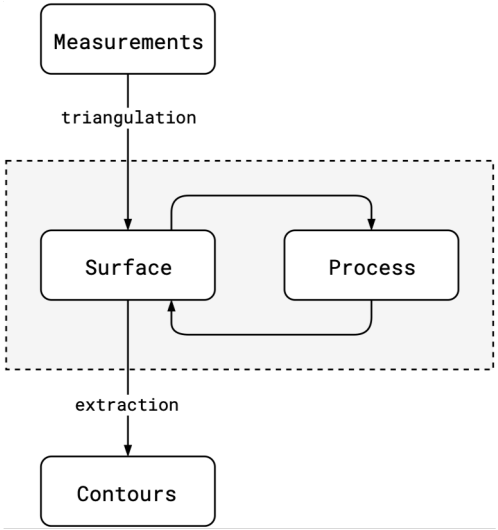


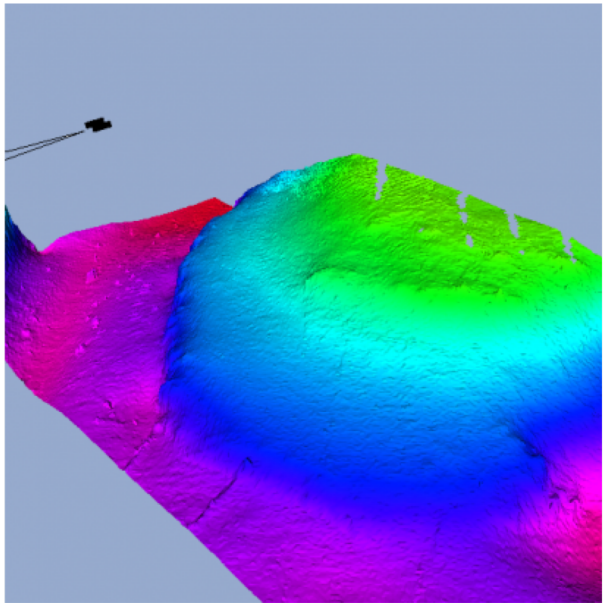
# Surface-based generalisation

- Generalises an intermediate surface
- Extracts isobaths at the end, only once

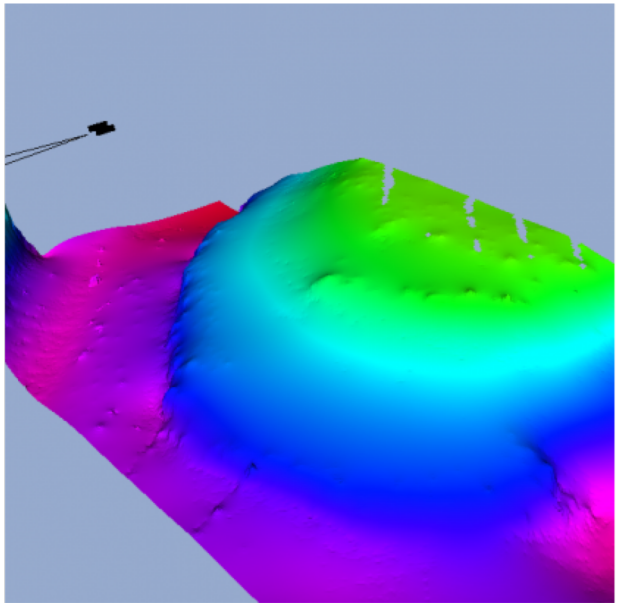
- Navigational surface
- Smooth surface > smooth isobaths
- Only move upwards > safe

- When is it good enough?





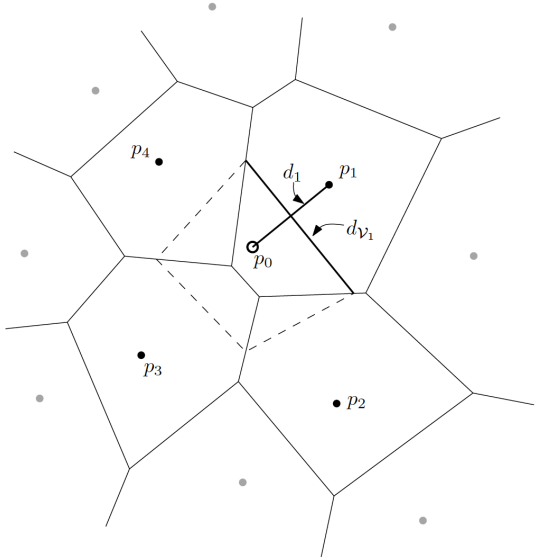
Before

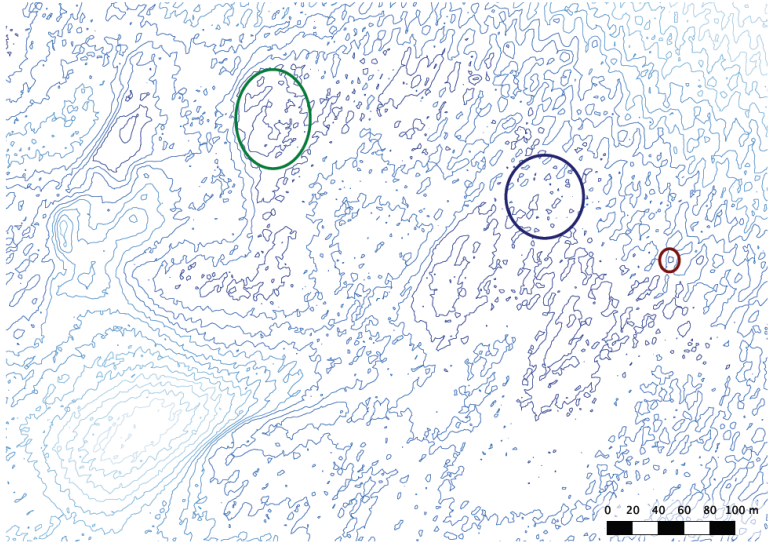


After

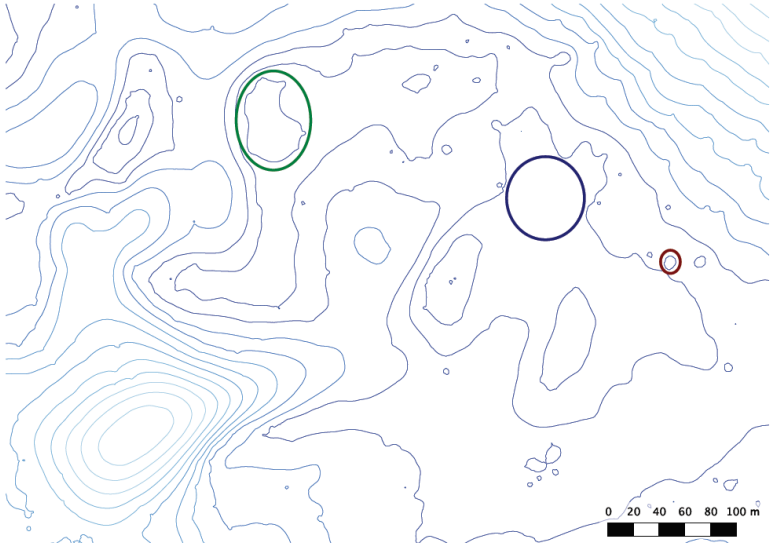
# Voronoi surface-based (VSBA)

- Generates a smooth surface
  - And thus smooth isobaths
- Laplace interpolation
  - Smooth, local, anisotropic, parameter-independent, linked to surface
- Iterative approach
  - Smoothing, densification
- When is it good enough?






Before

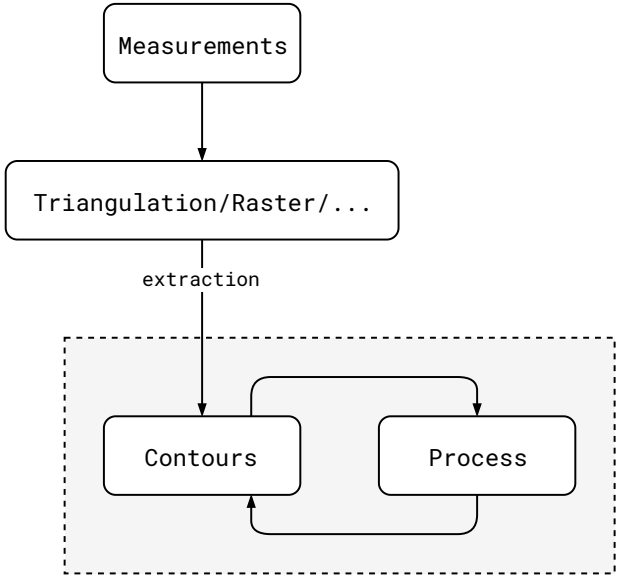


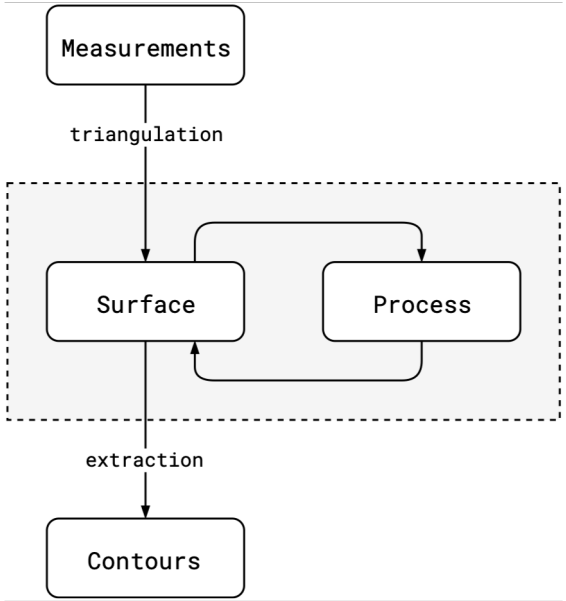

After

# Contents

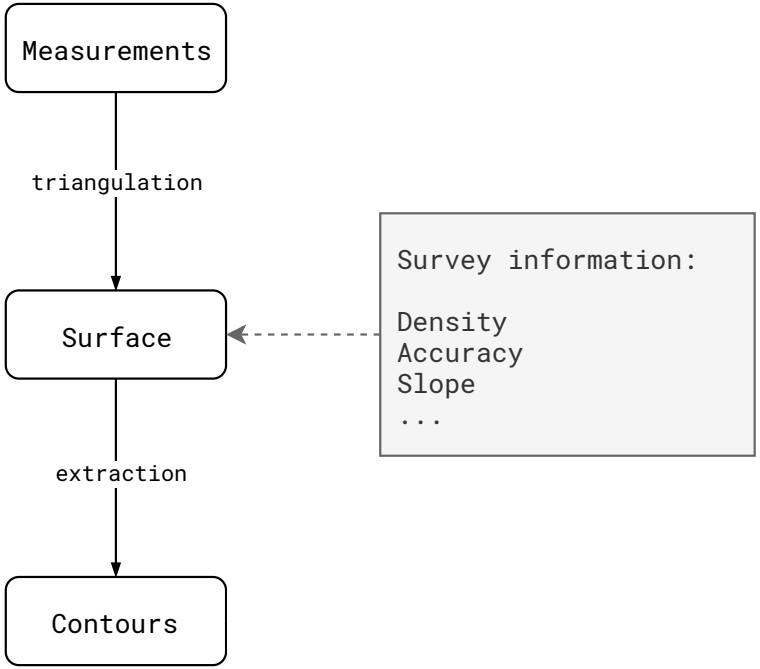
- Introduction
- Generalisation approaches
- Methodology
  - An integrated approach
  - Triangle region graph
  - Generalisation process
- Experiments
- Conclusion

# Line- and surface based

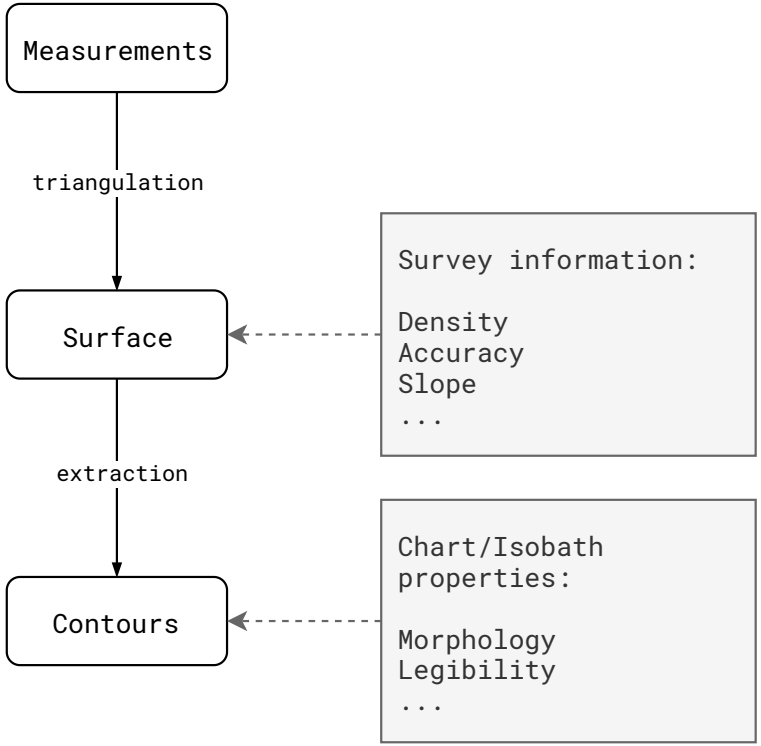


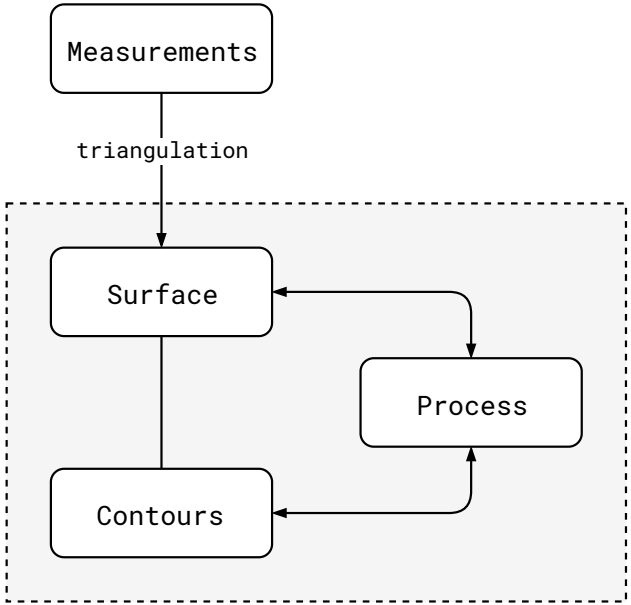
# Information locations



# Information locations



# An integrated approach

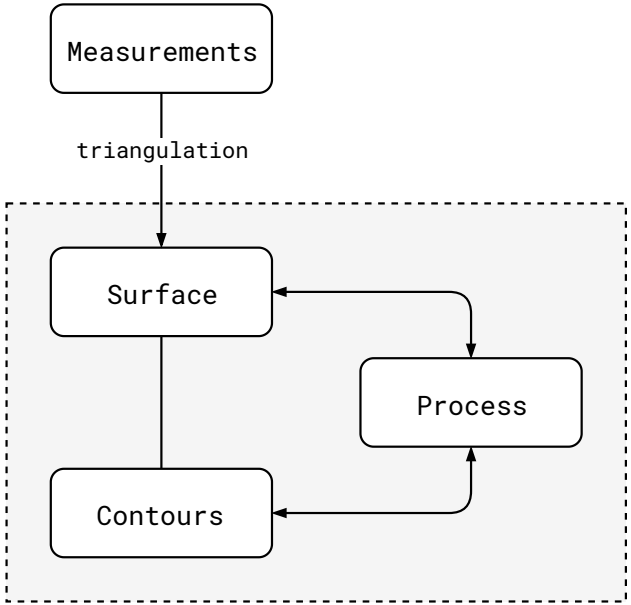


# Surface vs. line

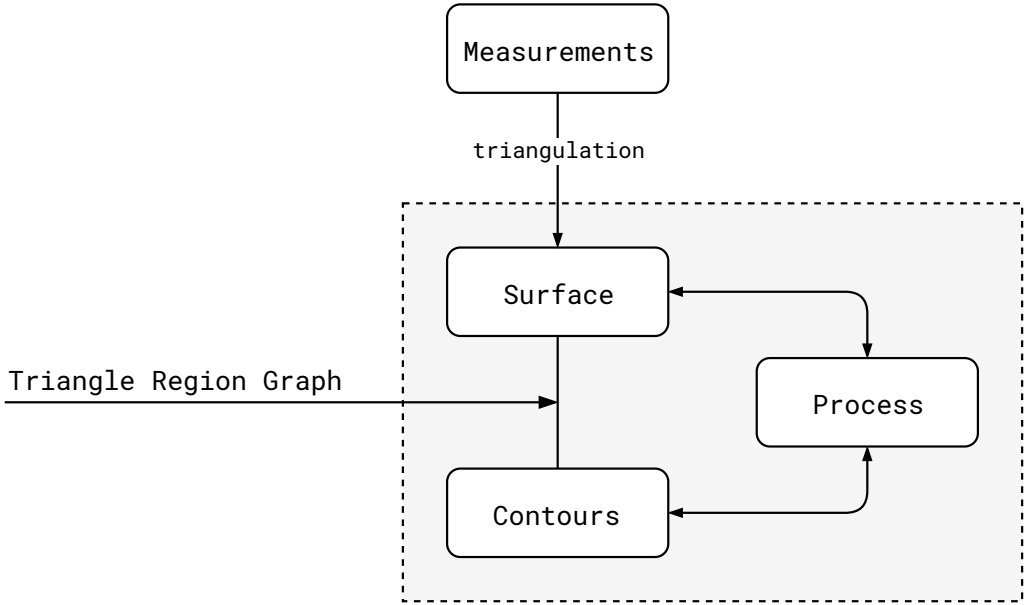
- Relatively simple concept
- Limited user-defined parameters
- Safe is always up, not left ór right
- Isobaths safe and topological correct

