UNIVERSITETET I OSLO

Multi-Criteria Decision Analysis

GEO(3|4)460 – spring 2025 – Luc Girod

(Based on a presentation by Désirée Treichler)

Overview

- Multi-Criteria vs. Multi-Objective
- Process:
  1. Define problem
  2. Find criteria
  3. Reclassify: criteria operationalisation
  4. Data integration
  5. Spatial aggregation
     - Boolean overlay
     - Weighted overlay -> How to find the weights?
     - Fuzzy sets
  6. Robustness analysis, verification
  7. Recommendation: suitability maps
- Examples

Goals

Combination/comparison of various criteria in order to find optimal solution or potential risks:

- Suitability analysis
- Decision support

>> *"80 percent of decisions have spatial context"* <<

Result: ***Suitability*** or ***susceptibility map***

Question: What is the difference?

MCA – Multi-Criteria Analysis
MCE – Multi-Criteria Evaluation

"MCA problems involve a set of **alternatives** that are **evaluated** on the basis of **conflicting** and incommensurate **criteria**"

"**Process** of **finding** appropriate **criteria**, **combining** and/or recalculating them in a way to **respond to a given problem**"

- Where is the most suitable/risky area?

Examples from your own life?

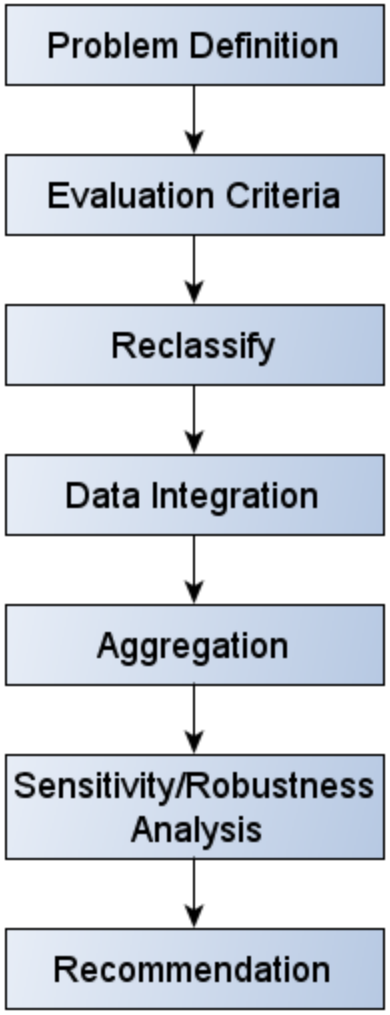
Multi-Objective Evaluation

MOE problems involve a set of (conflicting) **objectives** for the same area

- usually conflicting land use
- which objectives can be realised **where**?

Recommended online learning tool for MOE: http://www.gitta.info/Suitabilityi/en/html/unit_MOAnalysis.html

MCE – Workflow overview



Examples:

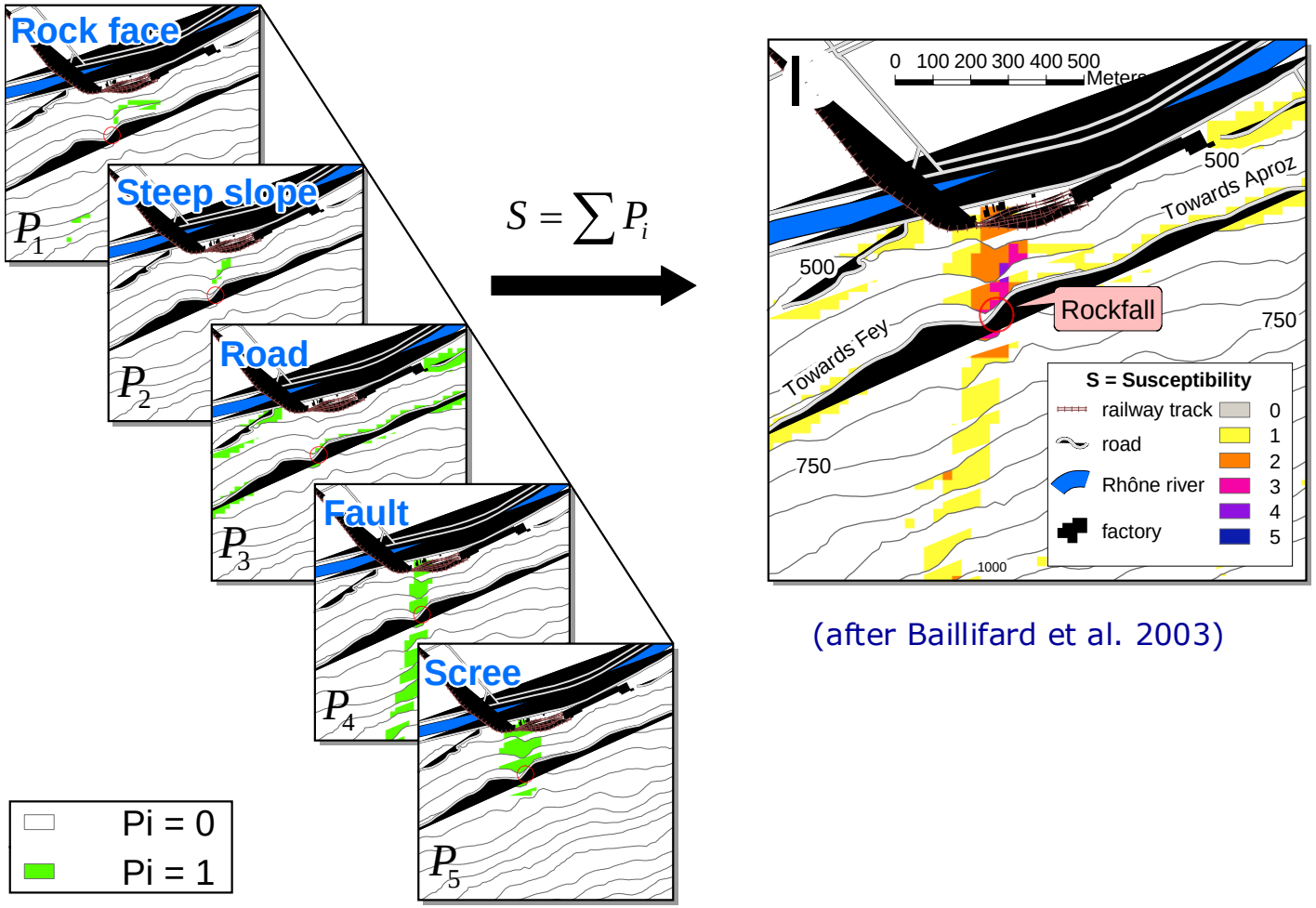
- Rock fall hazard reduction
- Location for new EV charging station
- Where to live in Oslo
- … and your own project!

Recommended online learning resource:

http://www.gitta.info/Suitability/en/html/index.html

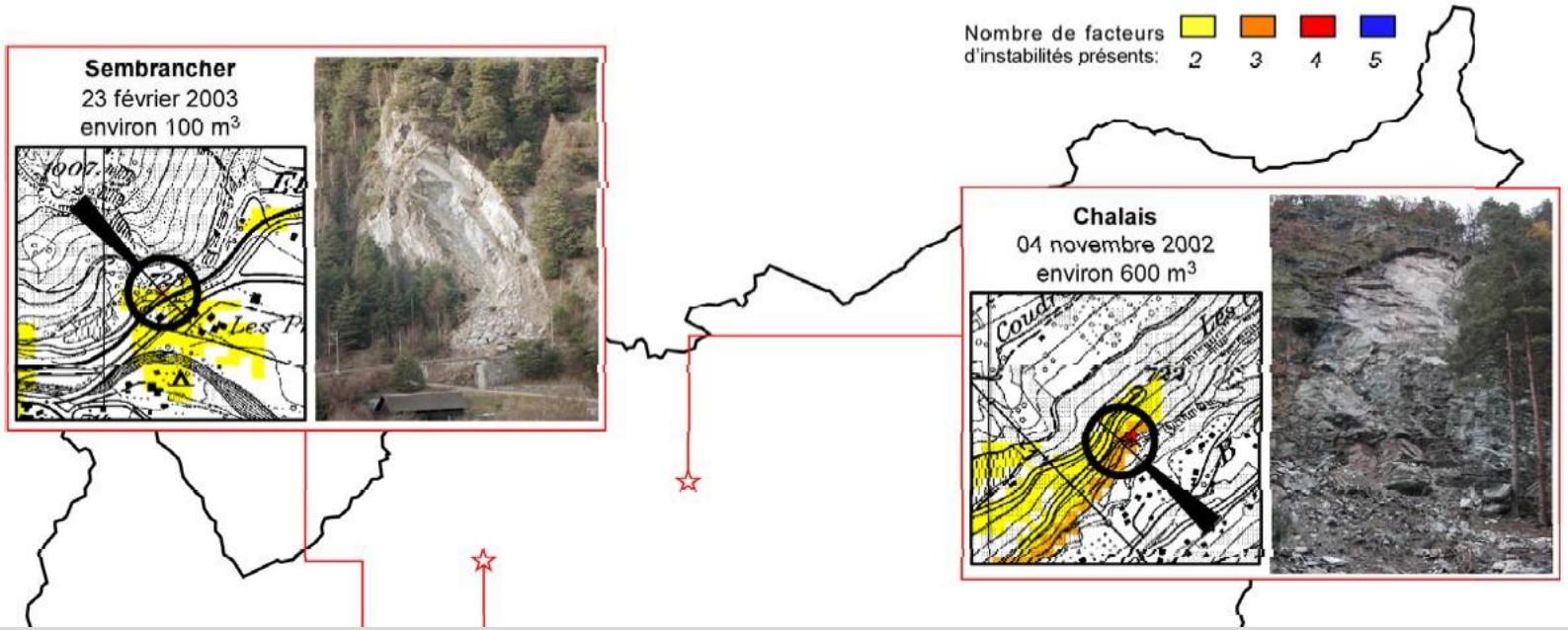
Rock instabilities detection along the roads in the Swiss Alps