- Starting from a surface, we can always use lines afterwards
- S-100

# An integrated approach

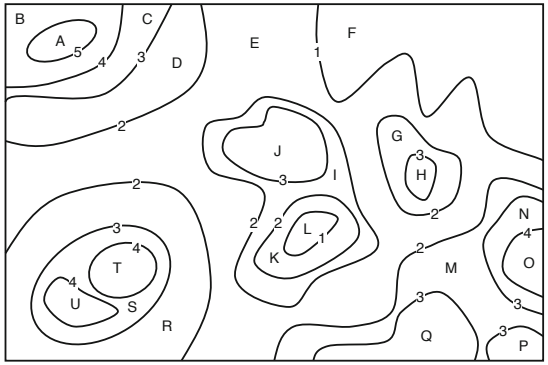


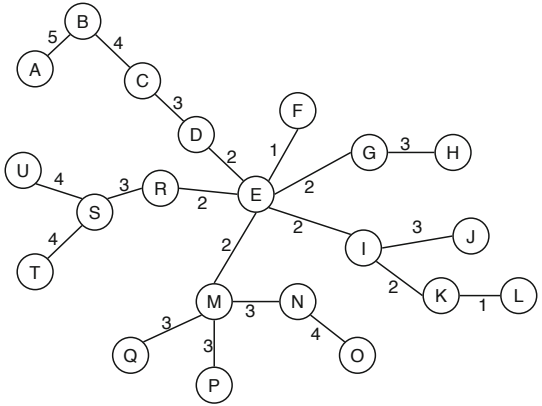
# An integrated approach

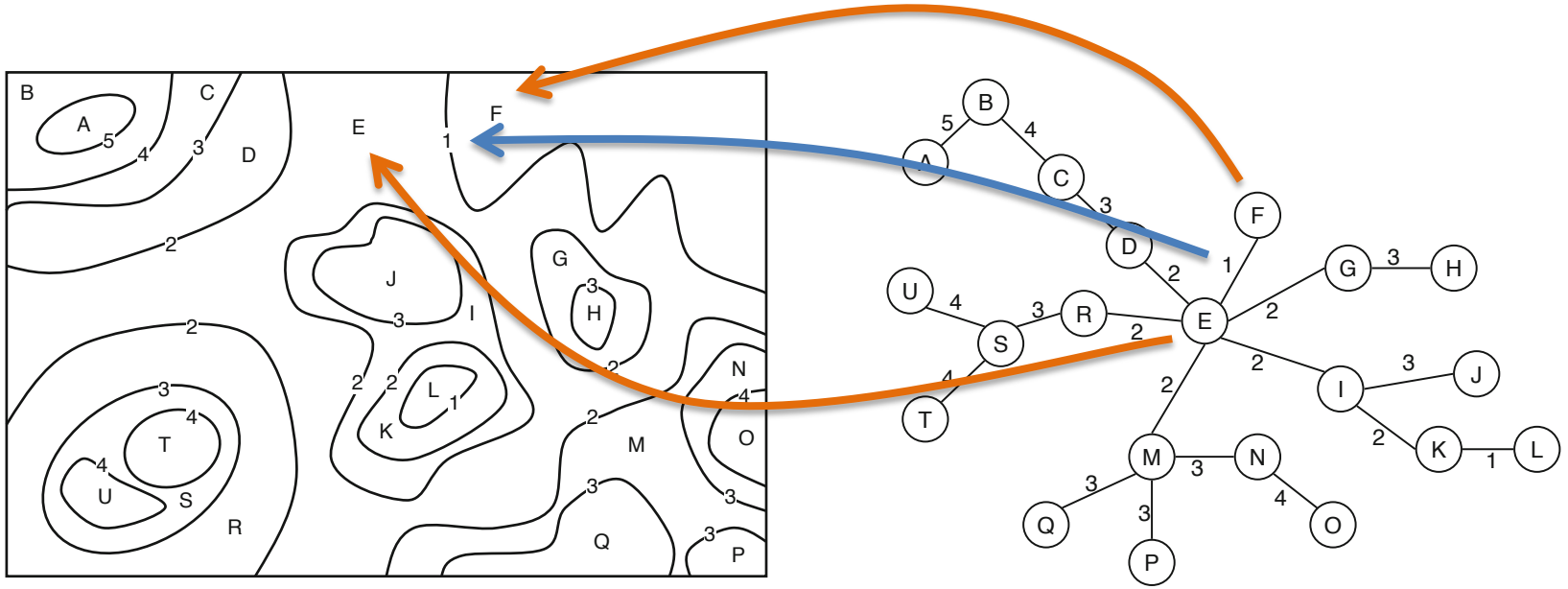


# Region graph

- Establish relations between isobaths
  - Not the triangulation
- Based on inter-isobath area
- Isobaths implicitly defined: edges




B
A
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U

# Triangle region graph (TRG)

- Extension of the region graph
  - Inspired by the interval tree
  - Includes the triangulation as regions

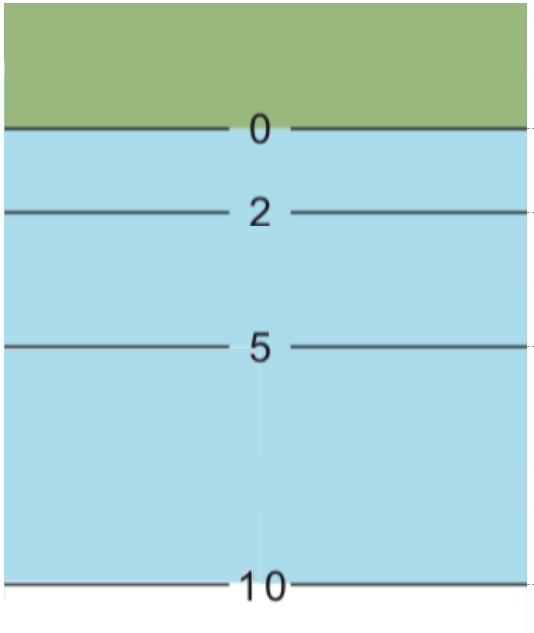
- Links together:
  - Isobaths (e.g. separation)
  - Inter-isobaths areas (depth areas > ENCs)
  - Triangulation (survey data)

# TRG Generation

- Directly from the triangulation
  - not the isobaths
- Isobath values as input
  - > inter-isobath regions

isobath values

intervals




-inf to 0

0 to 2

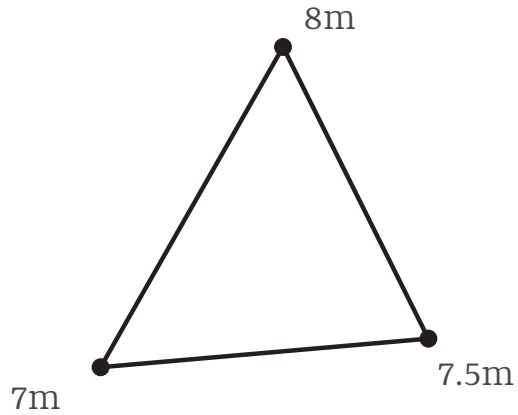
2 to 5

5 to 10

10 to inf

# Triangle intervals

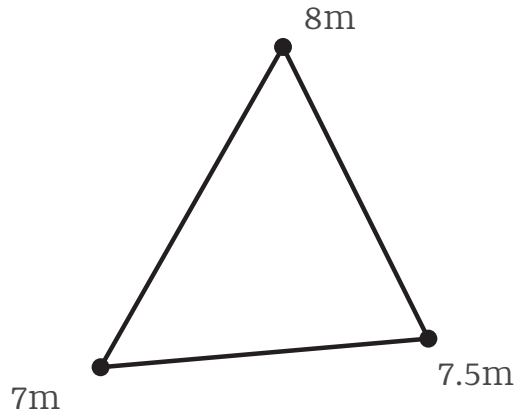
- Triangle intersects either:
  - One interval

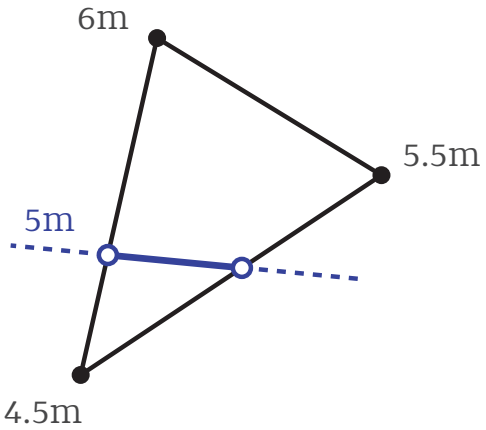



5 to 10

# Triangle intervals

- Triangle intersects either:
  - One interval
  - Or multiple

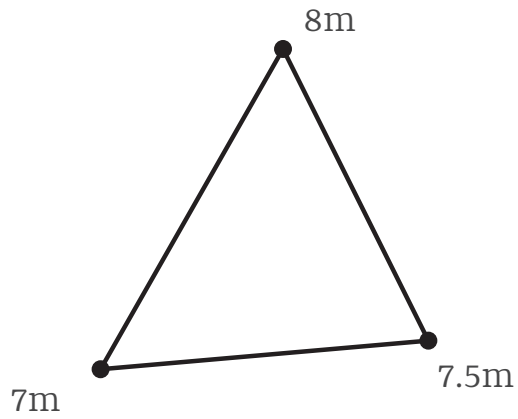


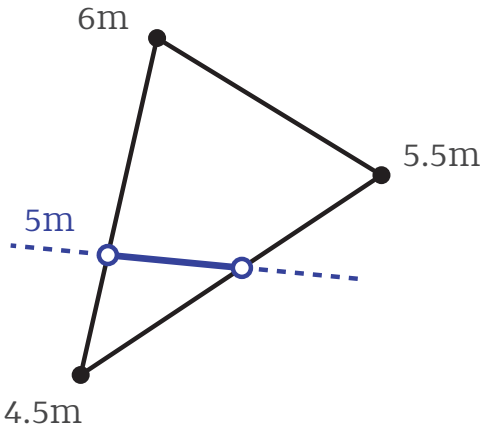




2 to 5 5 to 10

# Triangle intervals

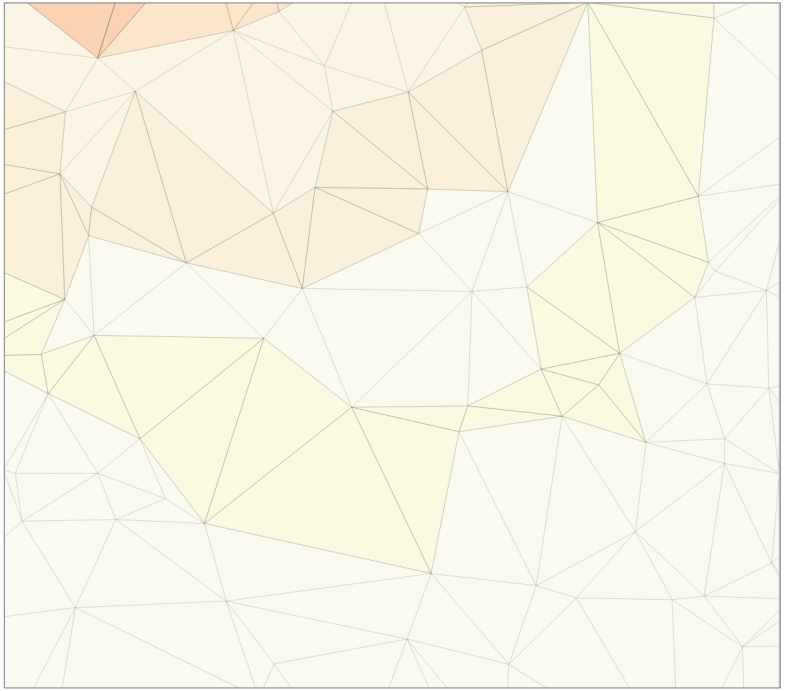
- Triangle intersects either:
  - One interval
  - Or multiple > it contains an isobath!



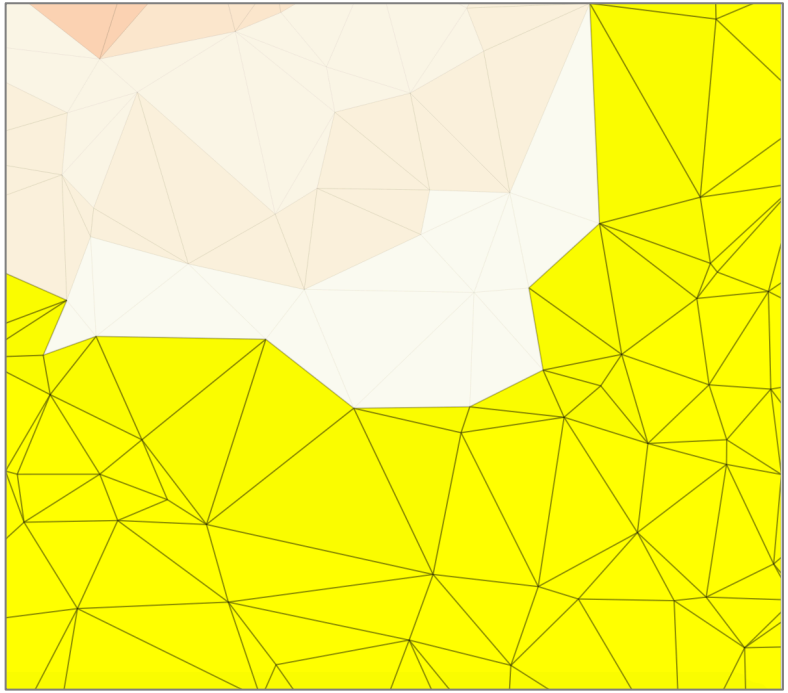



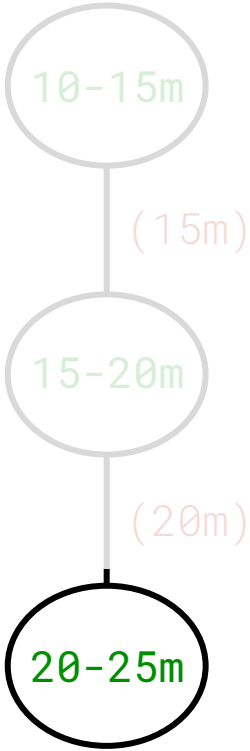

2 to 5 5 to 10

# TRG Structure

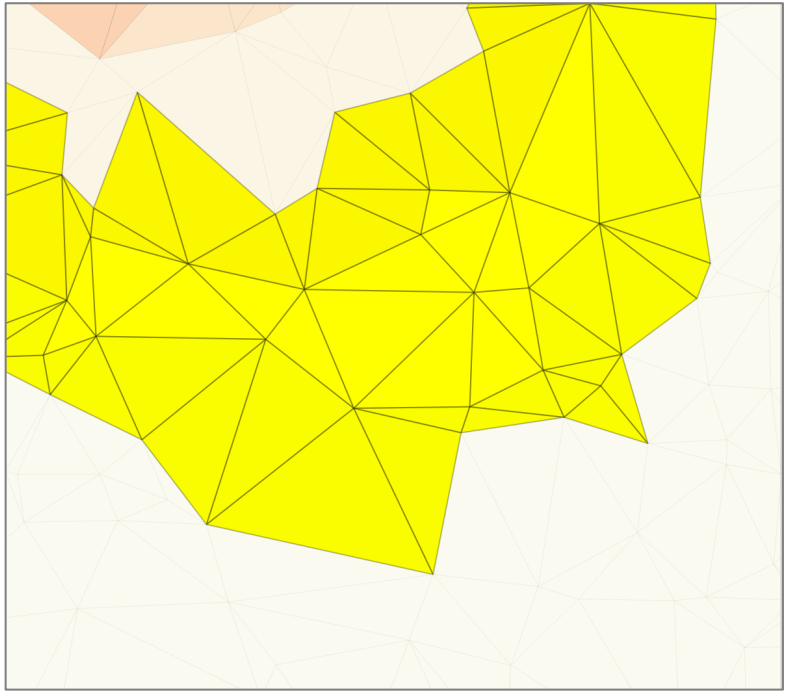


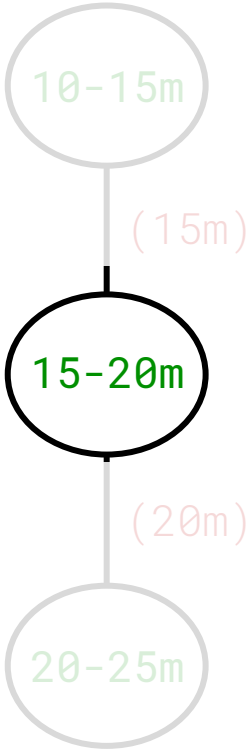
# TRG Structure



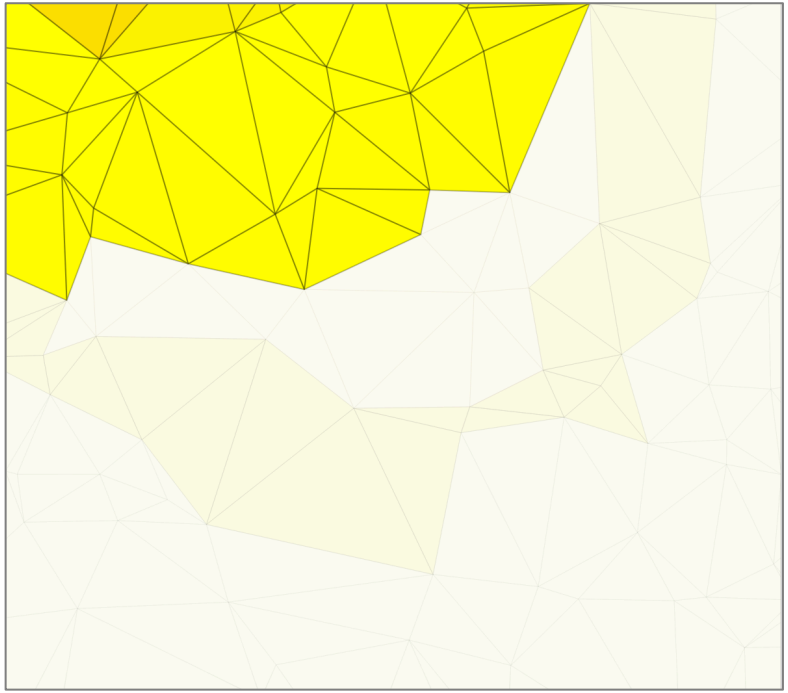


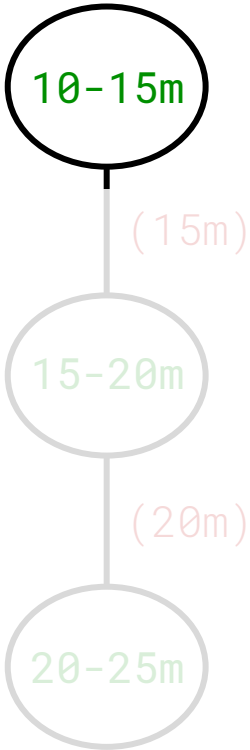
# TRG Structure



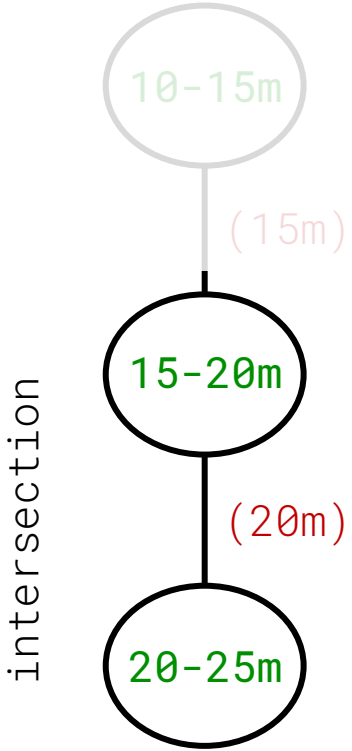


# TRG Structure

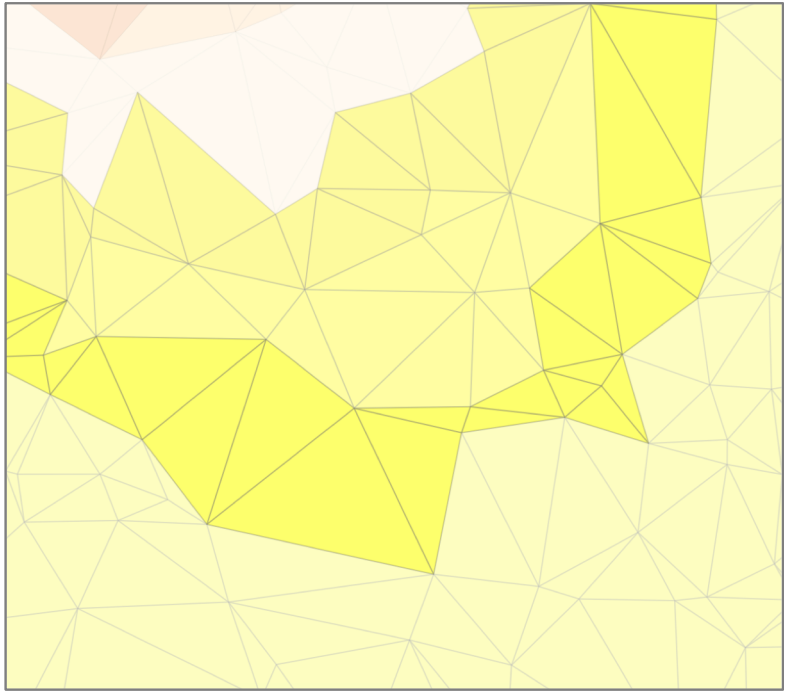


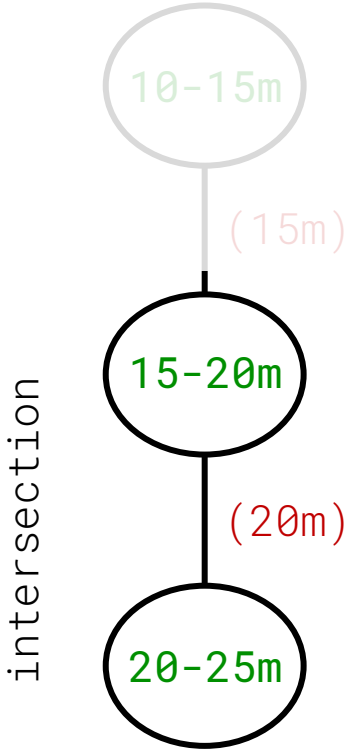


# TRG Structure

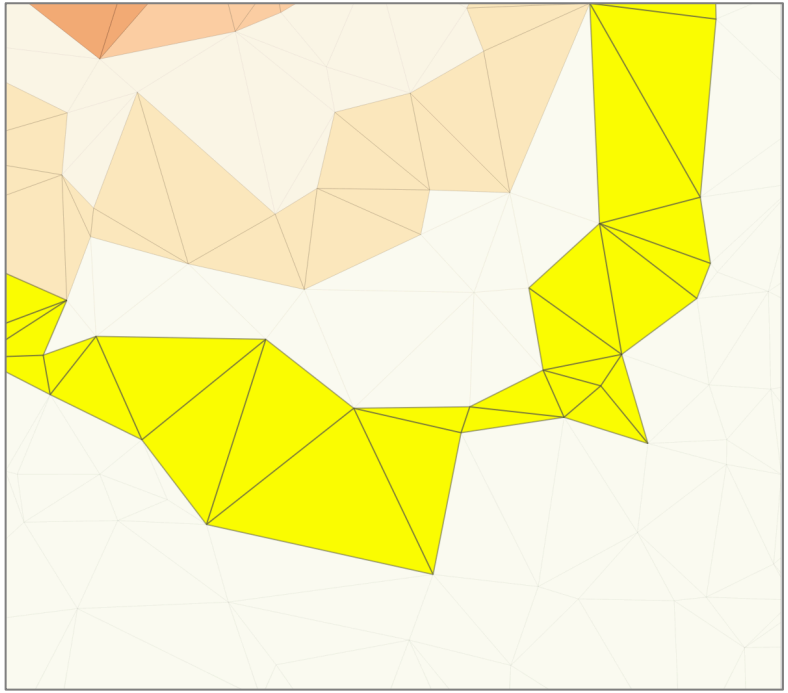


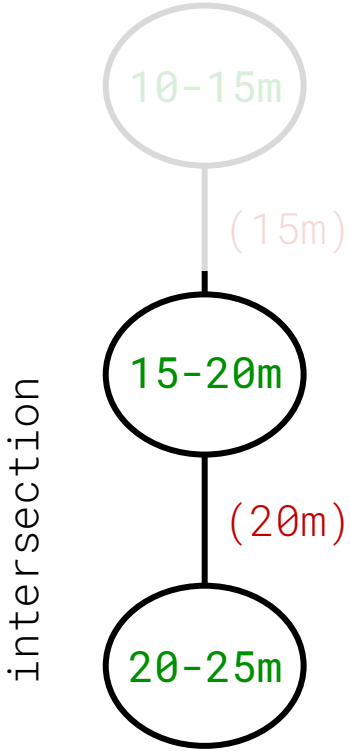
# TRG Structure



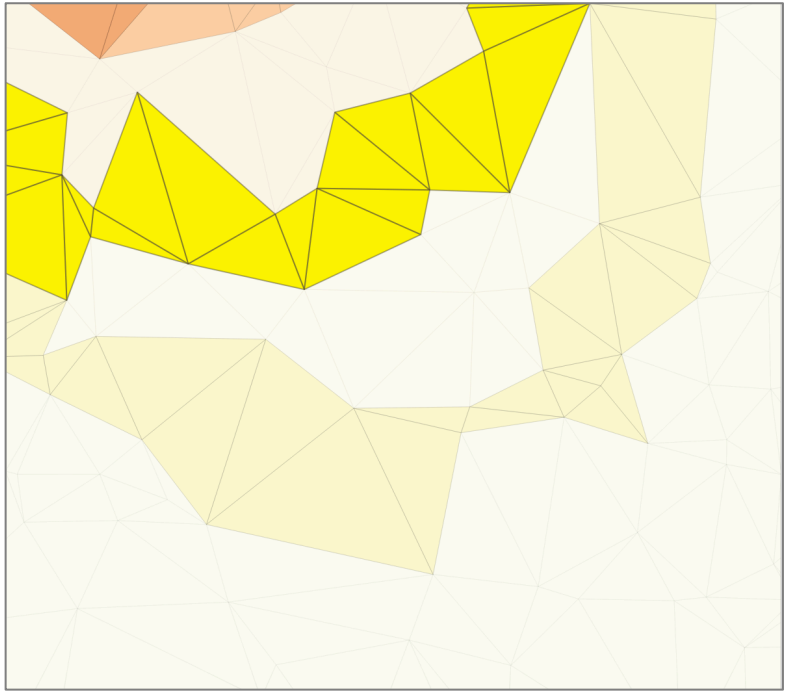


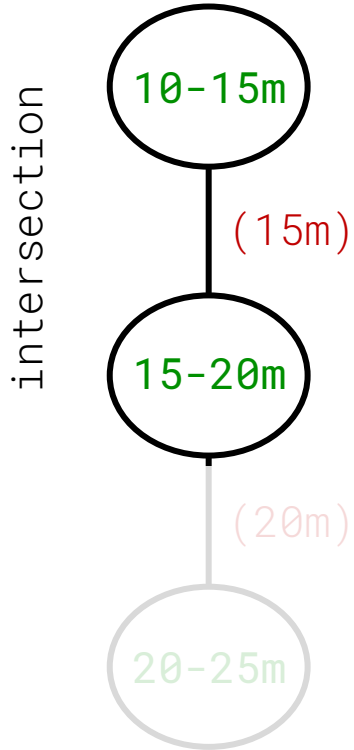
# TRG Structure



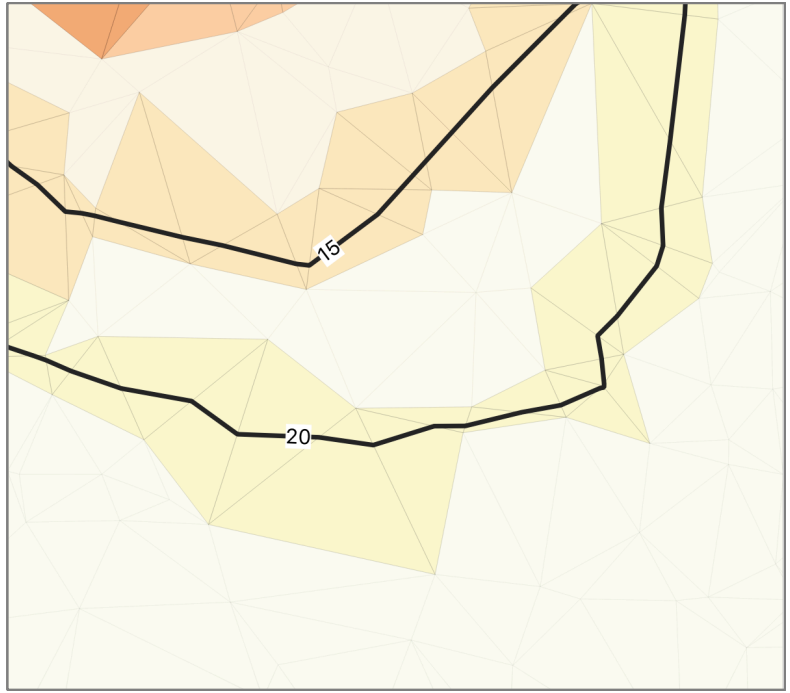


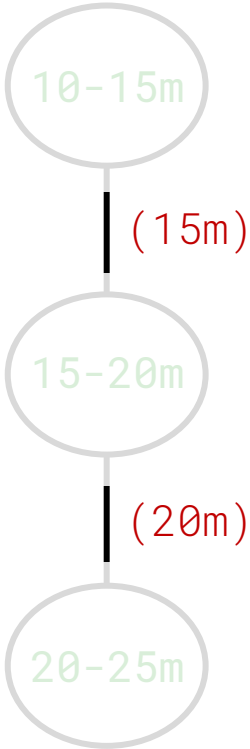
# TRG Structure

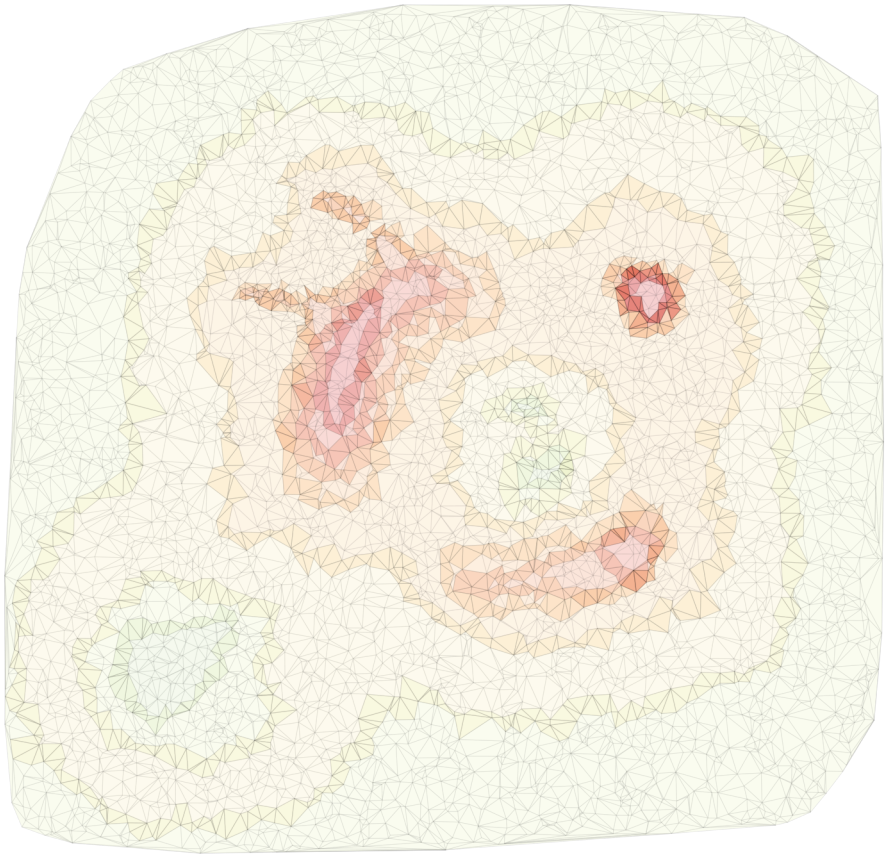


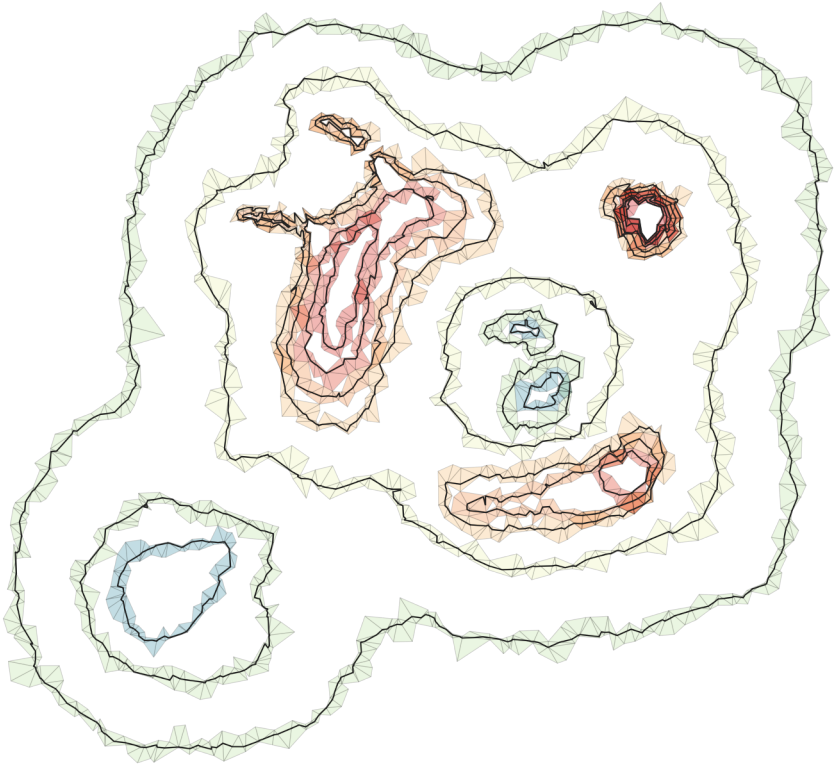


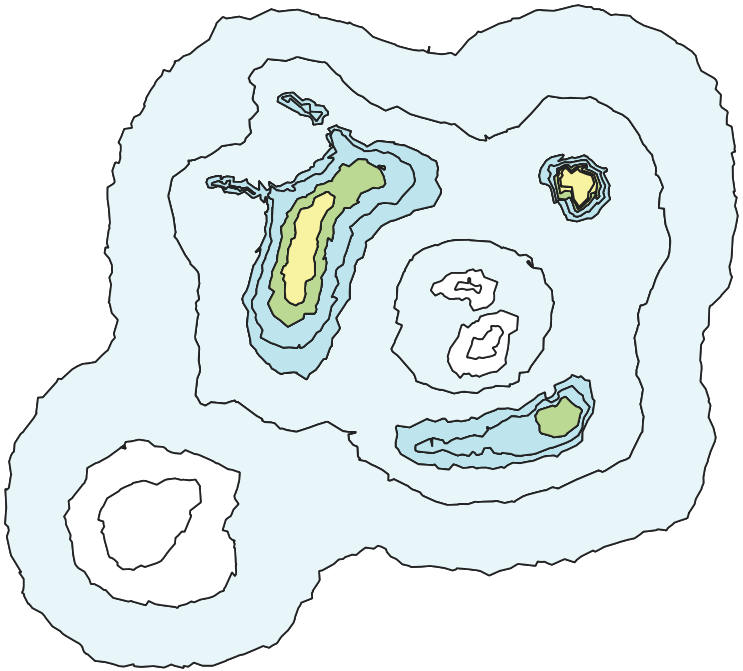
# TRG Structure

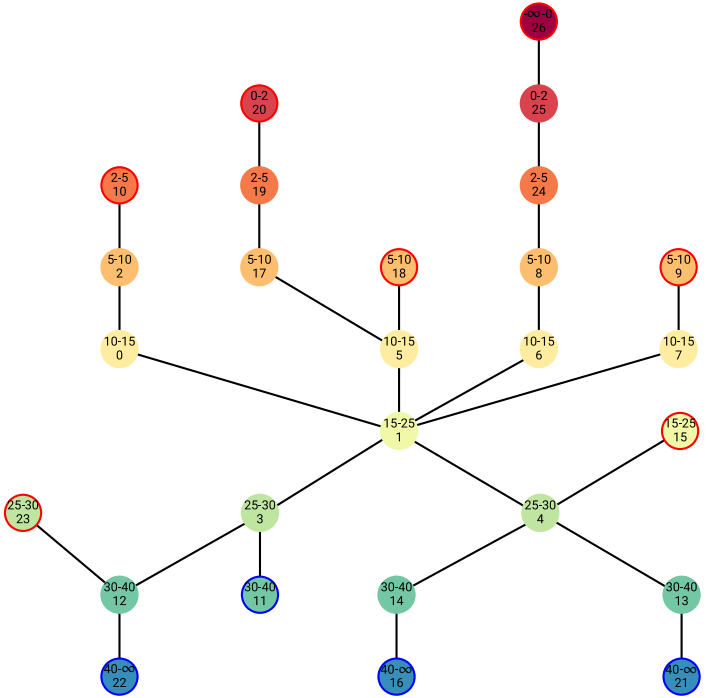






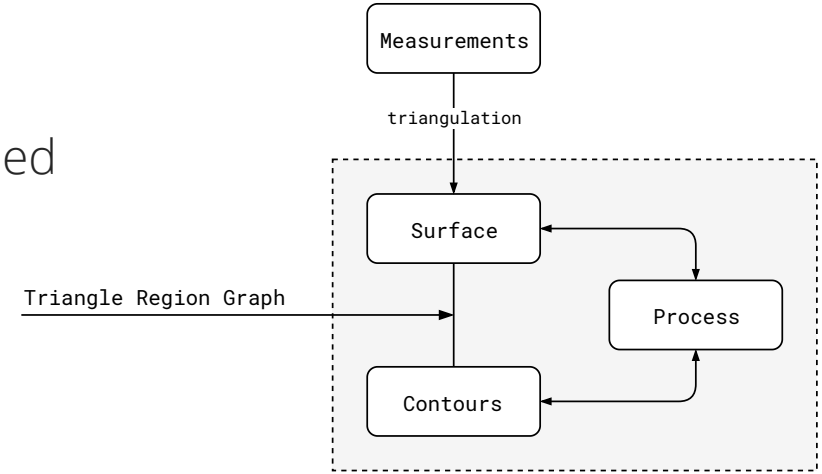



∞-0
26
0-2
20
0-2
25
2-5
10
2-5
19
2-5
24
5-10
2
5-10
17
5-10
18
5-10
8
5-10
9
10-15
0
10-15
5
10-15
6
10-15
7
15-25
1
15-25
15
25-30
23
25-30
3
25-30
4
30-40
12
30-40
11
30-40
14
30-40
13
40-∞
22
40-∞
16
40-∞
21