Input data: nat. topo. and geol. maps + DEM (25 m cell grid)
Method: sum of 5 predisposition factors (present/absent)



(after Baillifard et al. 2003)

Rock instabilities detection along the roads in the Swiss Alps



A very simple method:

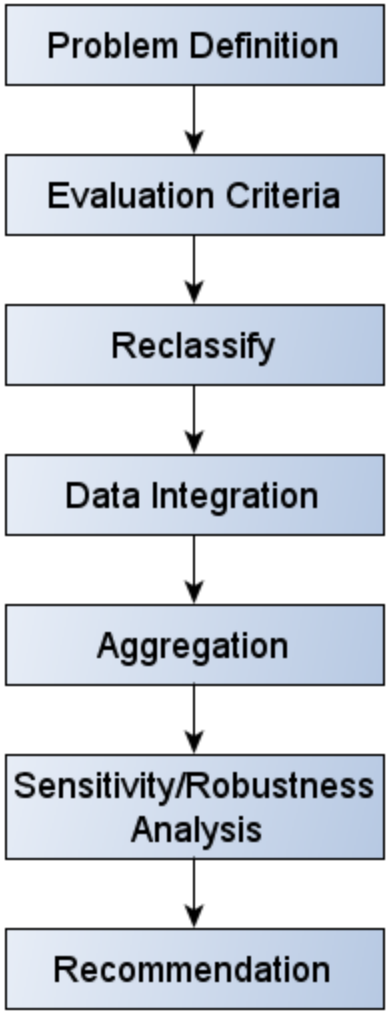
- one single phenomena, on a grid of 25 m cells

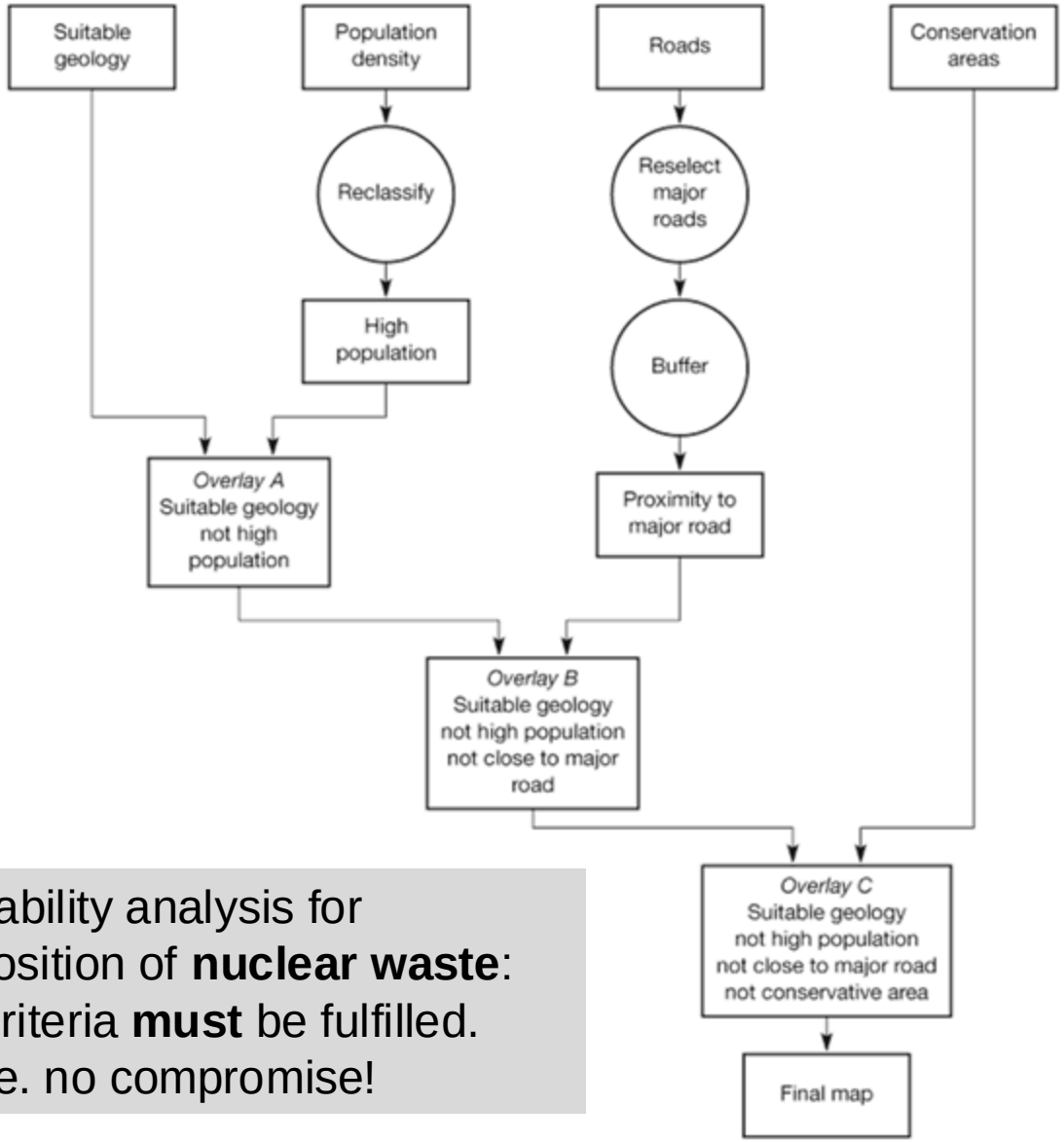
- it requires few input data (and only data which were already available)

- extremely easy to implement in a GIS

NGU

Workflow overview





Suitability analysis for deposition of **nuclear waste**:
All criteria **must** be fulfilled.
-> i.e. no compromise!

Heywood et al., An Introduction to Geographical Information Systems, 2/e

Workflow overview

UiO : University of Oslo

Input dataset

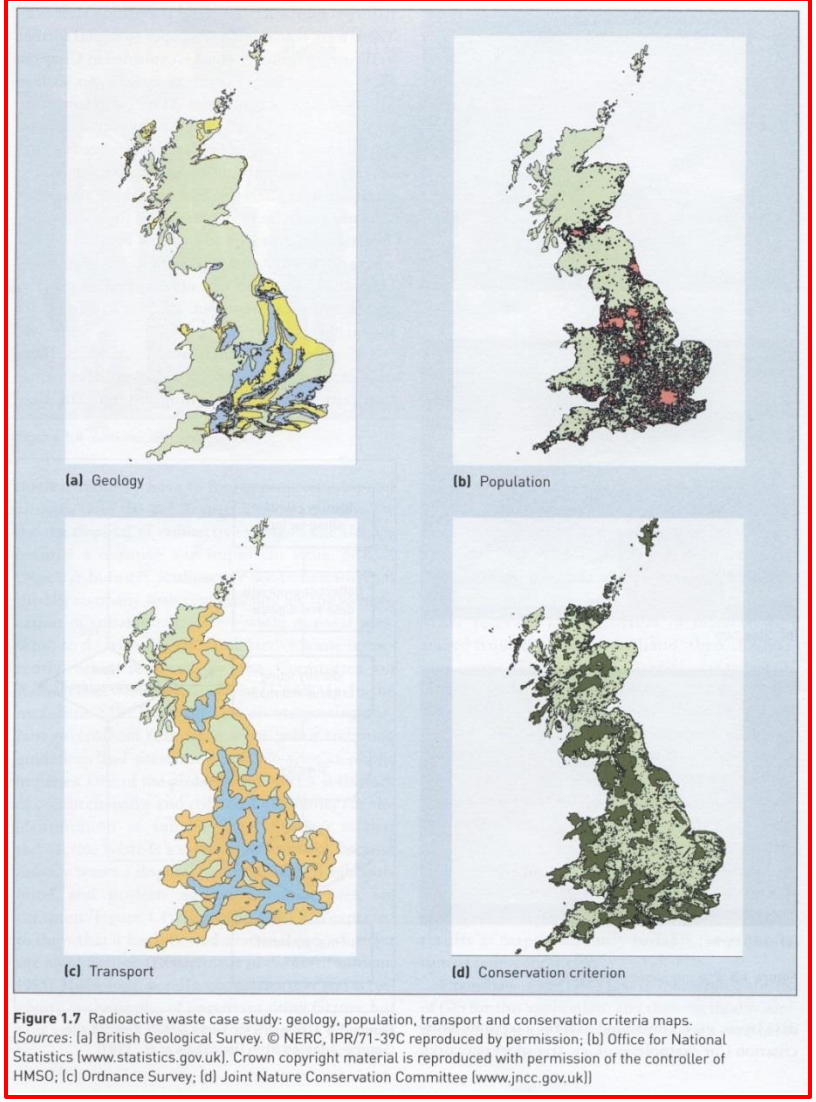
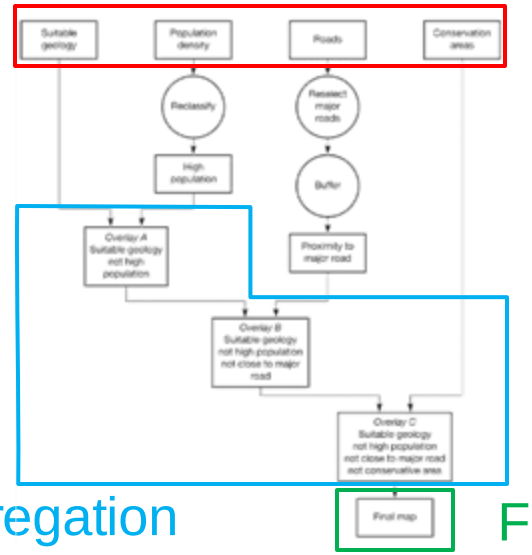


Figure 1.7 Radioactive waste case study: geology, population, transport and conservation criteria maps. (*Sources*: (a) British Geological Survey. © NERC, IPR/71-39C reproduced by permission; (b) Office for National Statistics (www.statistics.gov.uk). Crown copyright material is reproduced with permission of the controller of HMSO; (c) Ordnance Survey; (d) Joint Nature Conservation Committee (www.jncc.gov.uk))

Model

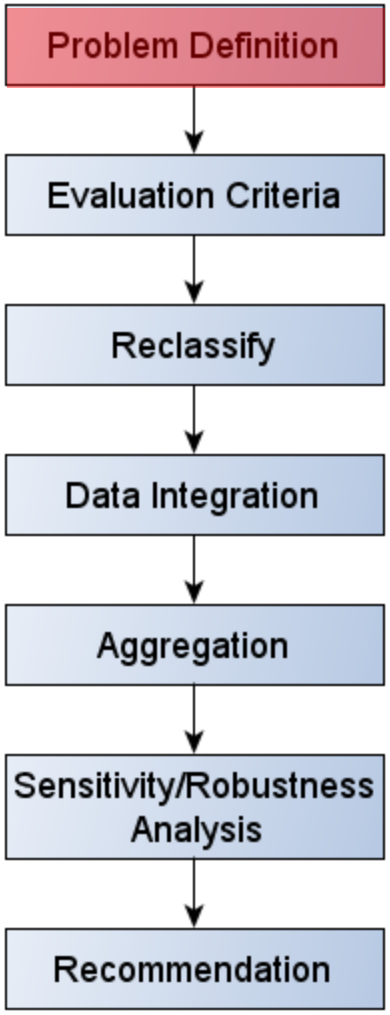


Aggregation

Final maps

Figure 1.8 Radioactive waste case study (a and b) results from different siting scenarios

Problem Definition

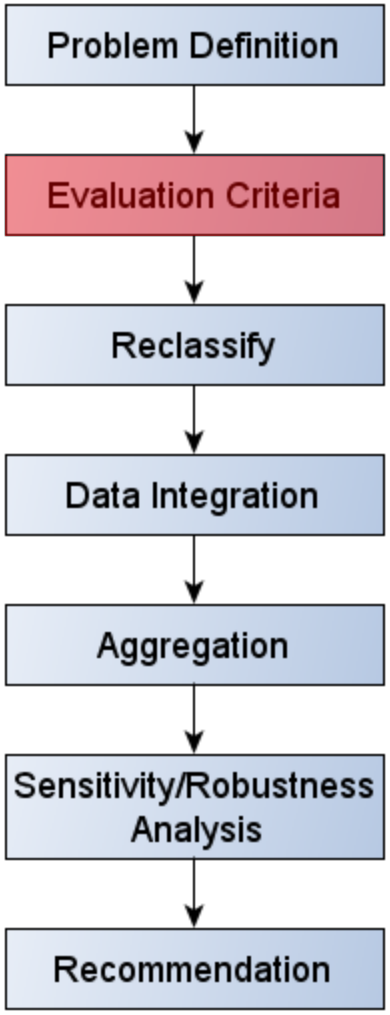


- Project goal?
- Related questions?

E.g.:

- Rockfall hazard map: Where in Jotunheimen could hikers be hit?
- Location for new EV charging station: Where is it needed? Where would it be profitable?
- Where in Oslo lies the ideal student flat?

Evaluation Criteria



- What is related to my project goal?
- What are possible criteria?
- Which criteria have the highest impact on the process?

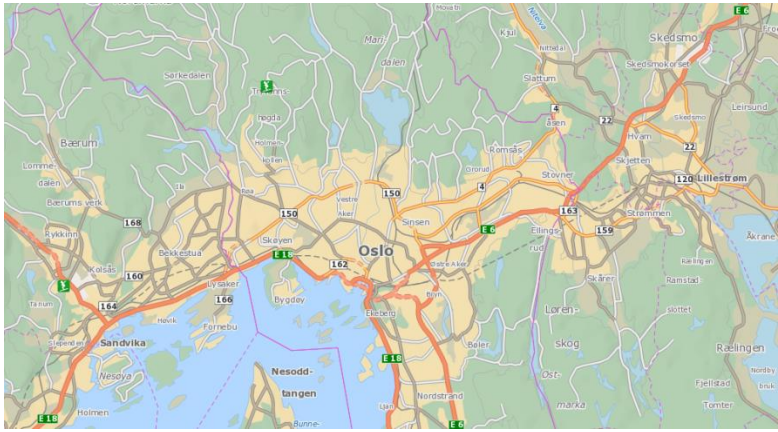
-> Which data represent the chosen criteria?

Chosen criteria…

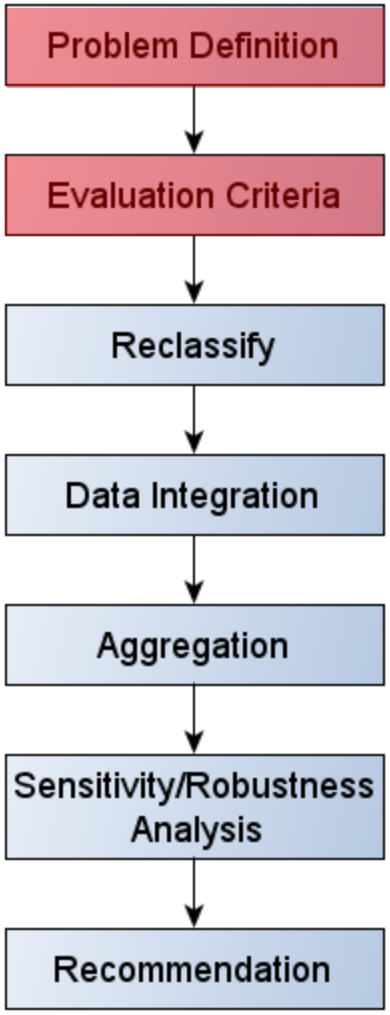
- represent characteristics of project goal
- can be ***spatial*** (geometry, topology) or ***factual*** (attributes), and
- ***hard*** (must-have) or ***weak*** (nice-to-have)

Example: Oslo

Where is the best place to live in Oslo?



finn.no

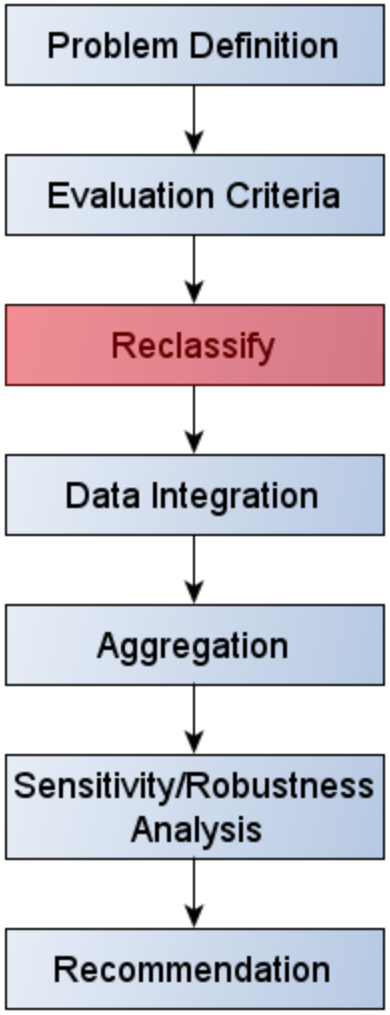


Task: Define problem and criteria!

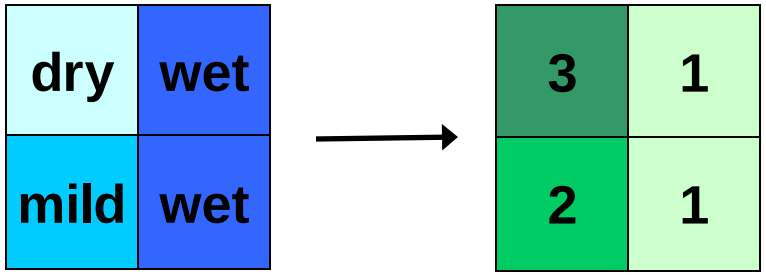
- What is related to my project goal?
- What are possible criteria?
  - spatial / factual
  - hard / weak
- Importance of criteria: what is their impact?
- Which data represent the chosen criteria?