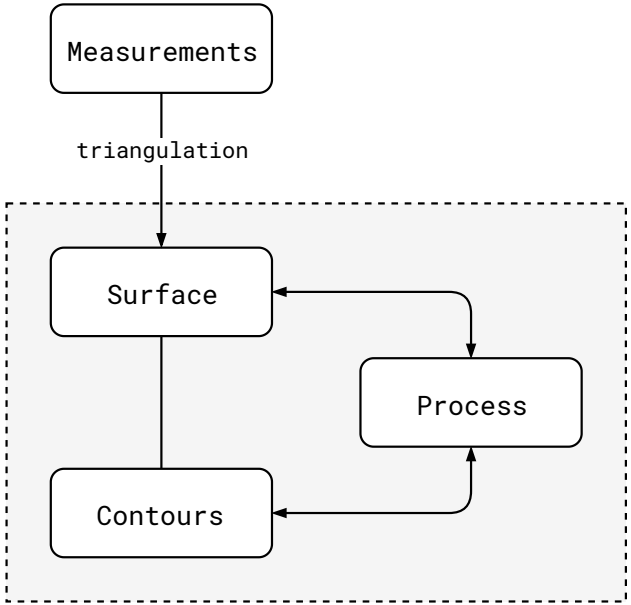
# TRG for isobath generalisation

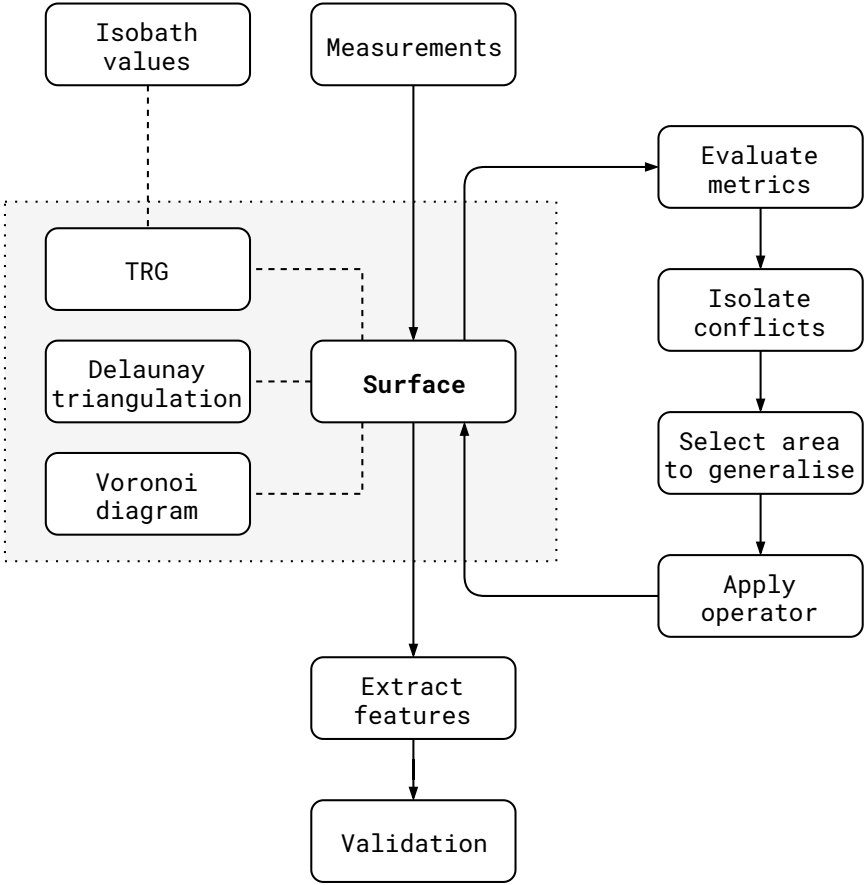
- Relates
  - Isobaths to isobaths
  - Isobaths to triangulation
  - > isobaths to survey data

- Efficient isobath extraction
- Depth areas implicitly defined



# An integrated approach




Isobath values
Measurements
Evaluate metrics
TRG
Isolate conflicts
Delaunay triangulation
Surface
Select area to generalise
Voronoi diagram
Apply operator
Extract features
Validation

# Generalisation process

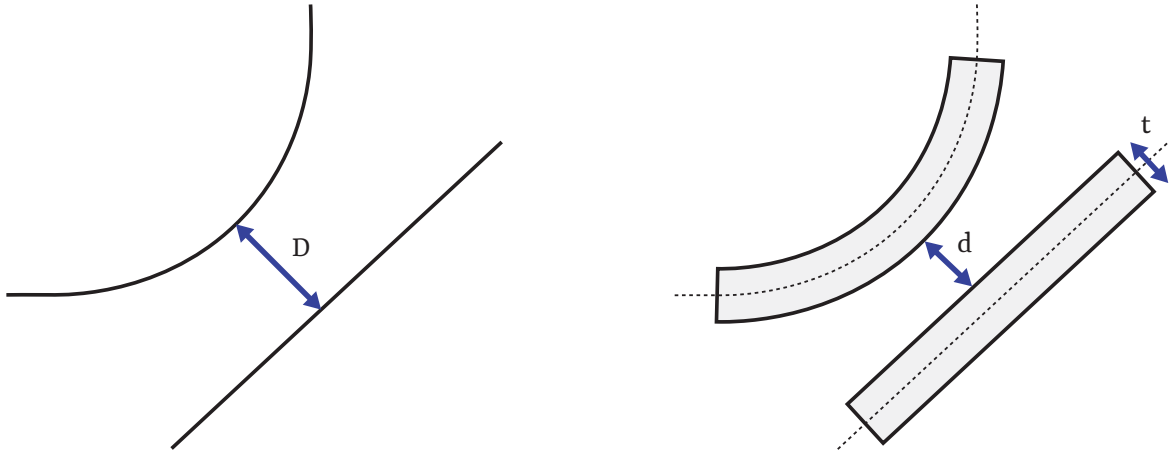
- Generalise where legibility is not good enough
- Legibility minimally met > morphology good as possible
- Safety and topology satisfied by definition

- Quantify with metrics
- Isolate conflicts

- Apply operator and maintain surface

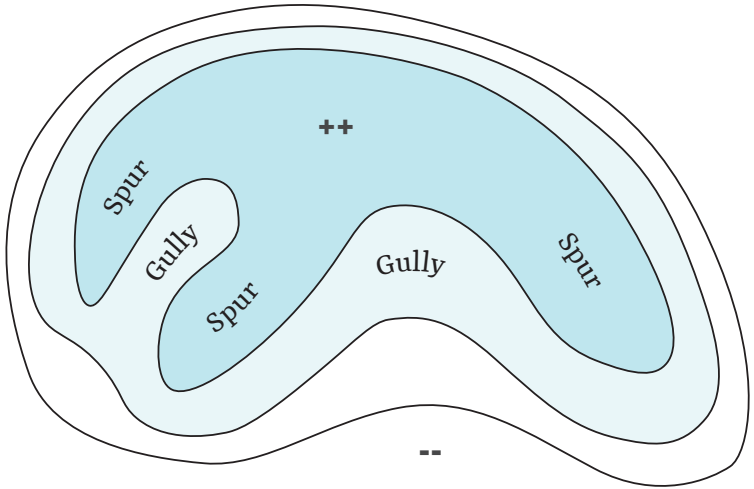
# Minimum legibility requirements

- Plotted lines may not visually overlap



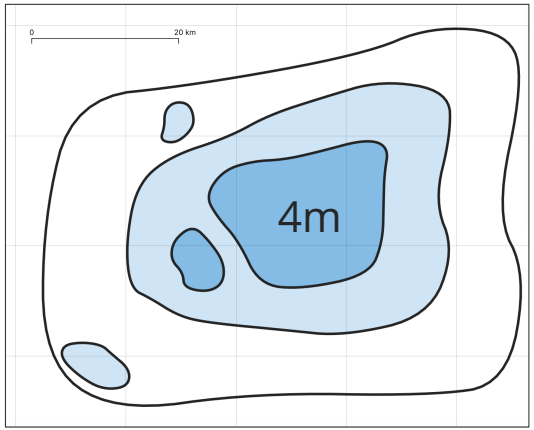
# Minimum legibility requirements

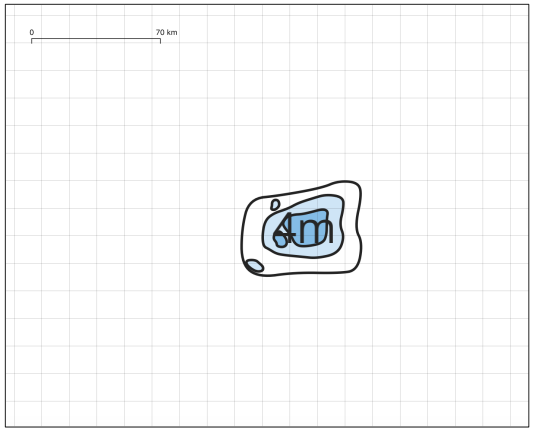
- Plotted lines may not visually overlap



# Minimum legibility requirements

- Plotted lines may not visually overlap
- Isobaths are large enough to contain at least one symbol



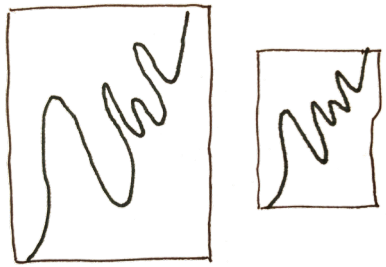



# Minimum legibility requirements

- Plotted lines may not visually overlap
- Isobaths are large enough to contain at least one symbol
- Irrelevant pits should be removed
- Channels or saddles irrelevant for navigation should be aggregated

# Minimum legibility requirements

- Plotted lines may not visually overlap
- Isobaths are large enough to contain at least one symbol
- Irrelevant pits should be removed
- Channels or saddles irrelevant for navigation should be aggregated
- Isobaths should be smooth

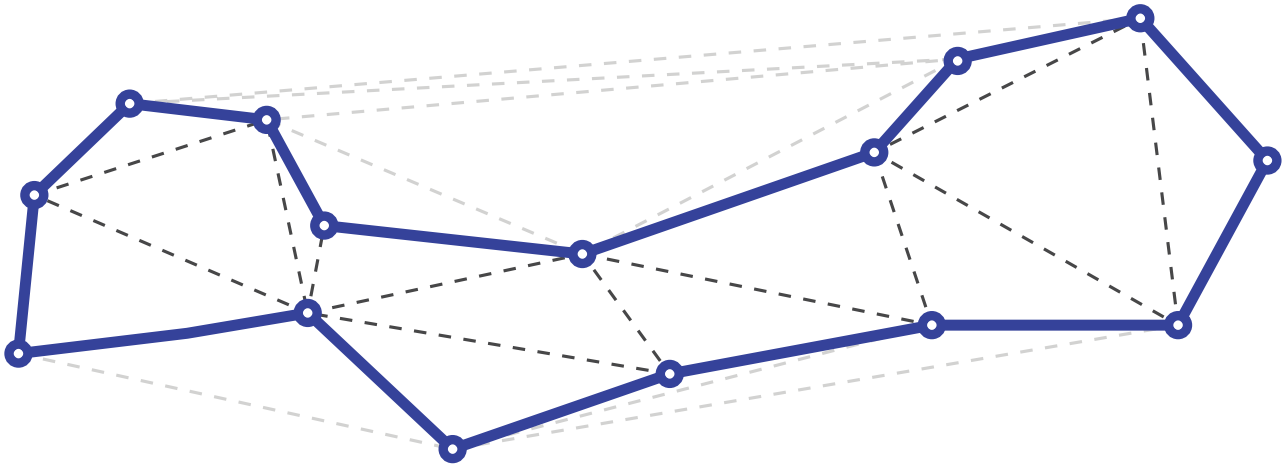


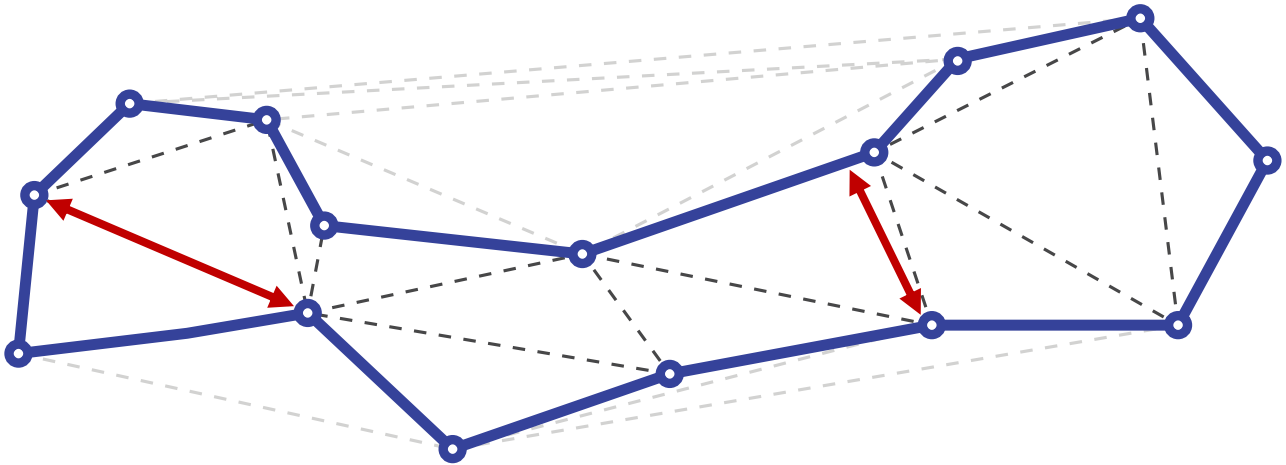
# Generalisation process

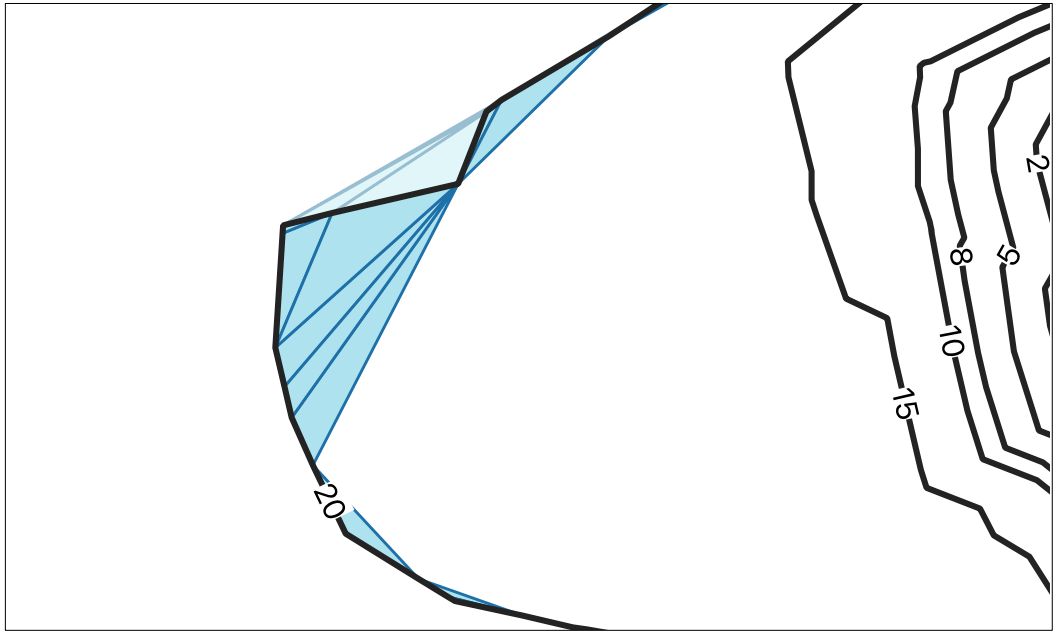
- Generalise where legibility is not good enough
- Legibility minimally met > morphology good as possible
- Safety and topology satisfied by definition

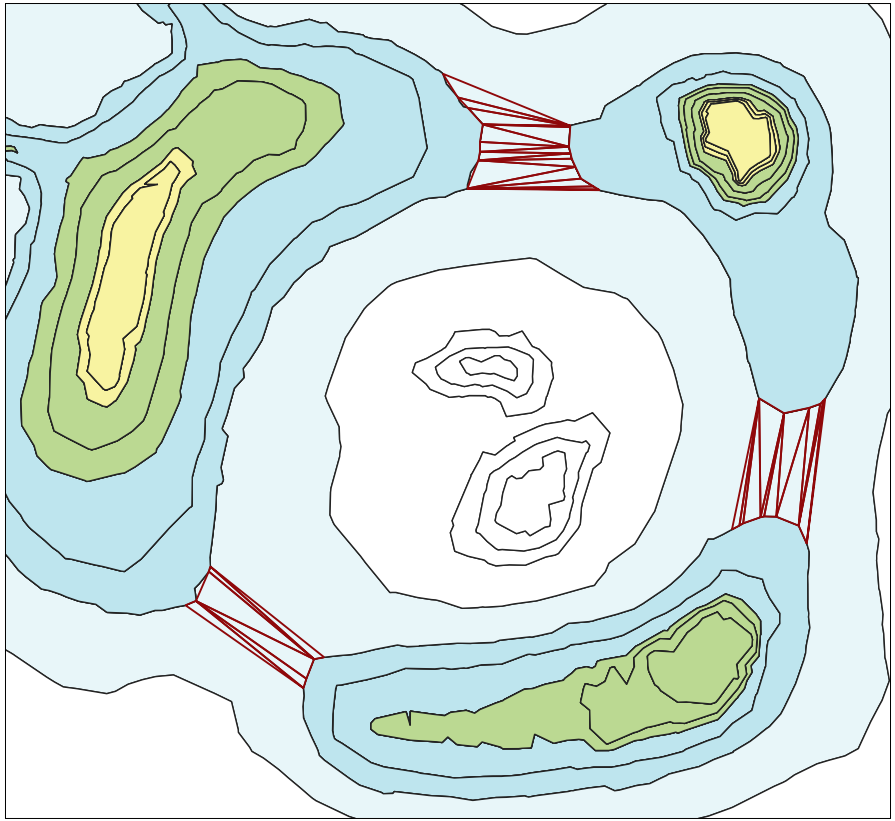
- Quantify with metrics
- Isolate conflicts

- Apply operator and maintain surface

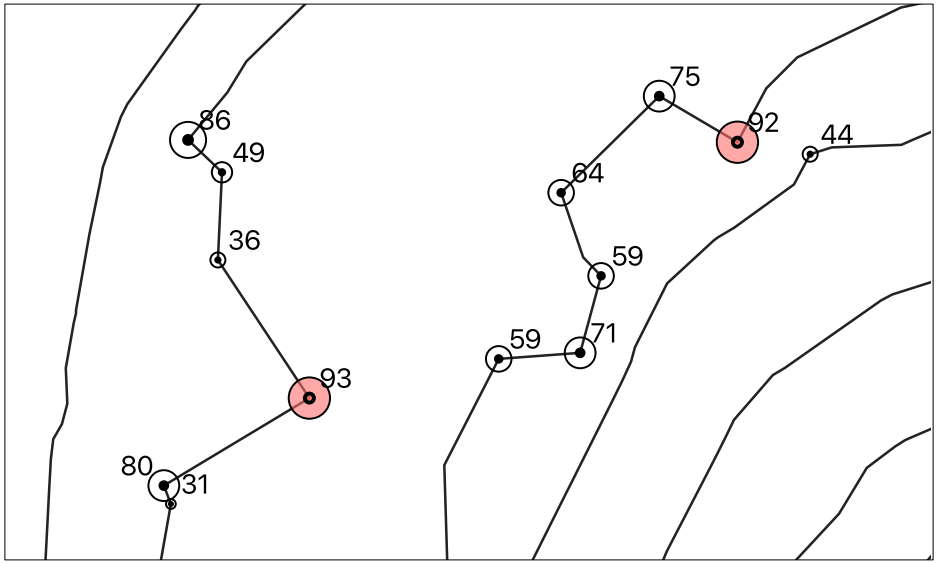





2
5
8
10
15
20



TU Delft


86
49
36
93
80
31
75
92
44
64
59
59
71

# Generalisation process

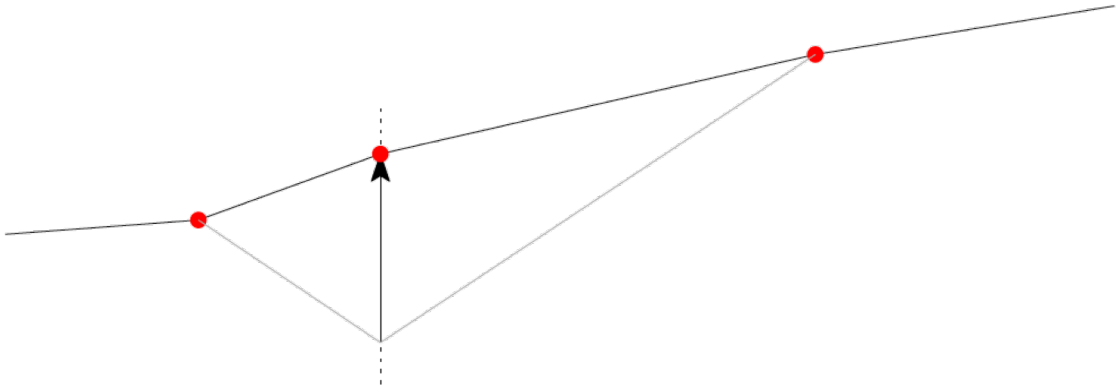
- Generalise where legibility is not good enough
- Legibility minimally met > morphology good as possible
- Safety and topology satisfied by definition