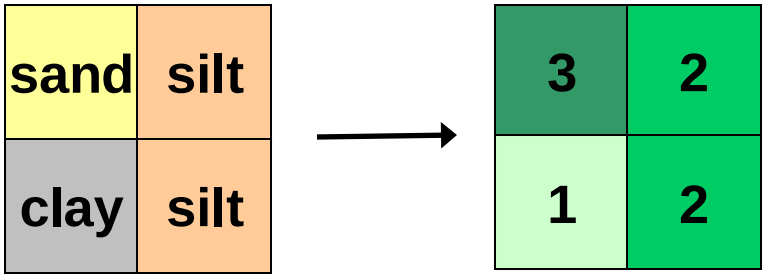
Try to find 3-5 criteria of different types!

Reclassify / operationalisation



How to get from abstract criteria/spatial data to **numeric** model input – for arithmetic operations

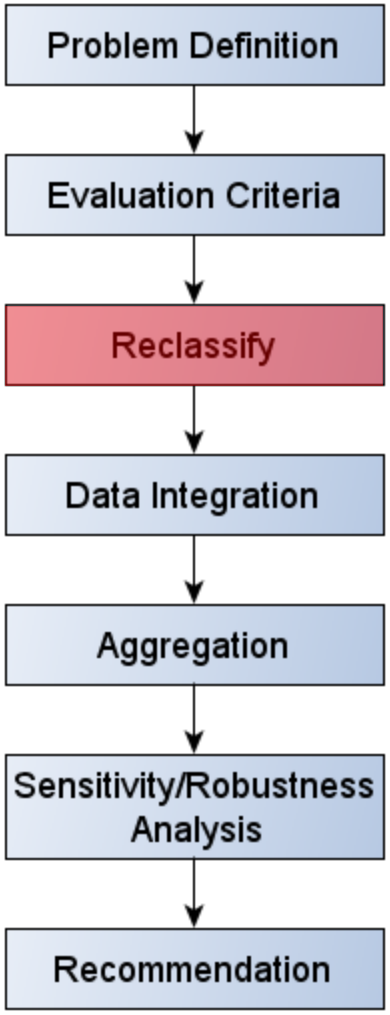


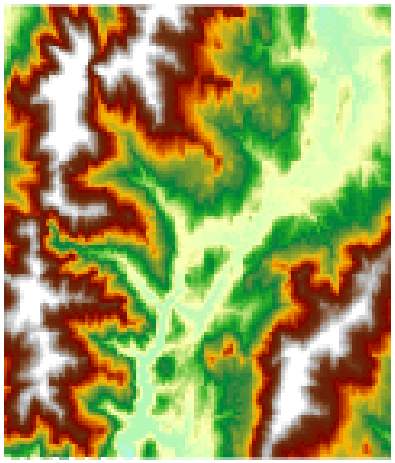


nominal (text) → interval (numbers)

Input values → Scaled values

Reclassify / operationalisation





Why classes?

Before: **criterion steep terrain** – represented by continuous slope in º

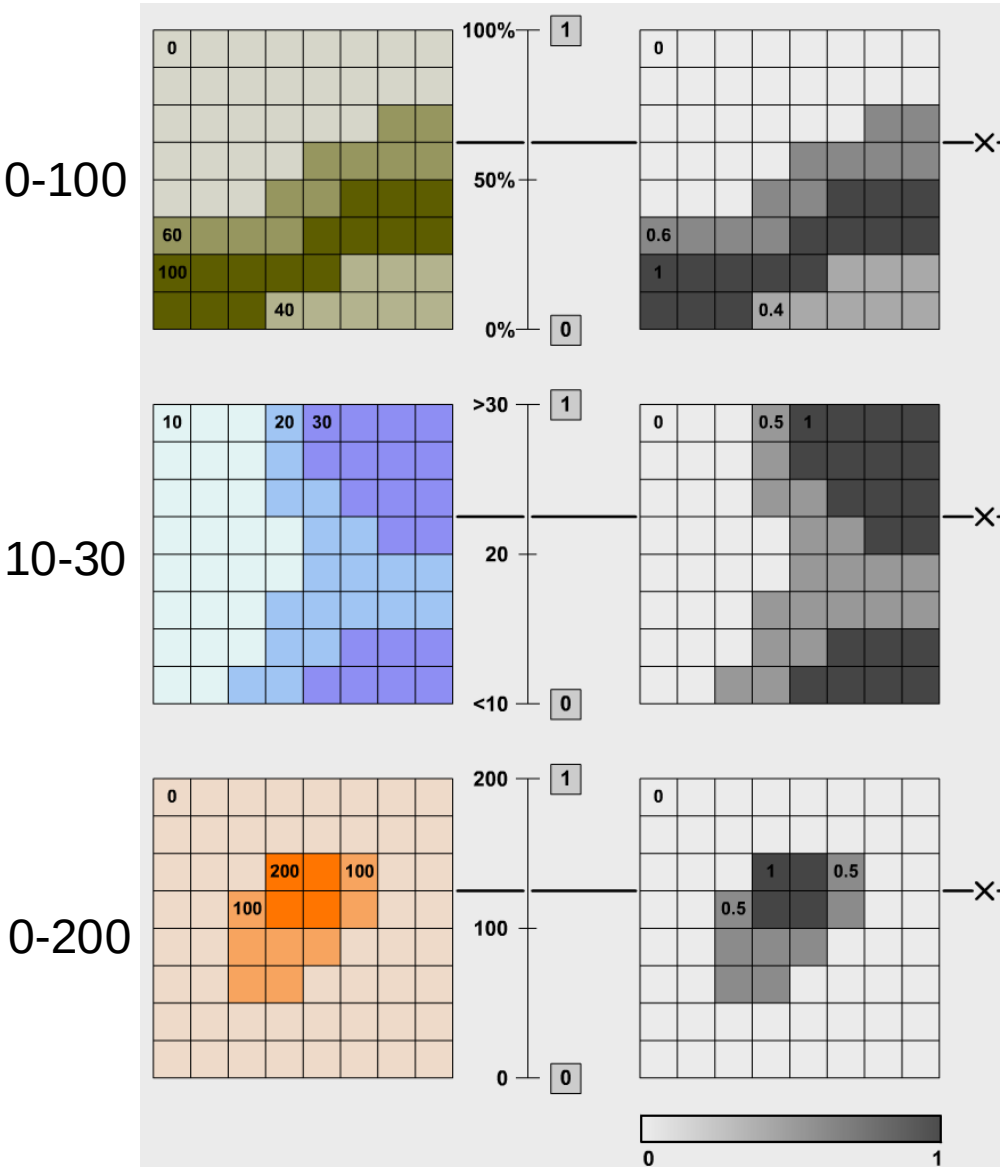
0 - 7	0
7 - 15	1
15 - 23	2
23 - 31	3
31 - 39	4
39 - 47	5
47 - 55	6
55 - 63	7
63 - 70	8
70 - 78	9

After: discrete grid with **classes 0-9**

1
1
3
5
10
10
5
3
1
1

Data Integration

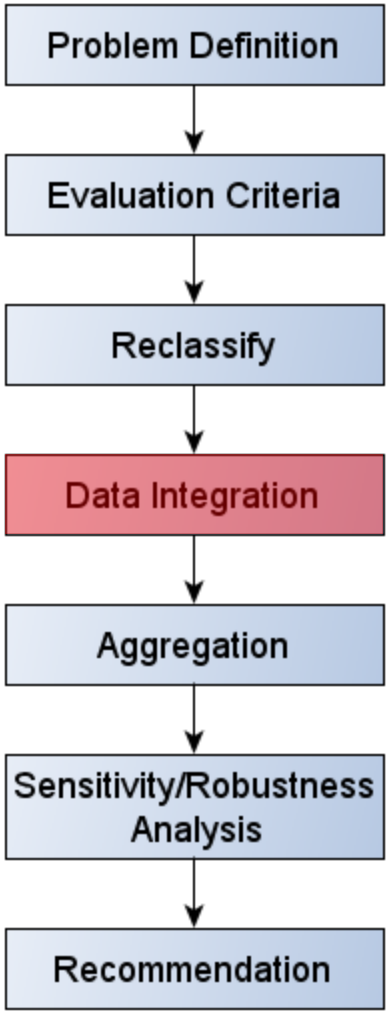
- Problem Definition
- Evaluation Criteria
- Reclassify
- Data Integration
- Aggregation
- Sensitivity/Robustness Analysis
- Recommendation



gisbsc.gis-ma.org/GISBScL7/de/html/VL7a_V_lo10.html

Data Integration

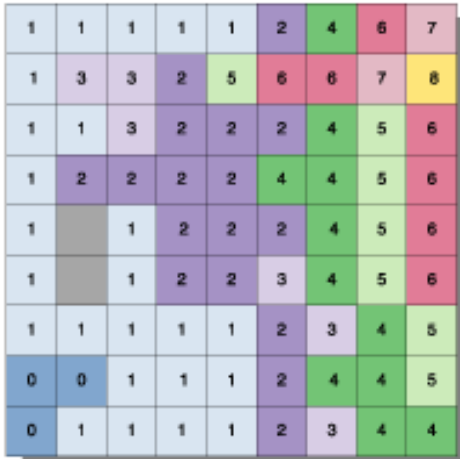
What happens if these don't agree?

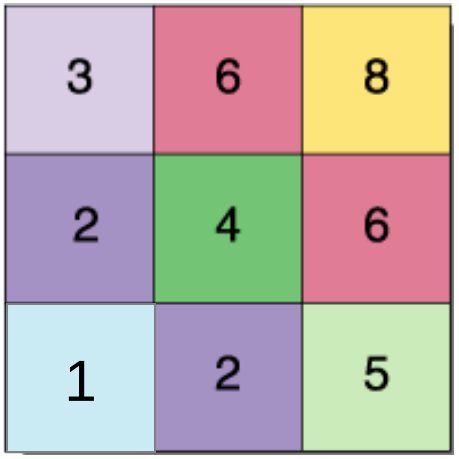


- Data type (raster or vector)
- Scale
- Spatial resolution
- Spatial reference system

} Must agree!

OutGRID = AGGREGATE(InGRID, 3, MAX)

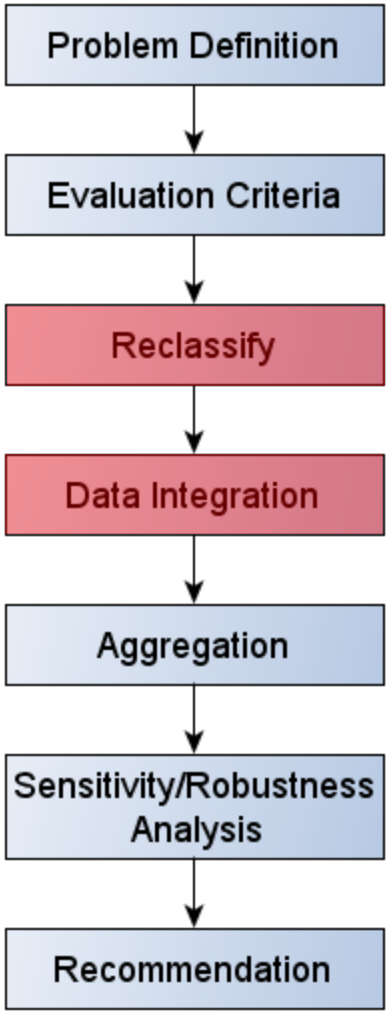


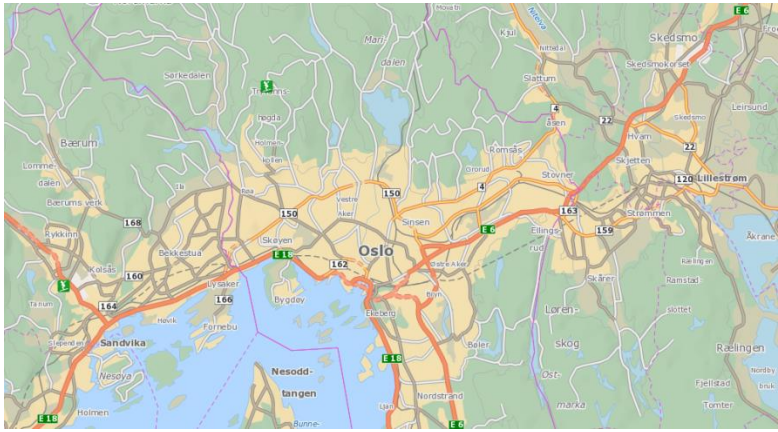


No data

Example: Oslo

Where is the best place to live in Oslo?



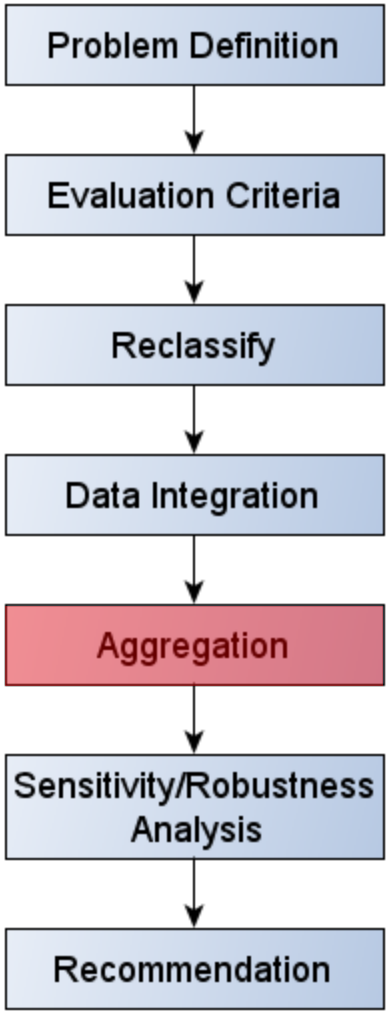


Source: finn.no

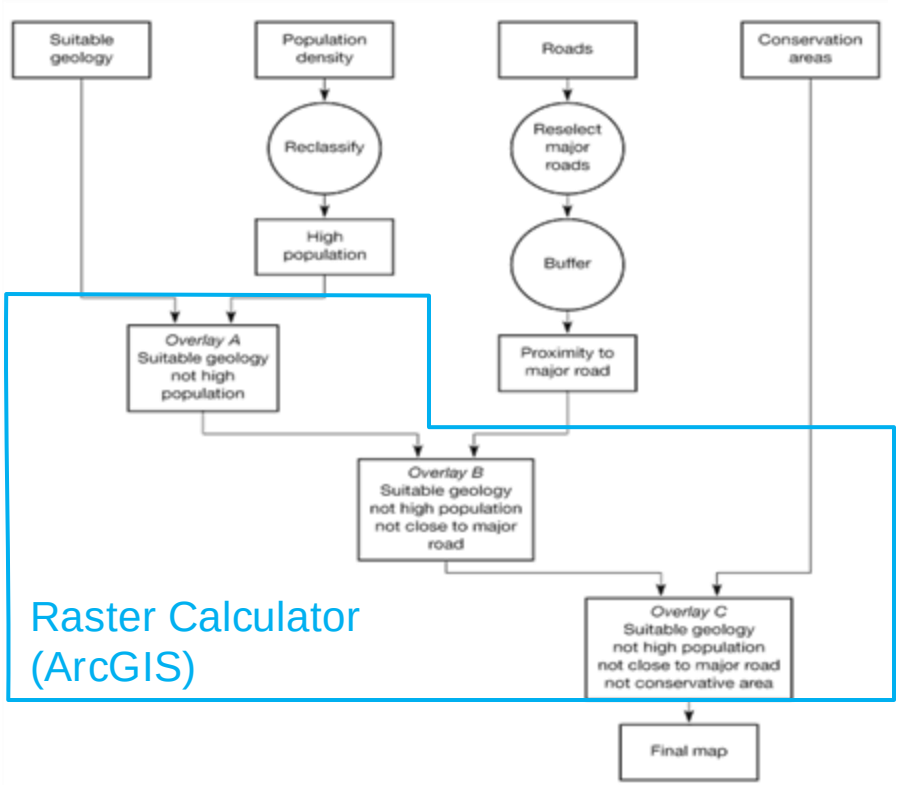
Task : Reclassify and re-scale your criteria!

- (If you haven't done that yet: find datasets that represent your criteria)
- Classify continuous data into discrete classes
- Rank text attributes (according to their suitability) using numeric values
- Scale all criteria to the same range – e.g. 0-1, or 0-100%

Aggregation / Overlay

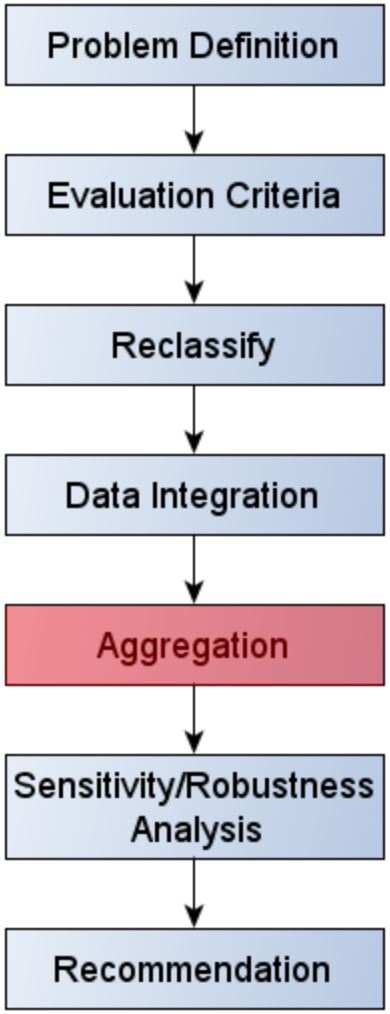


- Boolean Aggregation
- Weighted Aggregation
- Fuzzy Overlay



Aggregation - Boolean

Venn diagram

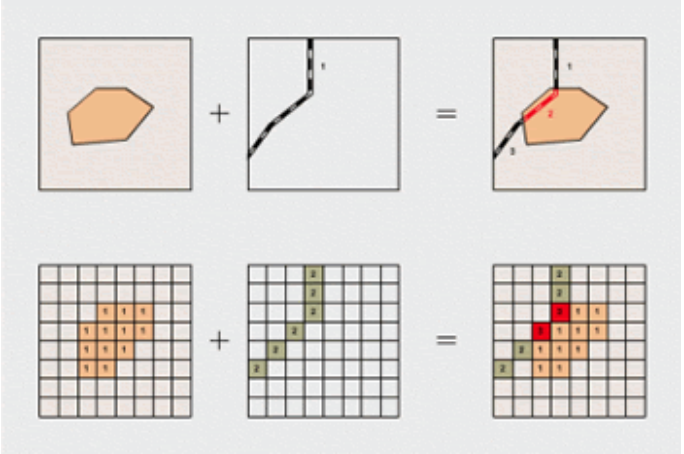


- Binary (true/false)
- AND, OR, XOR, NOT
- hard criteria
- all criteria have the same importance (?)