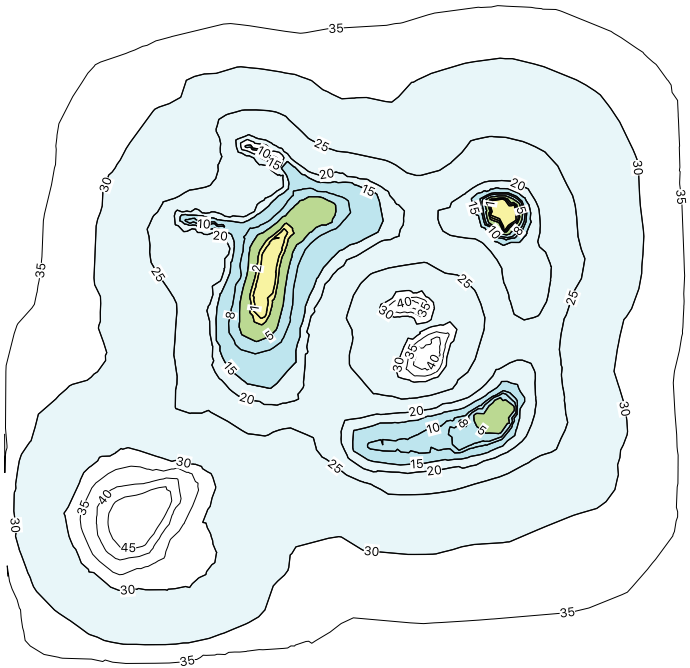
- Quantify with metrics
- Isolate conflicts

- Apply operator and maintain surface

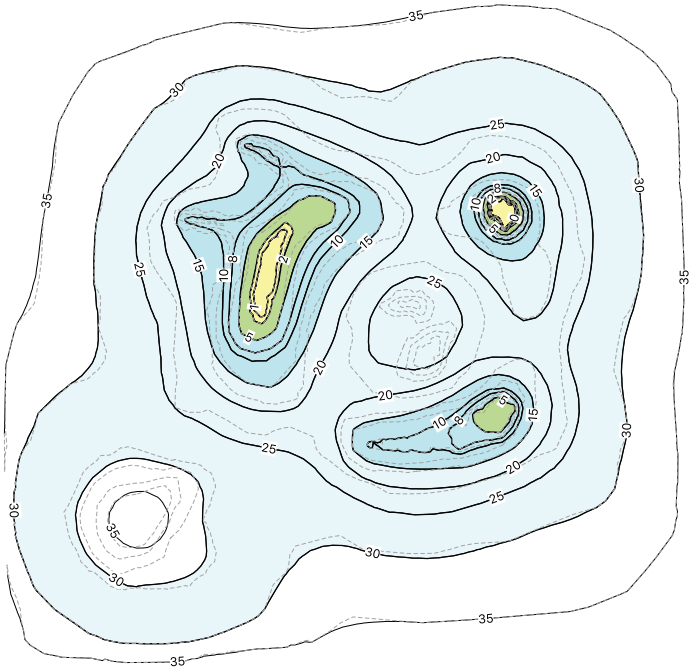
# Generalisation operators

- Smoothing
  - Smoothens the overall surface
  - Only upwards (safe)
  - One vertex at a time





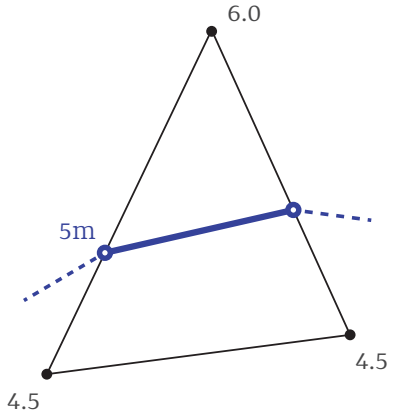
Before

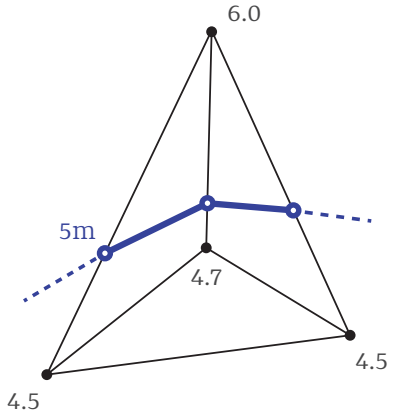


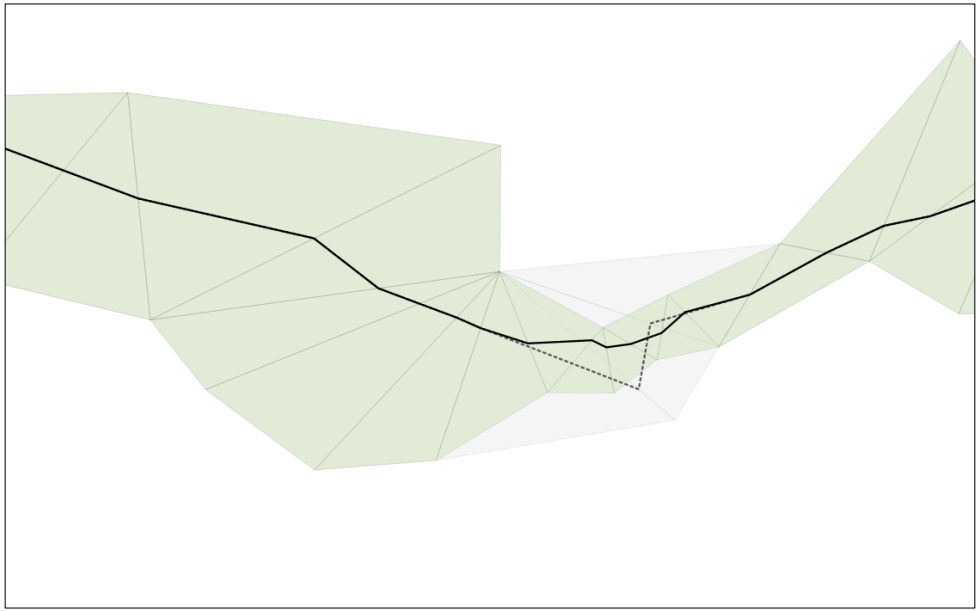
After

# Generalisation operators

- Smoothing
  - Smoothens the overall surface
  - Only upwards (safe)
  - One vertex at a time
- Densification
  - Inserts new vertices in the TIN
  - Decreases the discretization error
  - Effectively smoothens a line

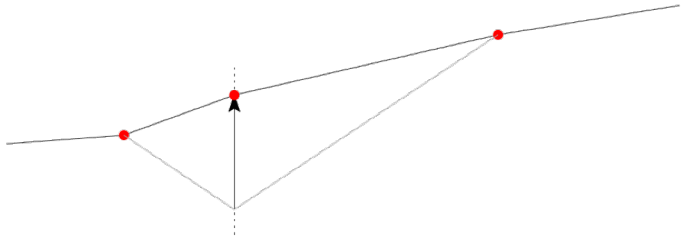


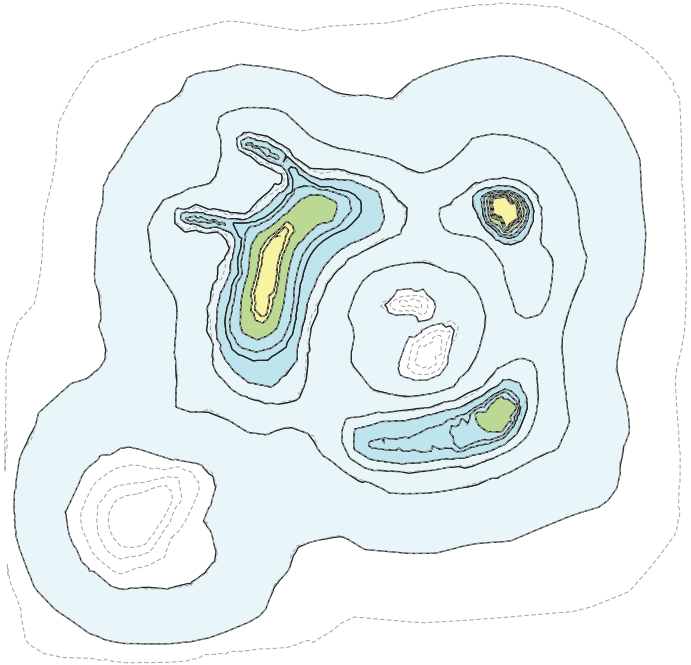





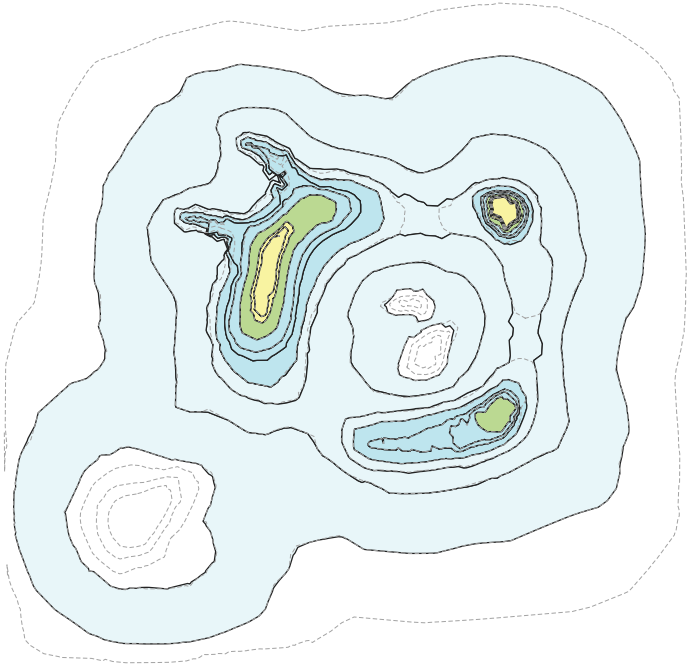
# Generalisation operators

- Smoothing
  - Smoothens the overall surface
  - Only upwards (safe)
  - One vertex at a time
- Densification
  - Inserts new vertices in the TIN
  - Decreases the discretization error
  - Effectively smoothens a line
- Displacement
  - Pushes vertices upwards
  - To a fixed value

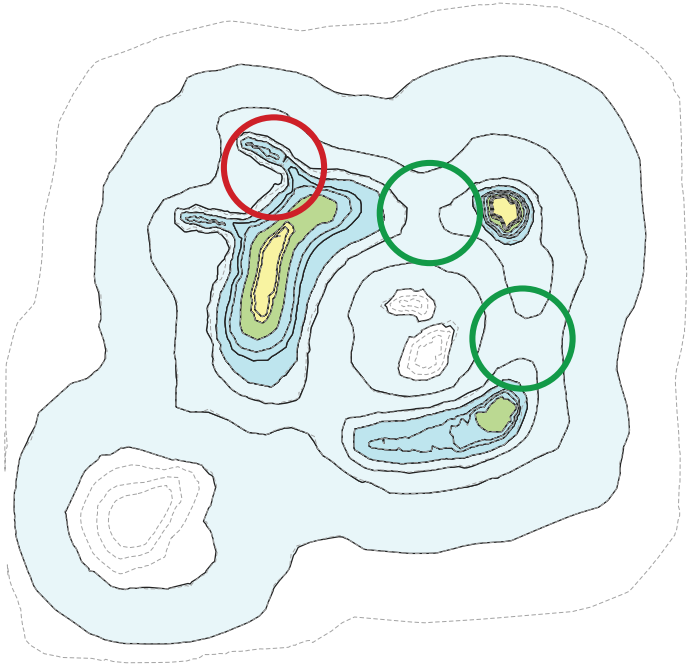




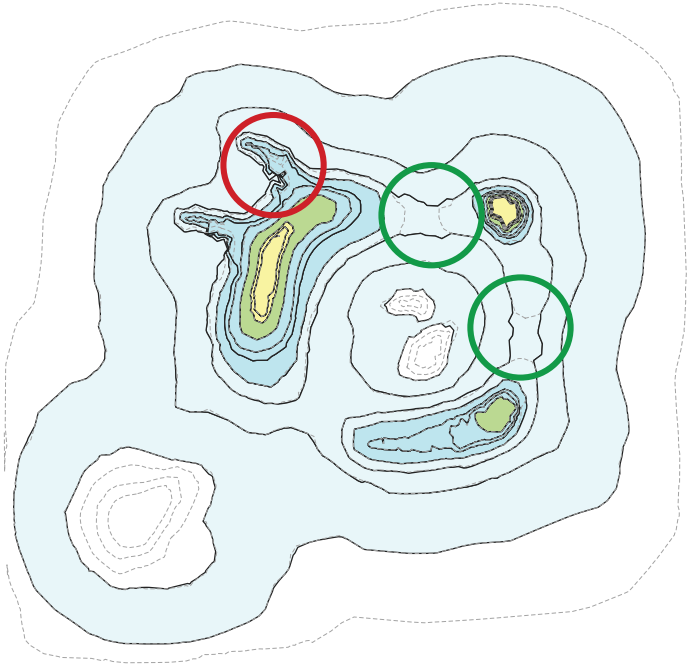
Before



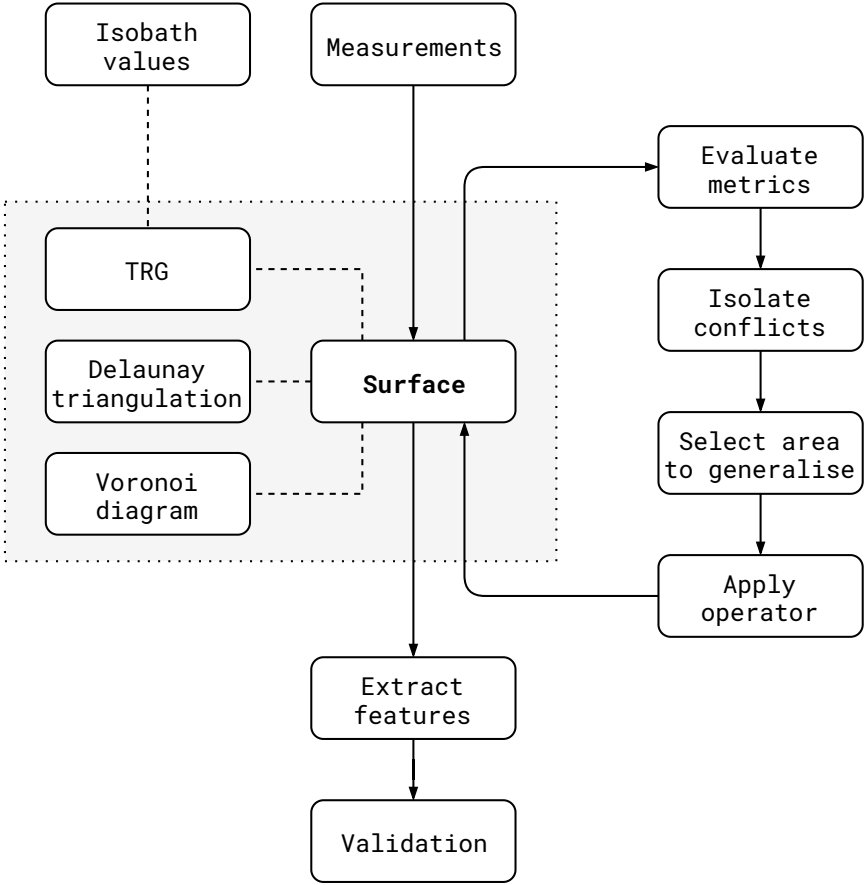
After



Before



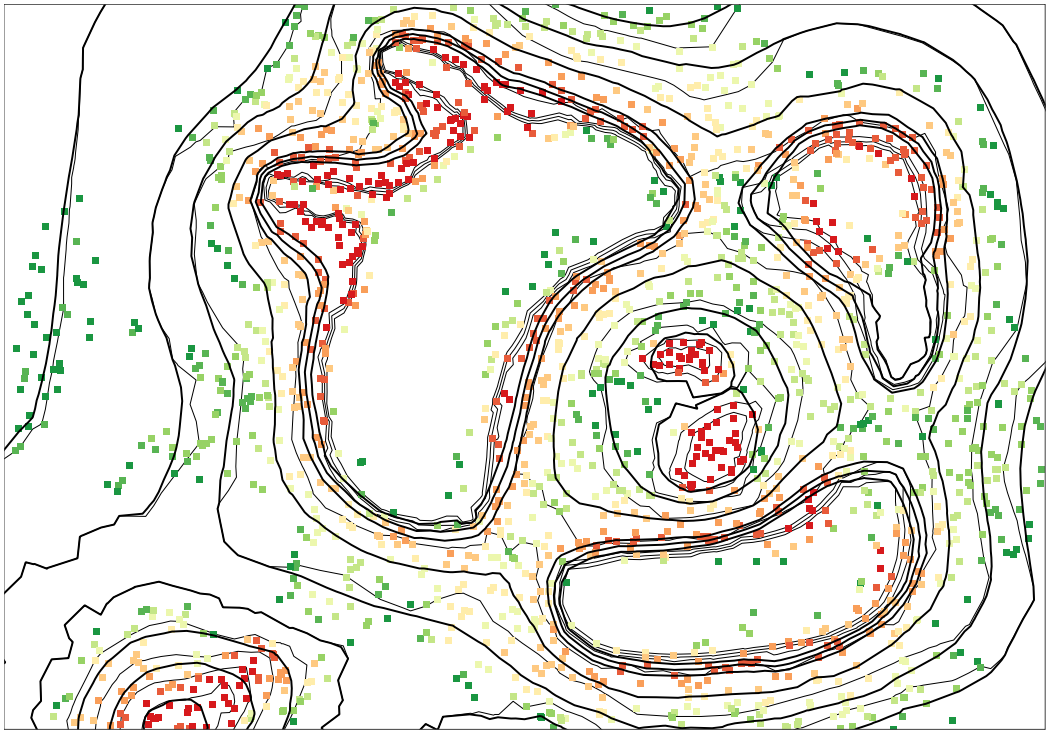
After


Isobath values
Measurements
Evaluate metrics
TRG
Isolate conflicts
Delaunay triangulation
Surface
Select area to generalise
Voronoi diagram
Apply operator
Extract features
Validation