Example: Line-in-Polygon (AND)

- Vector

- Raster

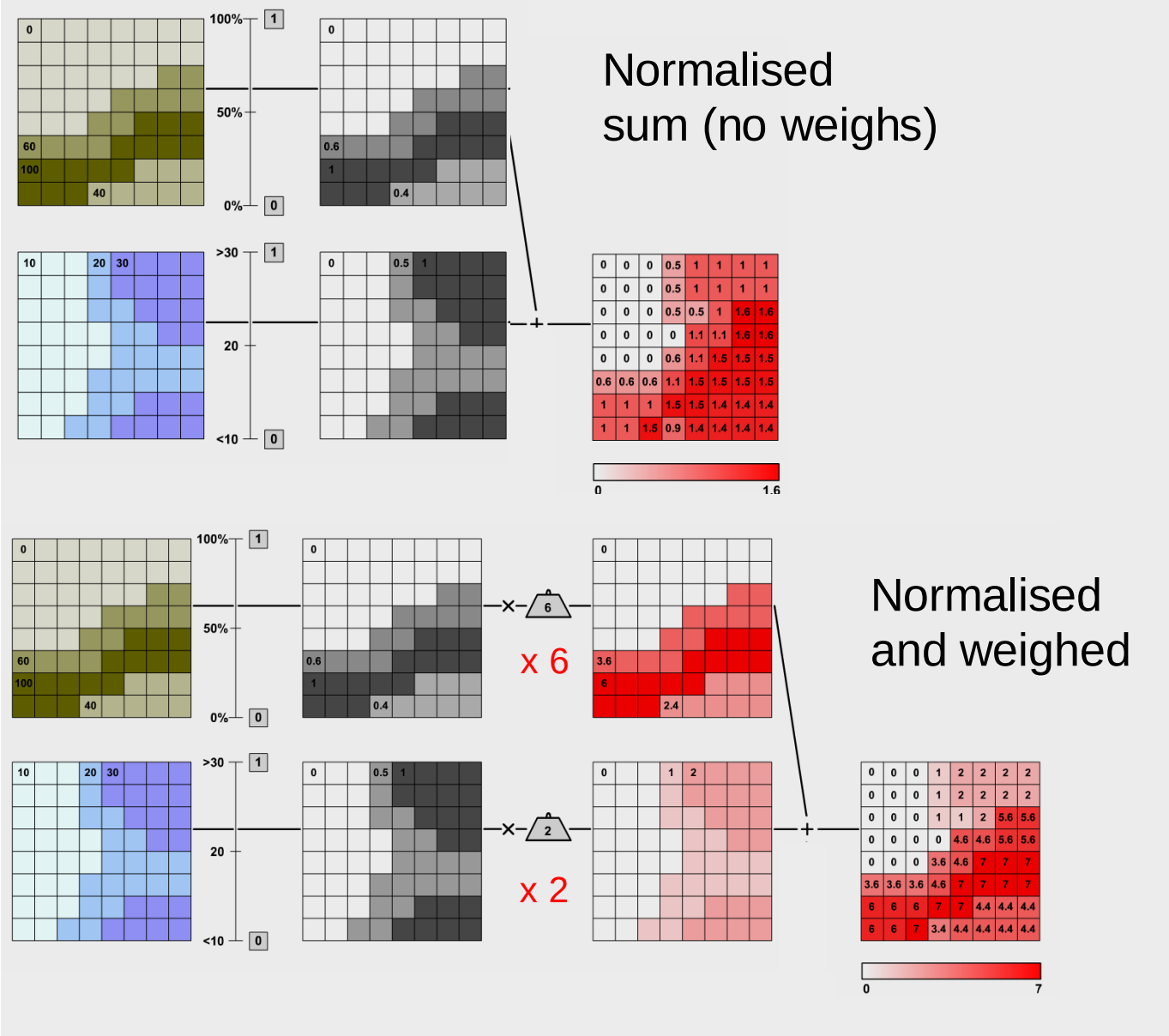


-> conservative: few suitable areas

http://www.gitta.info/Suitability/

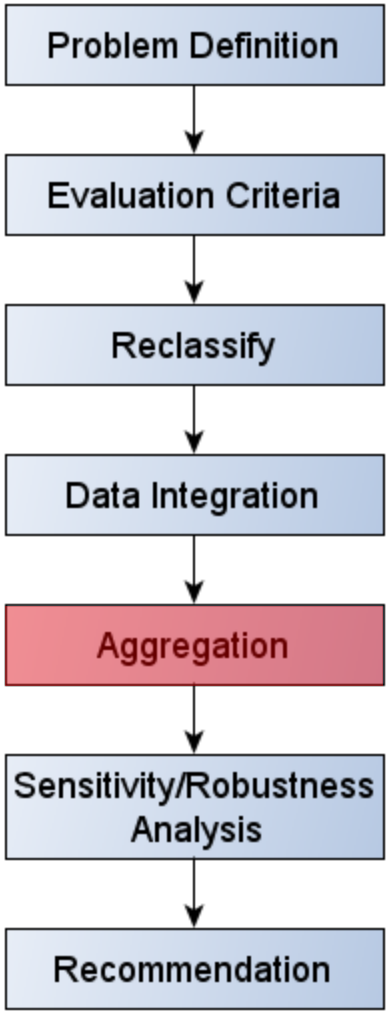
Aggregation - weighted

- Problem Definition
- Evaluation Criteria
- Reclassify
- Data Integration
- **Aggregation**
- Sensitivity/Robustness Analysis
- Recommendation



http://www.gitta.info/Suitability/

Aggregation - weighted



(0.75 × GRID1) + (0.25 × GRID2) = OutGRID

(2 × 0.75) + (3 × 0.25) = 2.25 → 2

2	2	3
2	1	1
1	2	2

+

3	3	2
1	3	1
2	3	1

=

2	2	3
2	2	1
1	2	2

Influence 75 %

Influence 25 %

How to assign weights?

- Relative importance of criteria
- May have soft AND hard criteria/classes
- Trick: use NaN for hard boolean exclusion

How to assign weights (1)

Determine relative importance

- **Ranking**: rank divided by sum of ranks. E.g. rank 4 criteria, 4=first, 1=last -> 4+3+2+1=10 weights -> most (4/10) to least (1/10) important
- **Rating – point allocation**: allocated points have to sum up to a given total (e.g. 100 -> 50+20+20+10=100)
- **Rating – ratio estimation**: relative importance within given value range (e.g. 0-100 points -> 100, 50, 45, 20)

Example: Oslo – Task: determine the weights of 3 criteria by different methods. Normalise the weights between 0 and 1. Do the methods produce the same result?

Criteria	***Rank***	***normalised weight***	***Point allocation***	***norm.***	***Ratio estimation***	***norm.***
Sum of weights	*6*	*1*	*100*	*1*	*230*	*1*

How to assign weights (2)

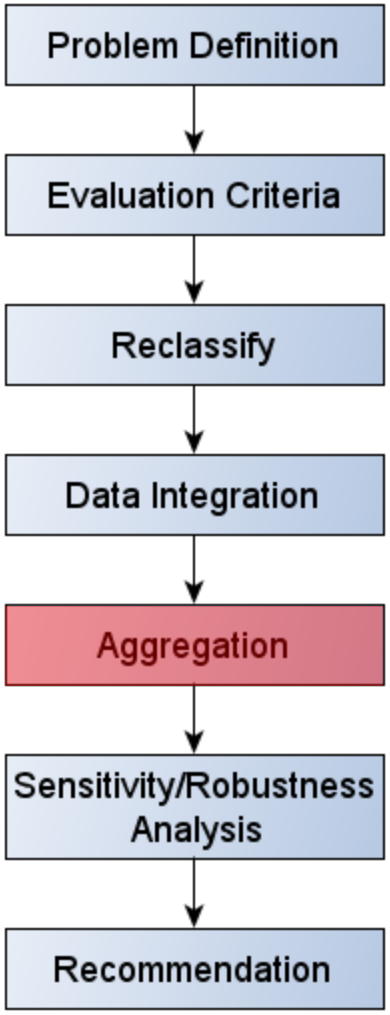
Pairwise comparison of criteria: statistically sound

- **Analytic Hierarchy process AHP** (Saaty, 1980)
- Rating: x to y / y to x
  - (1) Equally important — (1/1) equally important
  - (3) Moderately more important — (1/3) moderately less important
  - (5) Strongly more important — (1/5) strongly less important
  - (7) Very strongly more important — (1/7) very strongly less important
  - (9) Overwhelmingly more important — (1/9) overwhelmingly less important

Example: Oslo
Task: determine the weights of 3 criteria by pairwise comparison after Saaty's AHP

Crit. x \ Crit. y	A	B	C	sum	norm.
A	1				
B		1			
C			1		
Sum					1

How to assign weights (3)



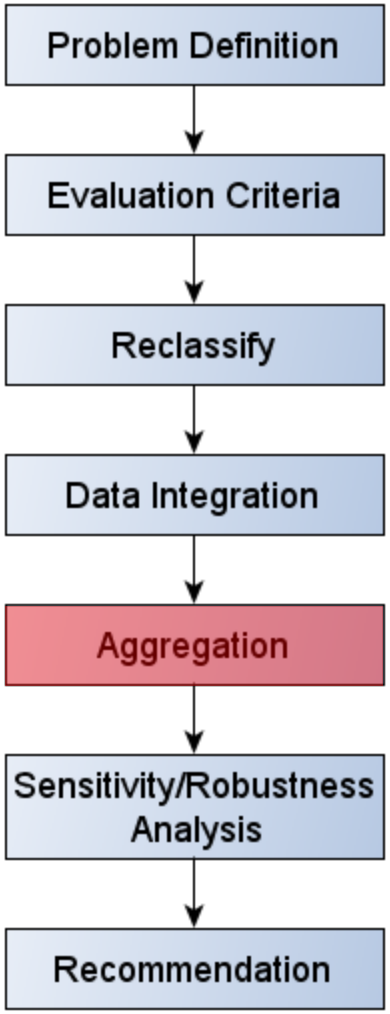
Which method to choose?

- Ordinal (ranking: simple) – interval (rating) – ratio scale (AHP: most complex)
- How **accurate** should the analysis be?
- How **competent** is the analyst?

-> always document how weights were determined!

Which weighing method?
- *Rock fall hazard*
- *Nuclear waste*
- *Where to live in Oslo*

Aggregation – fuzzy



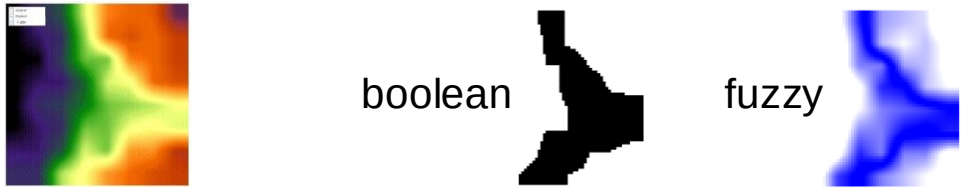
Based on **Fuzzy Set Theory**

Inaccuracies in Input -> wrong output

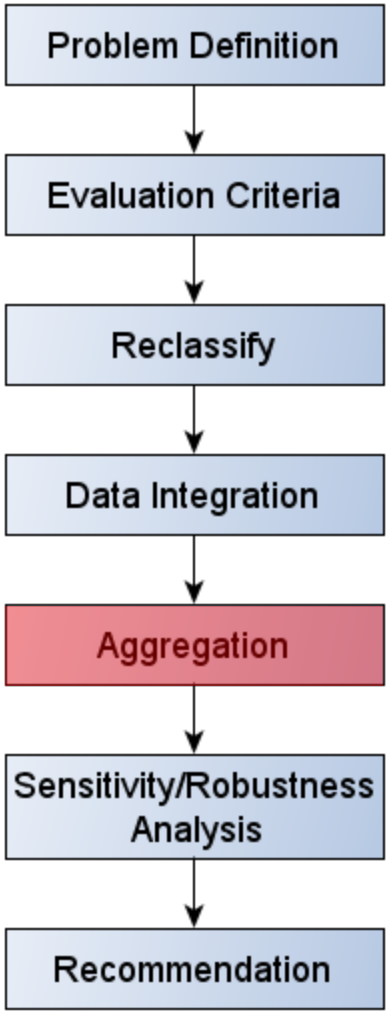
- Dissolution of sharp borders
- Transition zones
- Continuous data, small scale variation
- «degree of membership»

Examples:

- patchy vegetation: how to classify?
- Fuzzy/vague criteria: «medium slope»



Which aggregation method?



- Easy & quick vs. complicated & long
- Nature of criteria: categorical/continuous
- Importance of spatial variation
- Conservative vs. flexible approach

Largest uncertainties:

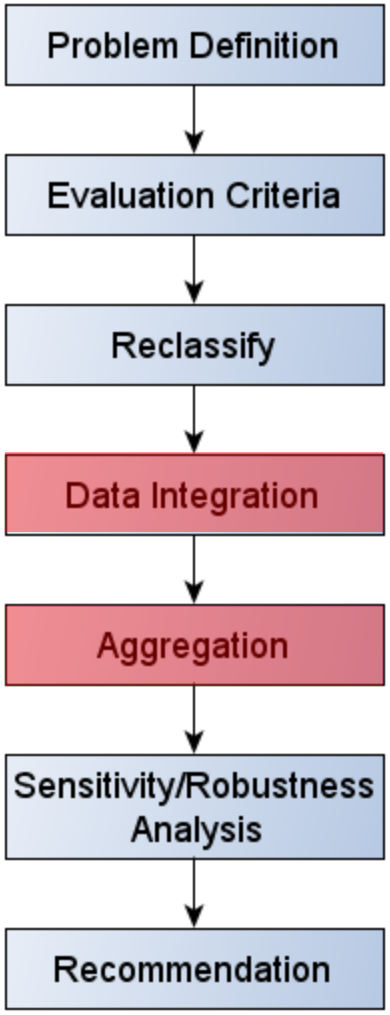
- Most criteria are fuzzy: **classification**
- How to assign **weights**?

} Sensitivity Analysis!

Which aggregation method: Boolean, weighed, fuzzy, combination?

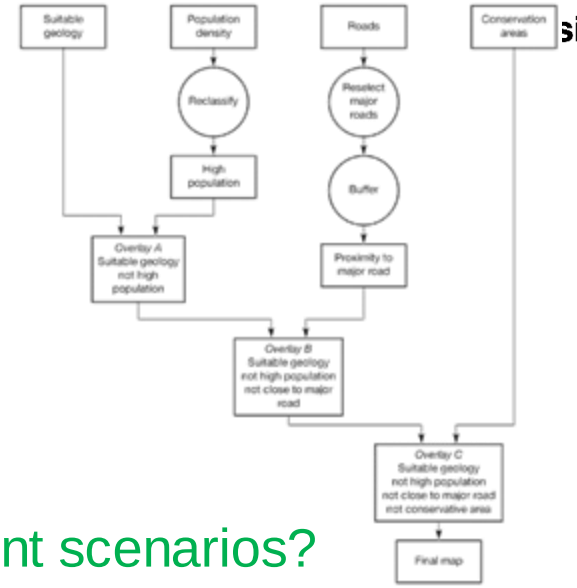
- *Rock fall hazard*
- *Nuclear waste*
- *Where to live in Oslo*

Raster or Vector?



- Raster: «quick and efficient»
  - easy matrix calculations (raster calculator)
  - can represent continuous / fuzzy data
  - no clear boundaries
  - requires data preparation (raster creation from vector)
- Vector: clear boundaries, more complex
  - complex spatial operations
  - spatially exact: clear borders, zones
  - accurate distance criteria
  - categoric data: most spatial planning data

Sensitivity Analysis



- Problem Definition
- Evaluation Criteria
- Reclassify
- Data Integration
- Aggregation
- Sensitivity/Robustness Analysis
- Recommendation

Final map – different scenarios?