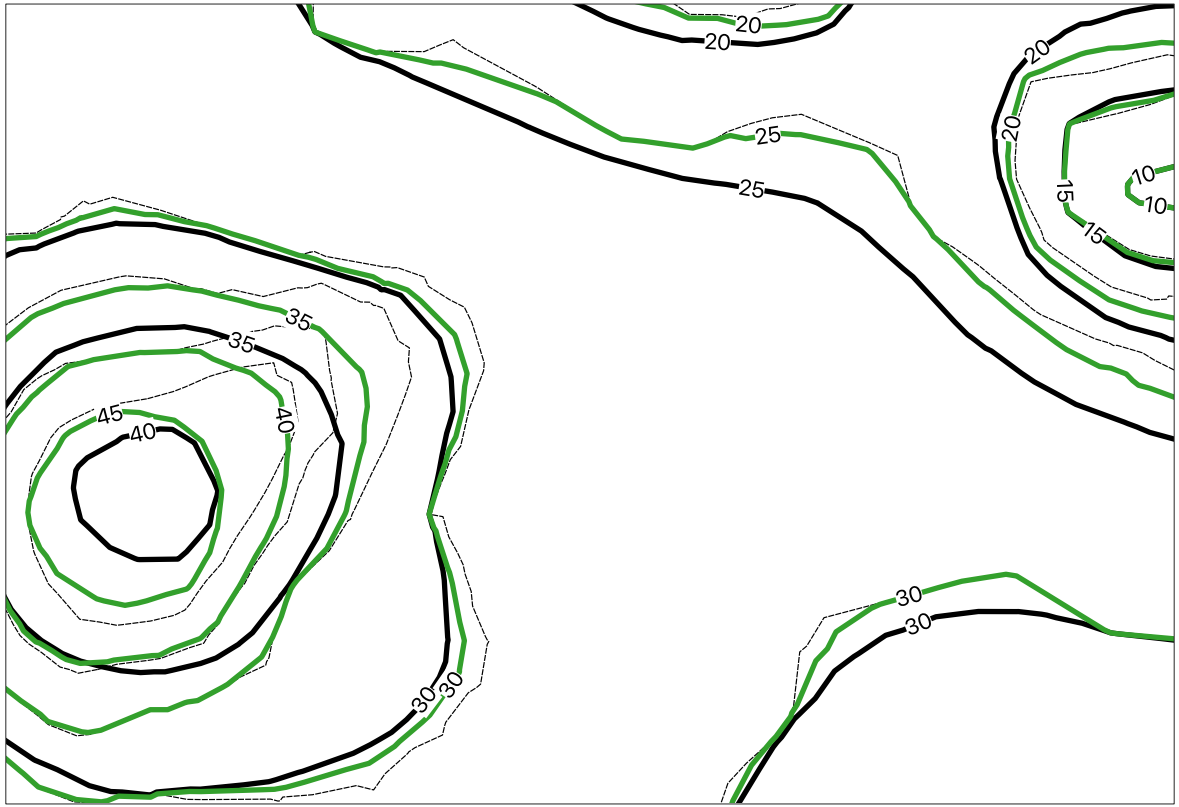
# Contents

- Introduction
- Generalisation approaches
- Methodology
  - An integrated approach
  - Triangle region graph
  - Generalisation process
- Experiments
- Conclusion

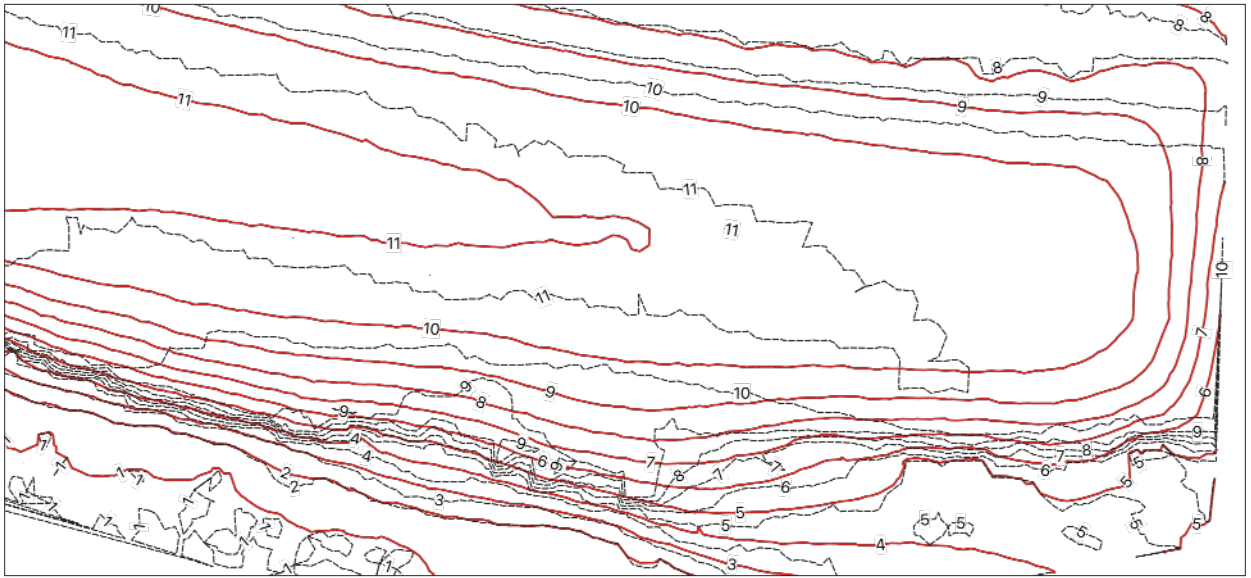
# Smoothing effects



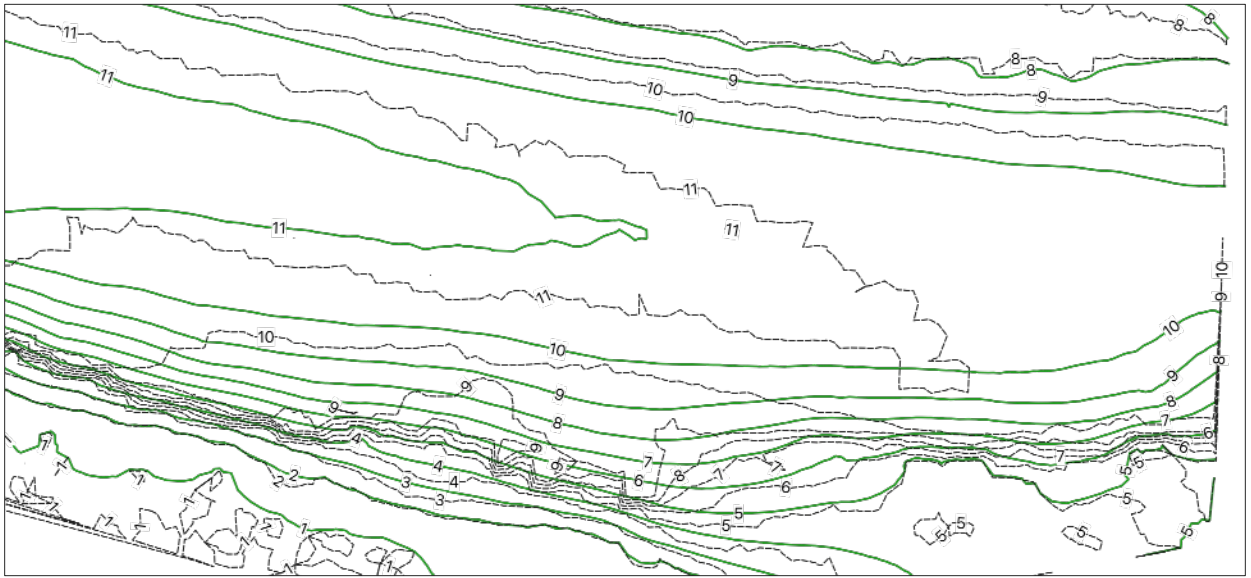

Changed vertices, targeted smoothing




50x large thresholds (black)
100x small thresholds (green)



Original approach: smoothing every vertex

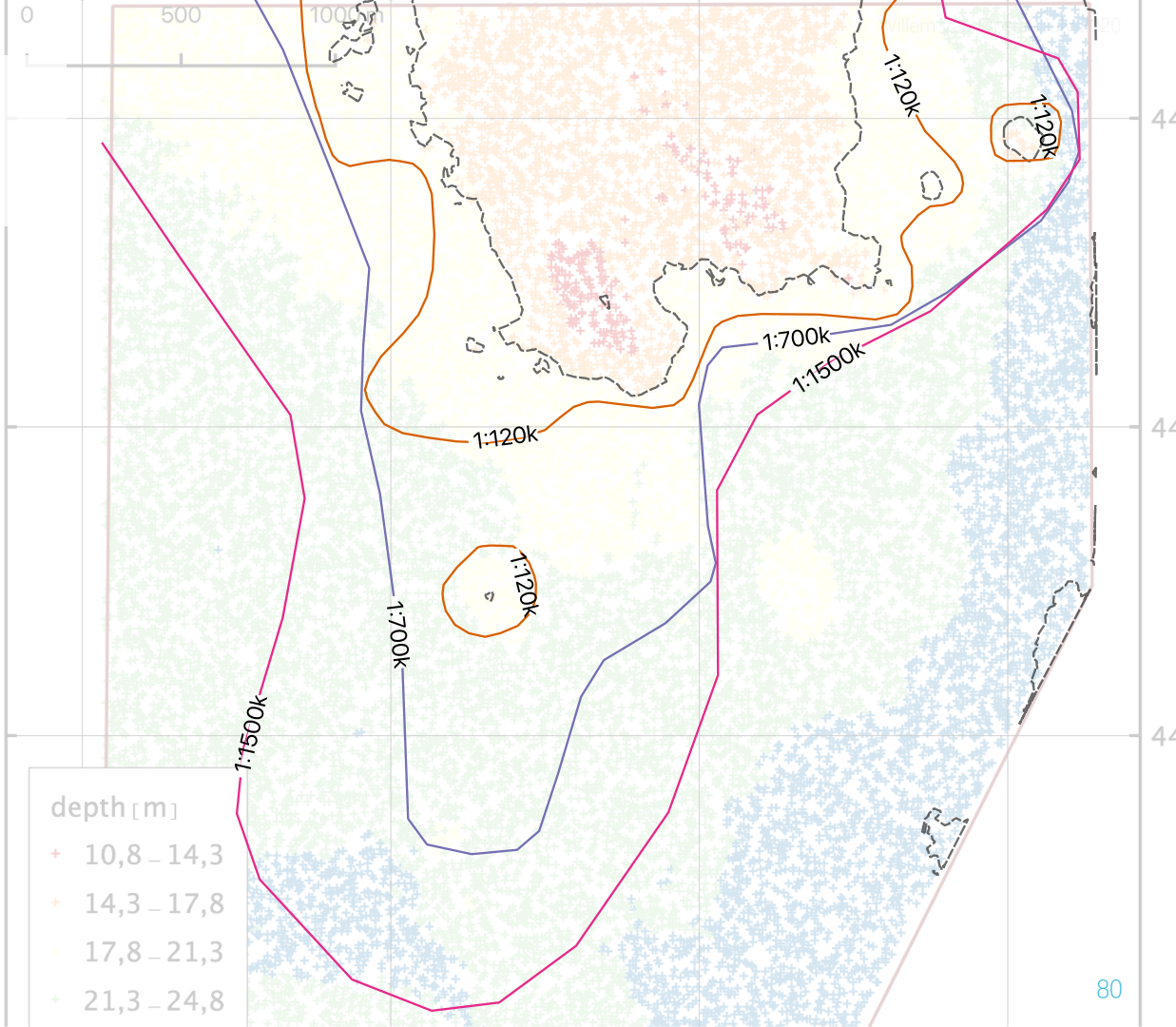


New approach: not smoothing the boundary

# Use cases

# New York

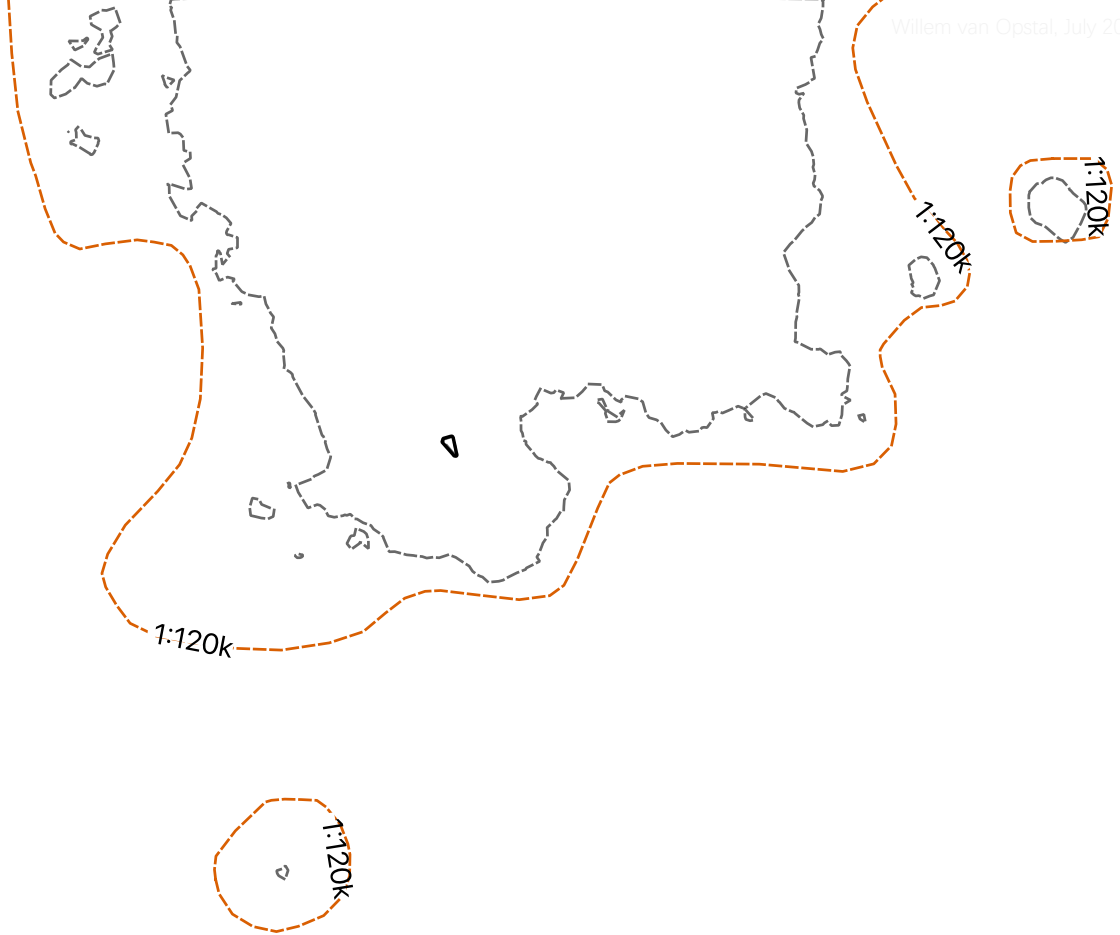
- Official ENC isobaths
  - 1:120k
  - 1:700k
  - 1:1500k



# New York

- 1:120k

- Original TIN
- Official ENC

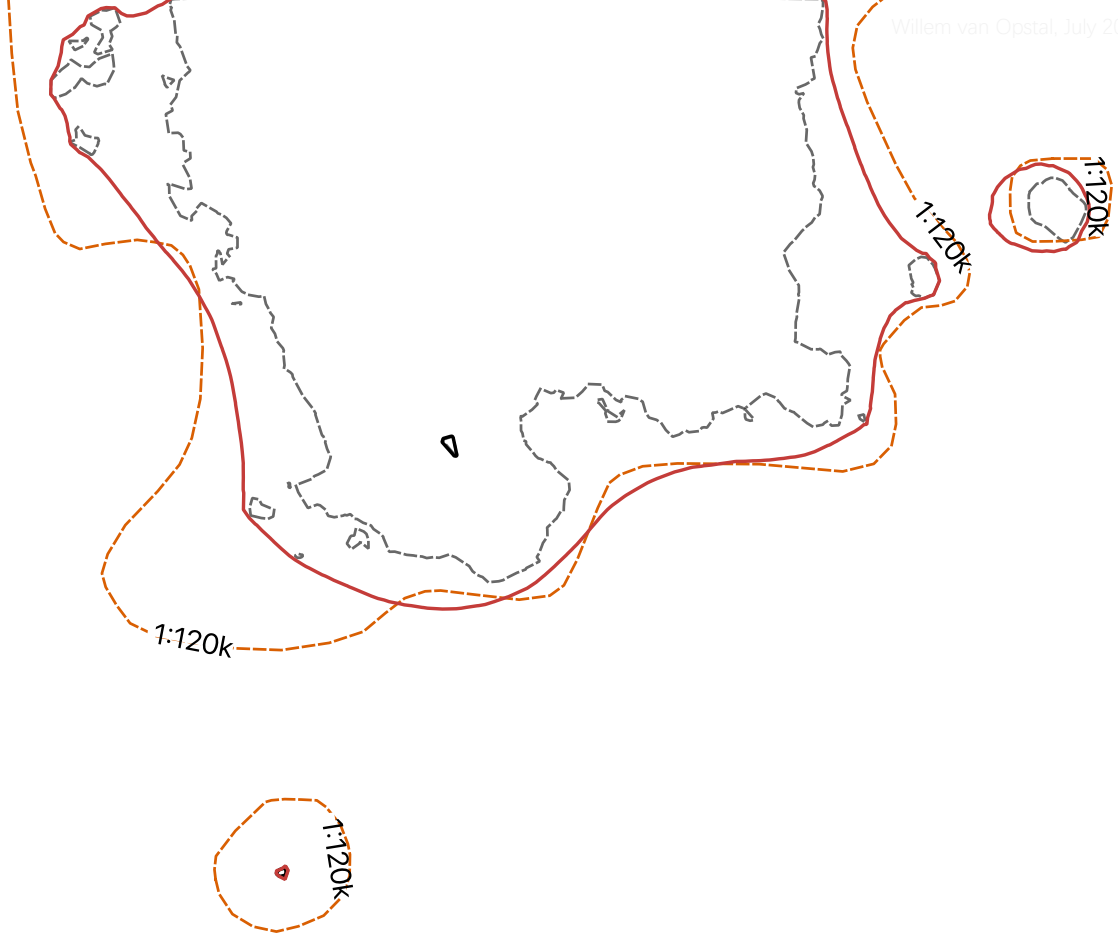


# New York

- 1:120k

- Original TIN
- Official ENC

- 250x Smoothing

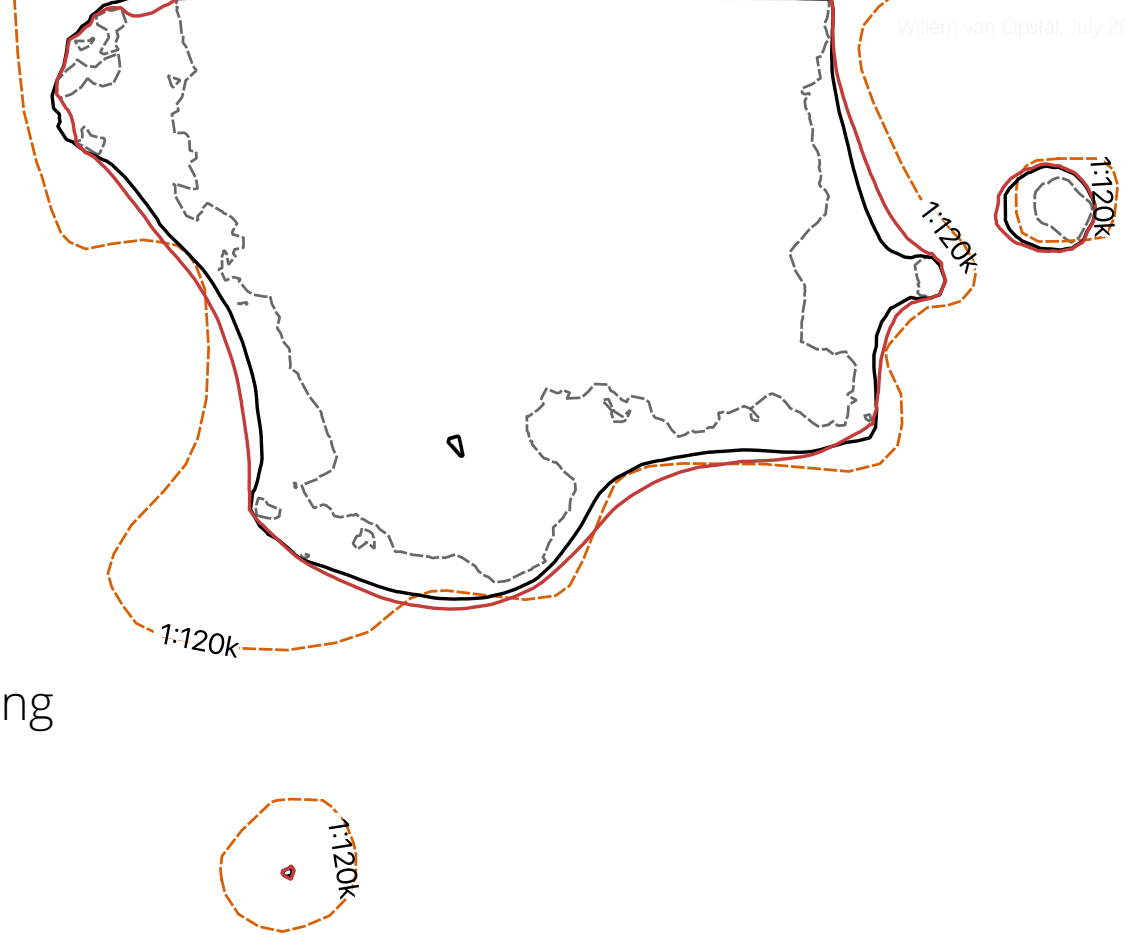


# New York

- 1:120k

- Original TIN
- Official ENC

- 250x Smoothing
- 250x Targeted smoothing

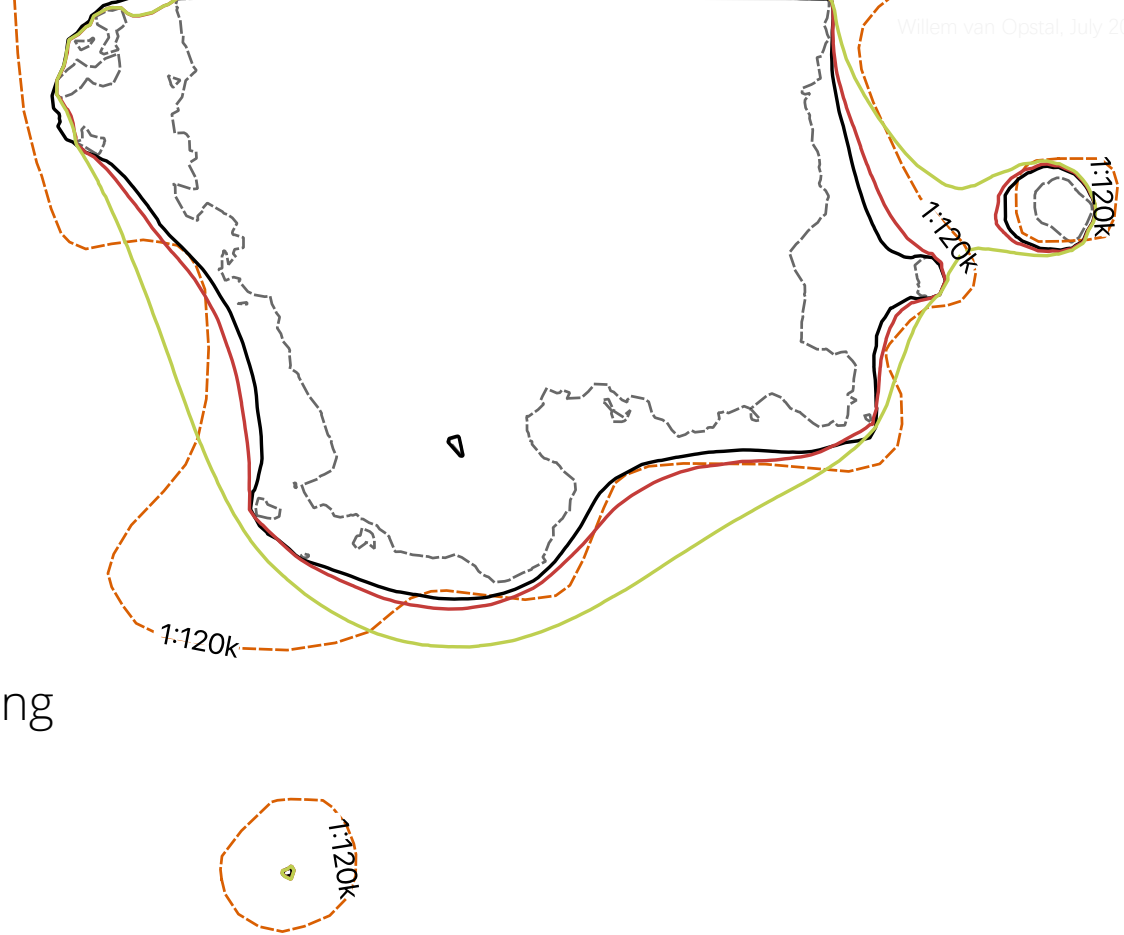


# New York

- 1:120k

- Original TIN
- Official ENC

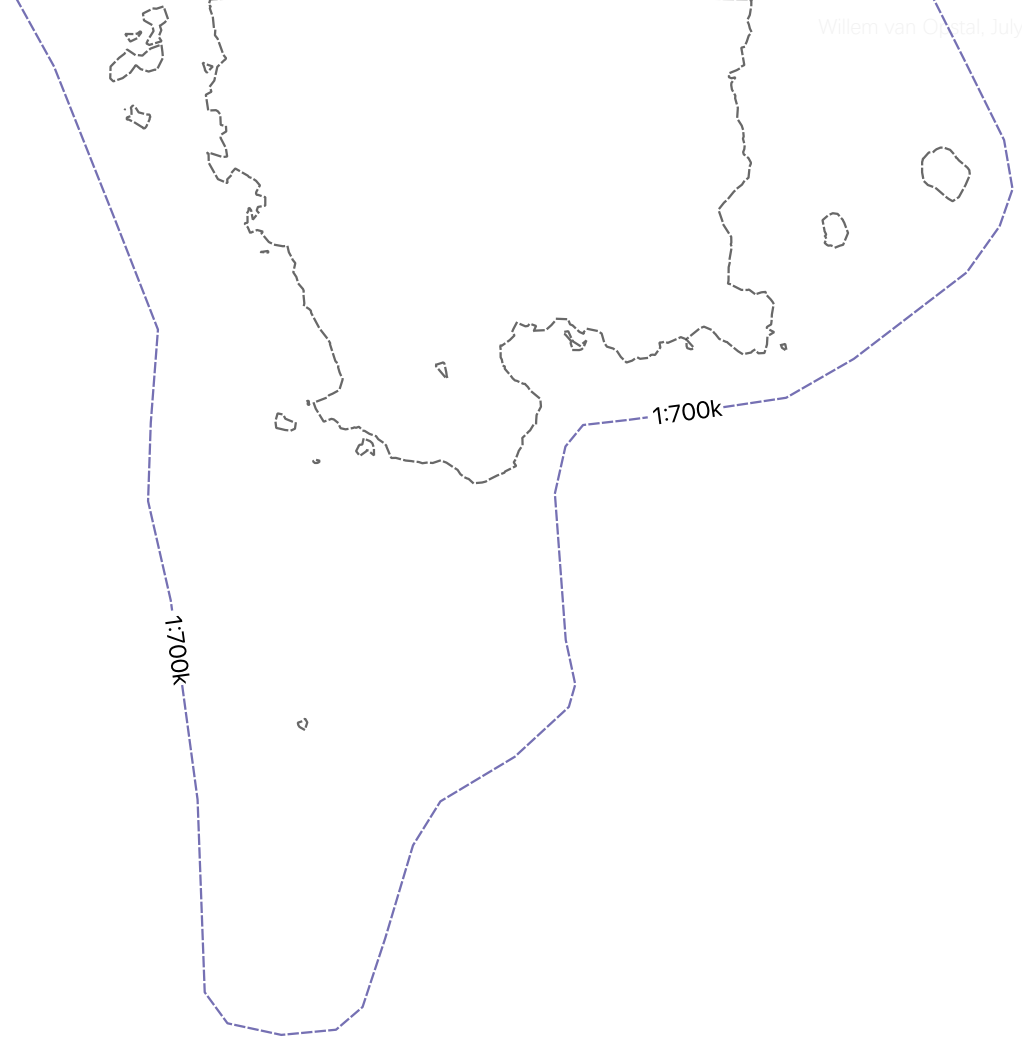
- 250x Smoothing
- 250x Targeted smoothing
- 1000x Smoothing



# New York

- 1:700k

- Original TIN
- Official ENC

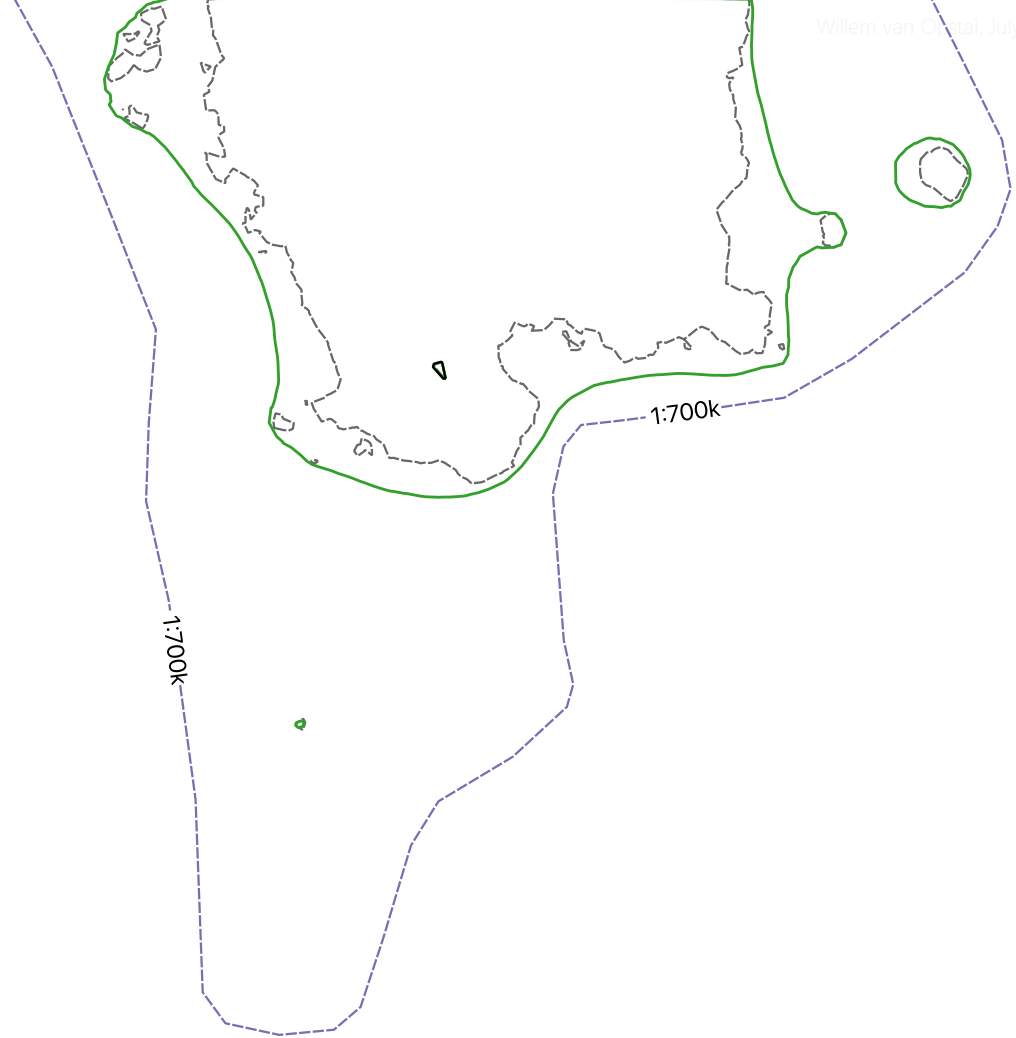


# New York

- 1:700k

- Original TIN
- Official ENC

- 250x Smoothing 120k

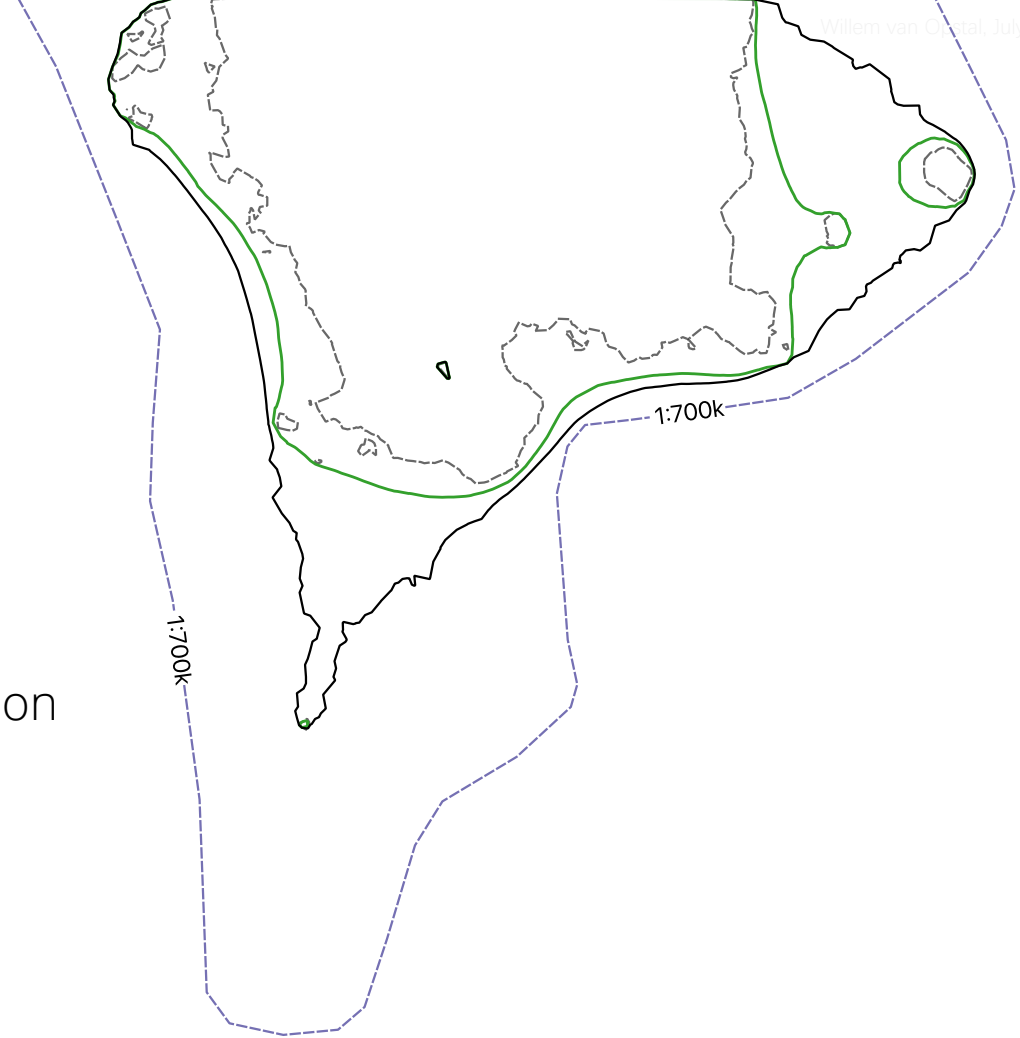


# New York

- 1:700k

- Original TIN
- Official ENC

- 250x Smoothing 120k
- 250x Smoothing + aggregation

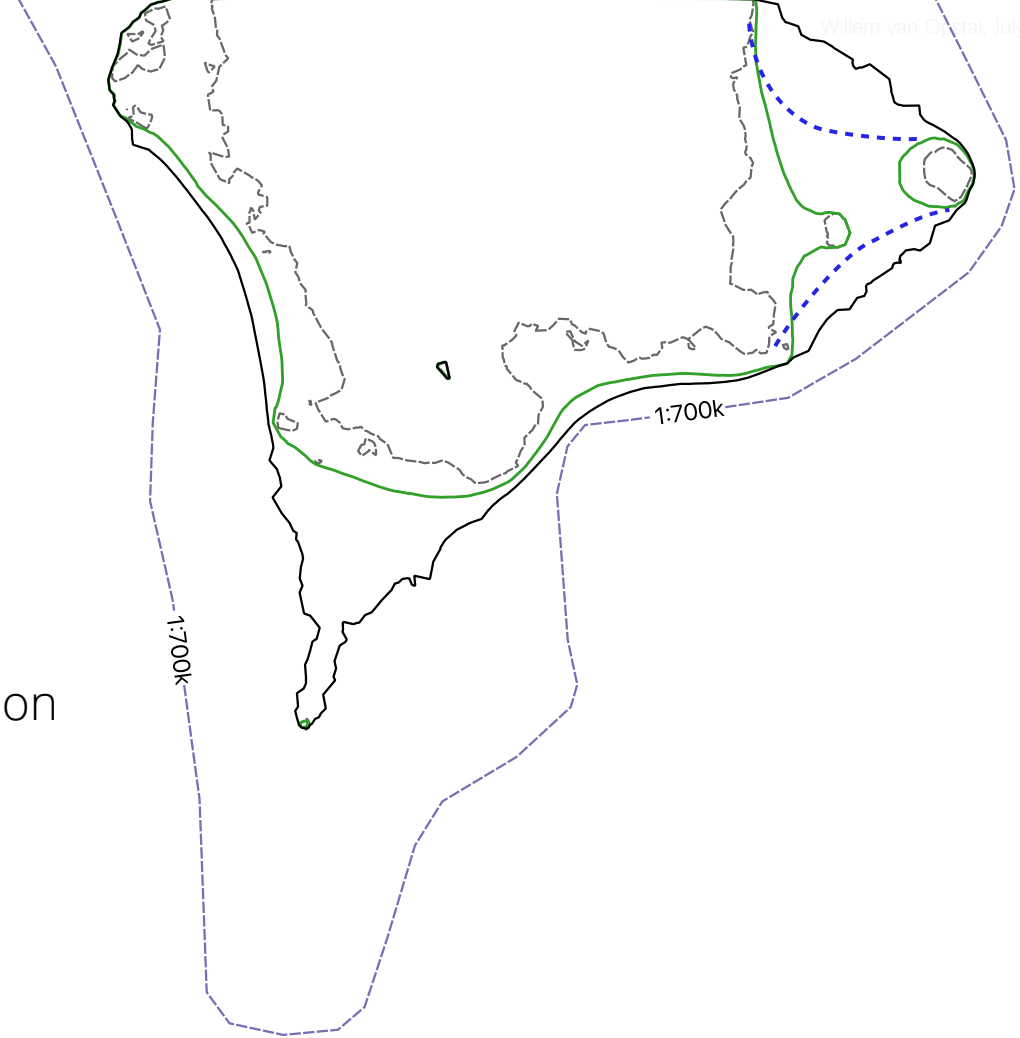


# New York

- 1:700k

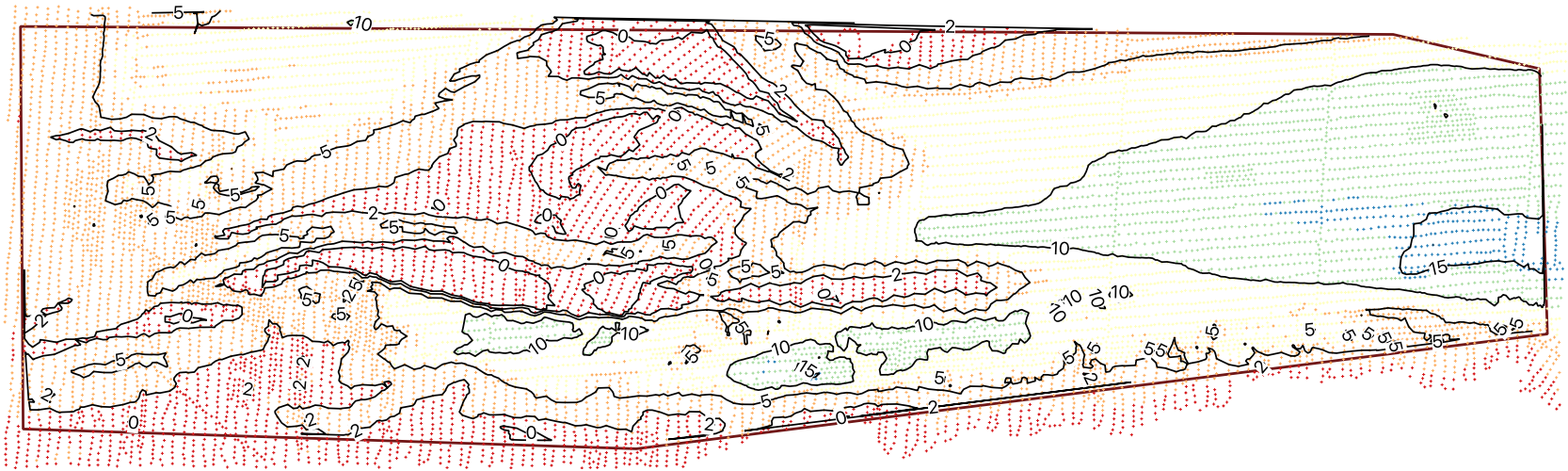
- Original TIN
- Official ENC

- 250x Smoothing 120k
- 250x Smoothing + aggregation



# Margate Road

- 1:100k
- Original TIN

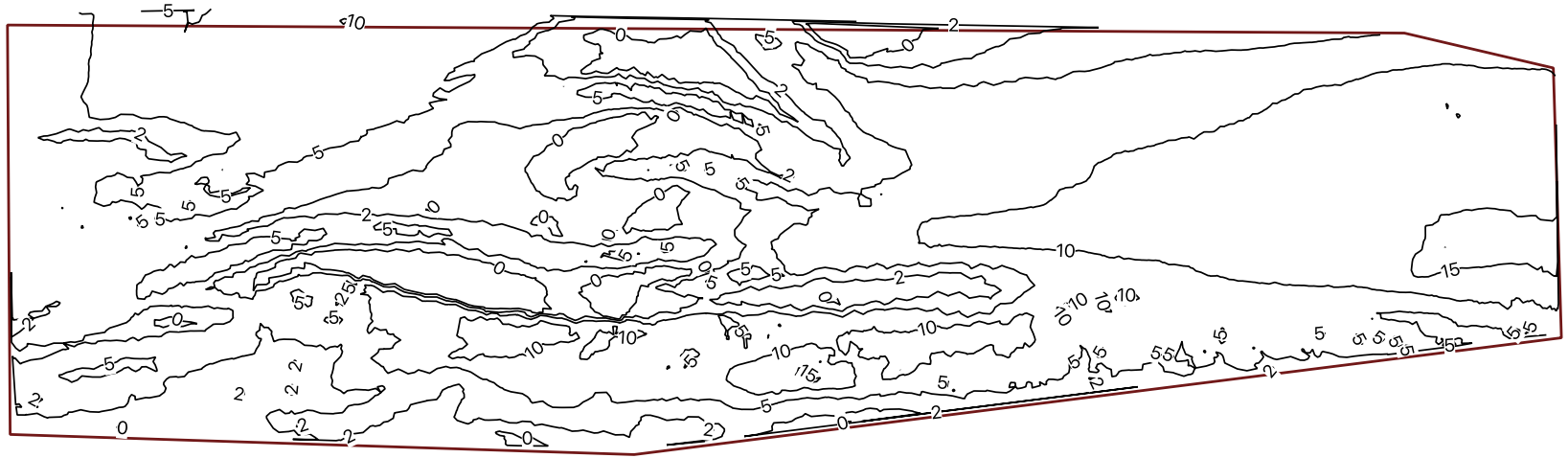


# Margate Road

- 1:100k
- Official ENC

# Margate Road

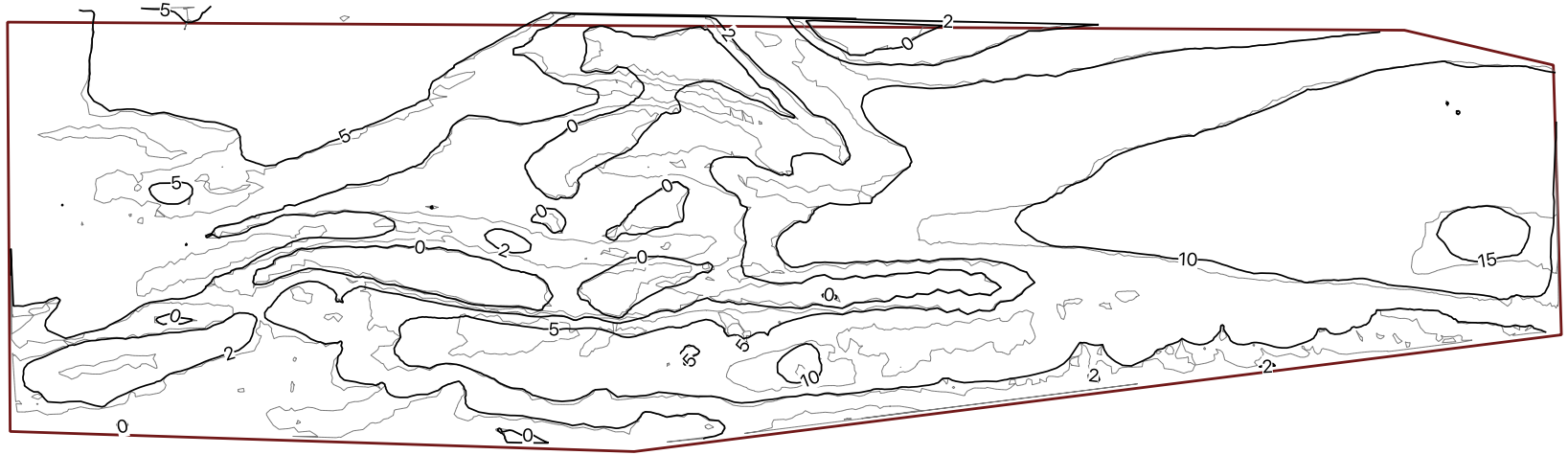
- 1:100k
- Original TIN



# Margate Road

- Original TIN
- TRGA Generated

- 1:100k




TU Delft

# Margate Road

- 1:100k
- TRGA Generated

# Margate Road

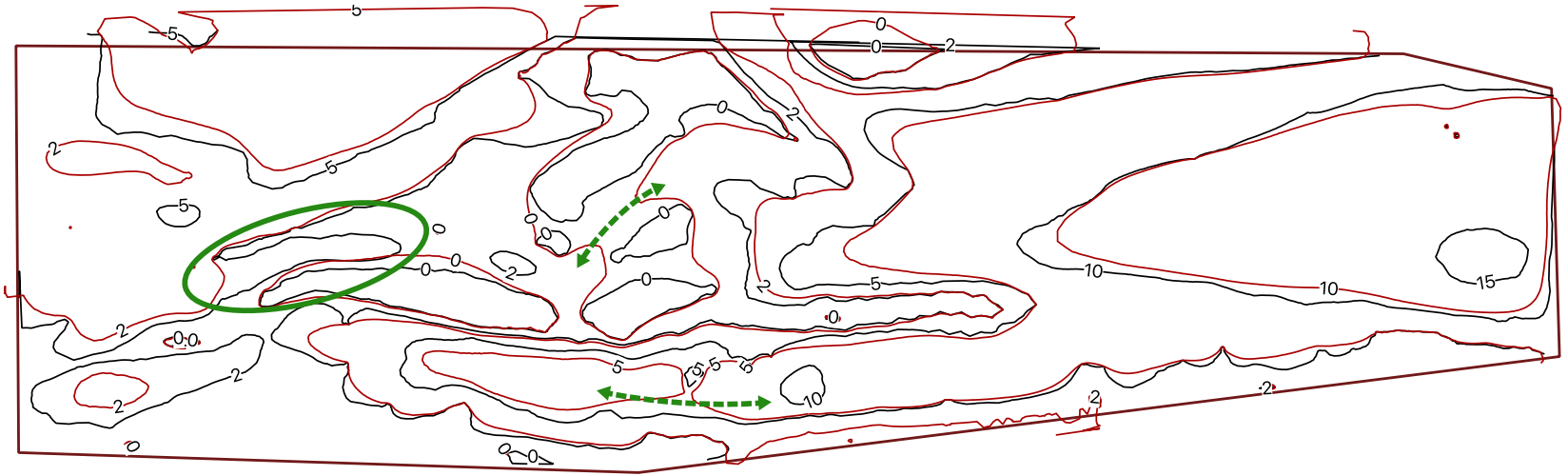
- TRGA Generated
- VSBA

- 1:100k

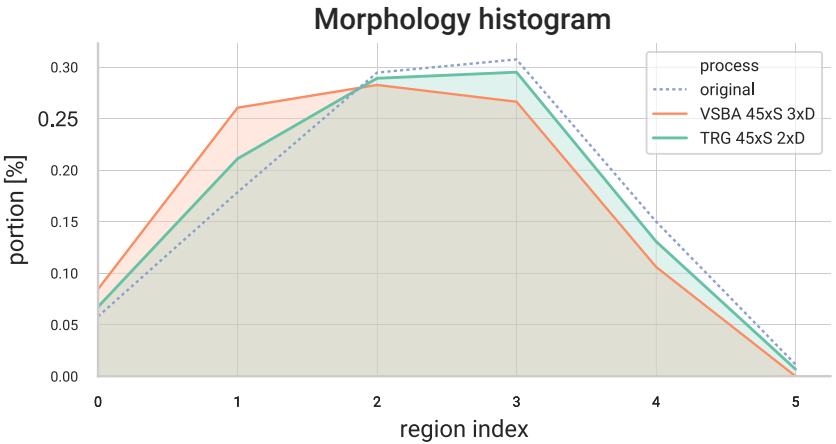
# Margate Road

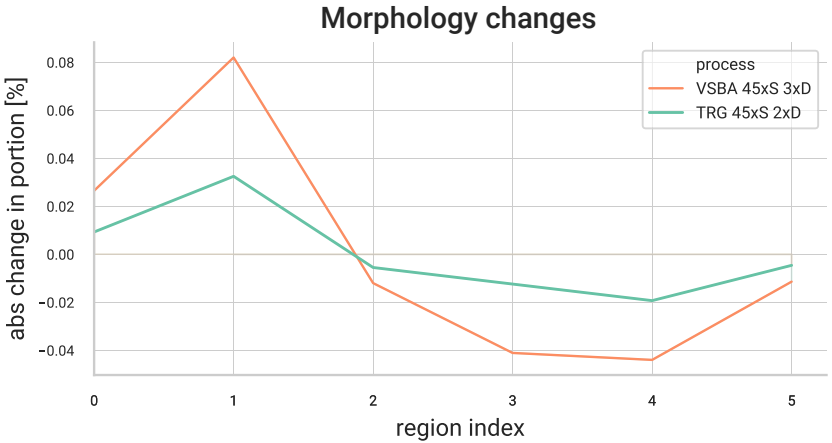
- TRGA Generated
- VSBA

- 1:100k



# Margate Road



# Contents

- Introduction
- Generalisation approaches
- Methodology
  - An integrated approach
  - Triangle region graph
  - Generalisation process
- Experiments
- Conclusions

# Triangle region graph

- Linking mechanism
  - Survey data – triangulation – isobaths – cartography
  - Triangles accounting for certain terrain features
  - Relations between isobaths: the terrain
- Always safe, also horizontally
- Integration of depth areas, soundings and isobaths
- Feature classification needs more information
  - Containment (directed graph)
  - Separate feature trees
- Maintenance efficiency

# Triangle region graph

- Linking mechanism
  - Survey data – triangulation – isobaths – cartography
  - Triangles accounting for certain terrain features
  - Relations between isobaths: the terrain
- Always safe, also horizontally
- Integration of depth areas, soundings and isobaths
- Feature classification needs more information
  - Containment (directed graph)
  - Separate feature trees
- Maintenance efficiency

# Triangle region graph

- Linking mechanism
  - Survey data – triangulation – isobaths – cartography
  - Triangles accounting for certain terrain features
  - Relations between isobaths: the terrain
- Always safe, also horizontally
- Integration of depth areas, soundings and isobaths
- Feature classification needs more information
  - Containment (directed graph)
  - Separate feature trees
- Maintenance efficiency

# Cartographic constraints

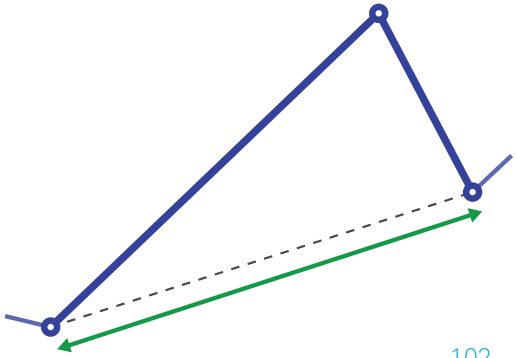
- It really is difficult to quantify legibility
  - Especially smoothness of a line
- Isolation of conflicts ok

- Metrics are not always solvable
  - Wrong metrics, wrong legibility requirements, wrong operators ?
- Spur/gully is too simple
- Affected by scale, density and thresholds

# Cartographic constraints

- It really is difficult to quantify legibility
  - Especially smoothness of a line
- Isolation of conflicts ok

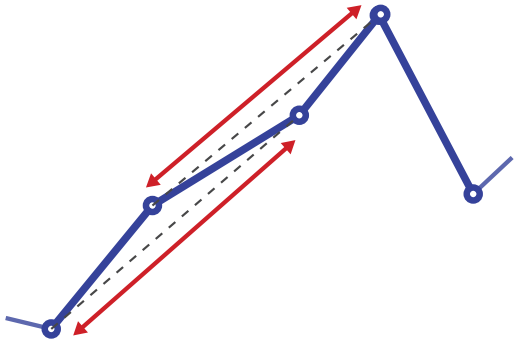
- Metrics are not always solvable
  - Wrong metrics, wrong legibility requirements, wrong operators ?
- Spur/gully is too simple
- Affected by scale, density and thresholds



# Cartographic constraints

- It really is difficult to quantify legibility
  - Especially smoothness of a line
- Isolation of conflicts ok

- Metrics are not always solvable
  - Wrong metrics, wrong legibility requirements, wrong operators ?
- Spur/gully is too simple
- Affected by scale, density and thresholds



# Generalisation process

- Integrated approach
- Slightly improved existing operators
- More parameters, but also more control

- Performs well at large scales
  - Maintains more morphology
  - Only generalises where needed
- Less at small scales

- Not smoothen beyond smooth
- Ideally more directly on the surface

# Generalisation process

- Integrated approach
- Slightly improved existing operators
- More parameters, but also more control

- Performs well at large scales
  - Maintains more morphology
  - Only generalises where needed
- Less at small scales

- Not smoothen beyond smooth
- Ideally more directly on the surface

# Generalisation process

- Integrated approach
- Slightly improved existing operators
- More parameters, but also more control

- Performs well at large scales
  - Maintains more morphology
  - Only generalises where needed
- Less at small scales

- Not smoothen beyond smooth
- Ideally more directly on the surface

# Conclusions

- To what extent can we locally steer generalisation operators to account for cartographic constraints, in a surface-based isobath generalisation method?

  - Through TRG we can integrate cartography within the surface
  - Conceptual framework of integration and evaluation has potential
    - also for other depth information
  - We can target generalisation operators to maintain morphology
  - Especially effective on large scales

  - We cannot yet generalise beyond *smooth*
  - Benefit from the development of more complex metrics & operators

# Conclusions

- To what extent can we locally steer generalisation operators to account for cartographic constraints, in a surface-based isobath generalisation method?

  - Through TRG we can integrate cartography within the surface
  - Conceptual framework of integration and evaluation has potential
    - also for other depth information
  - We can target generalisation operators to maintain morphology
  - Especially effective on large scales

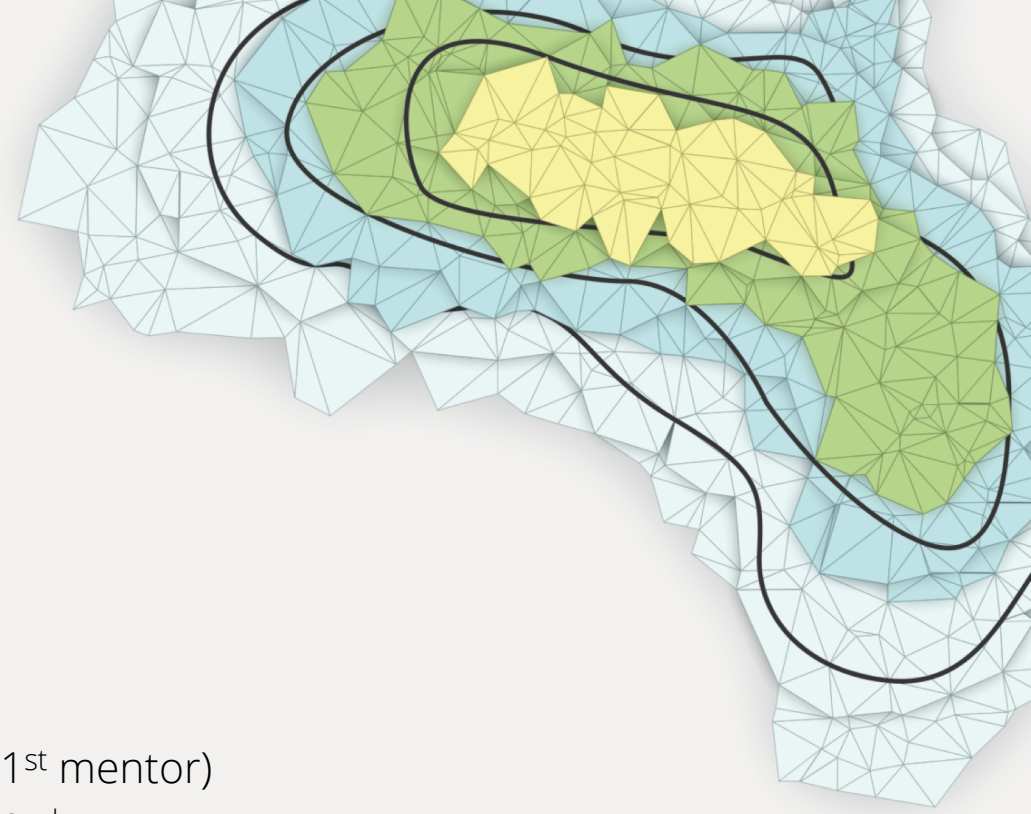
  - We cannot yet generalise beyond *smooth*
  - Benefit from the development of more complex metrics & operators

# Limitations and future work

- Additional operators: beyond smoothness
- Survey attributes: link is there, now the usage

- Feature classification: allow more complex metrics?
- Boundary problems and breaklines
- Integrate all IHO depth information
- Simplify isobaths, vertices

- Other evaluation models: human interaction, pursue morph. …
- Computational efficiency …
- Gridded bathymetry …
- …



# Thank you!

**Willem van Opstal**
Martijn Meijers (1st mentor)
Ravi Peters (2nd mentor)

July 9th 2020

TU Delft