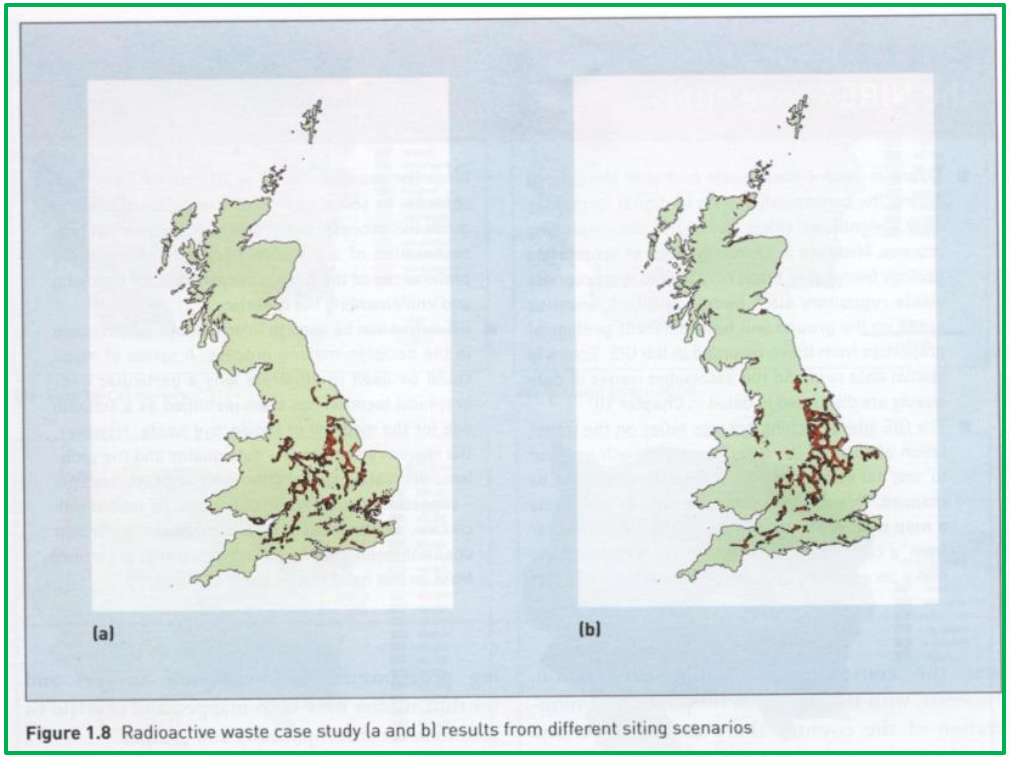
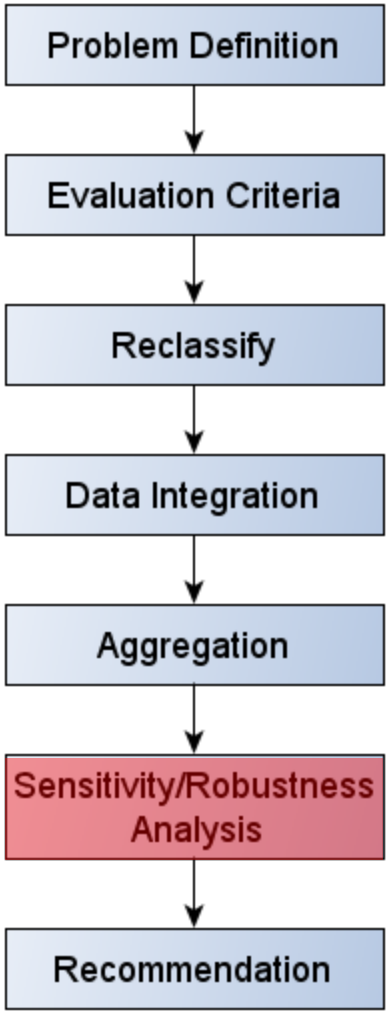
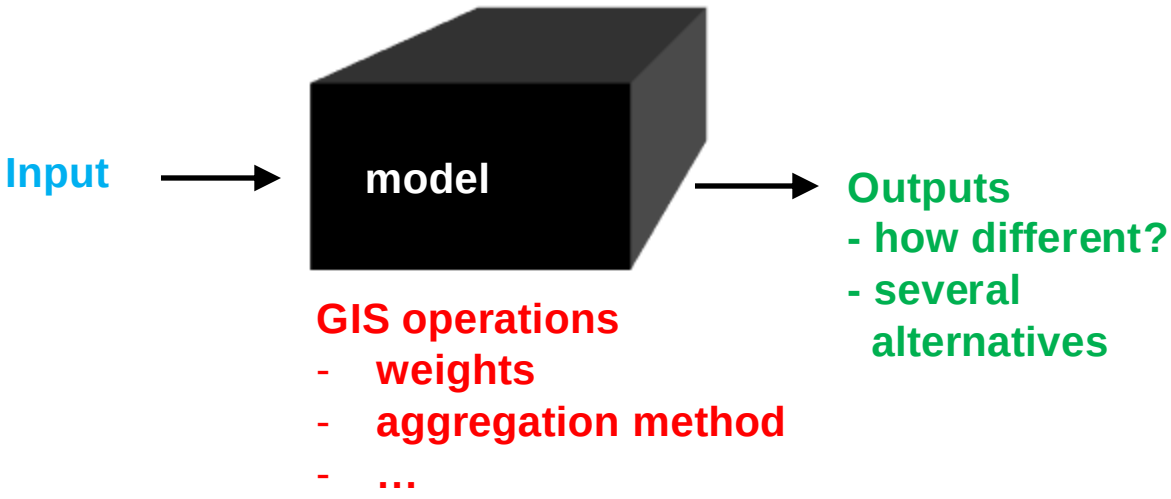


Figure 1.8 Radioactive waste case study (a and b) results from different siting scenarios

Sensitivity Analysis





How sensitive is the output to changes in the model?

-> Robustness of result

Sensitivity Analysis

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- Reclassify
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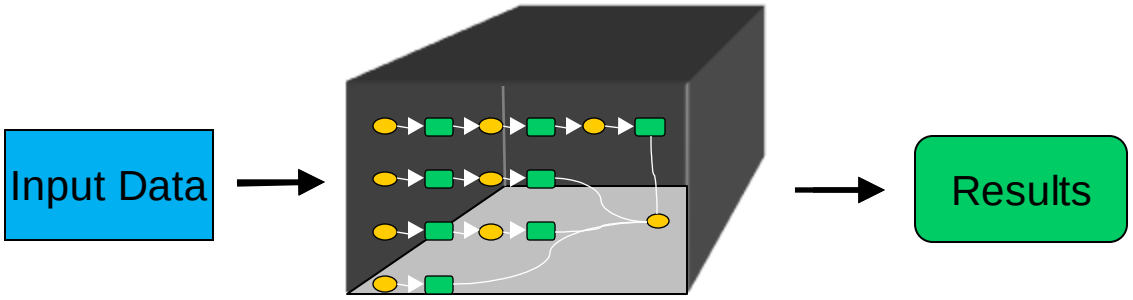
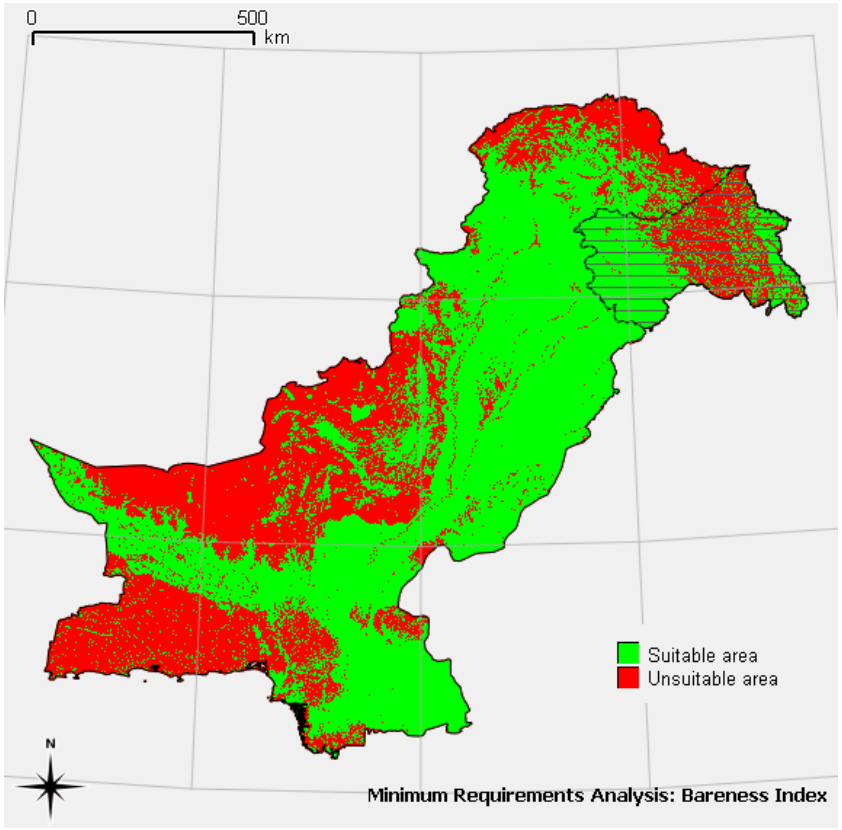
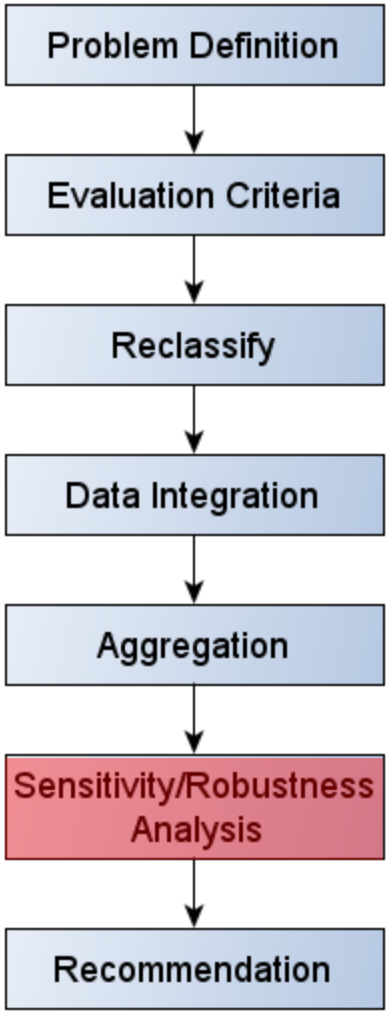


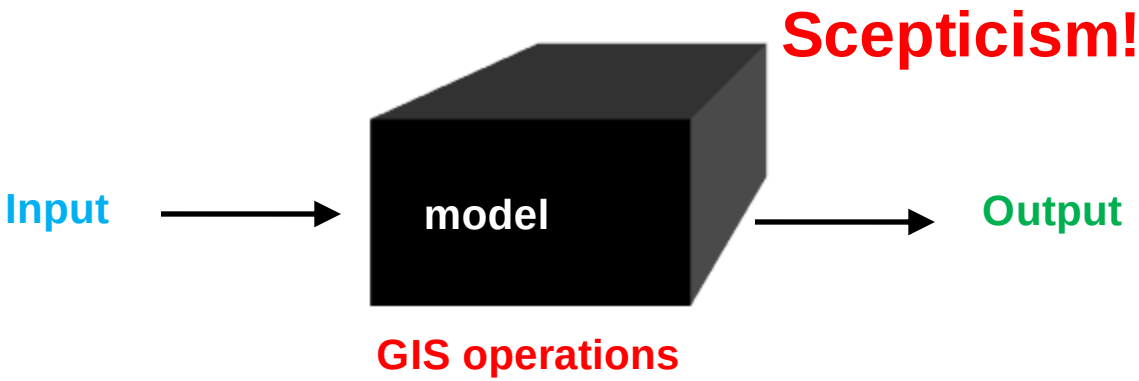
Transparency!



http://www.oliveoilpakistan.com/national_assessment.htm

Sensitivity Analysis



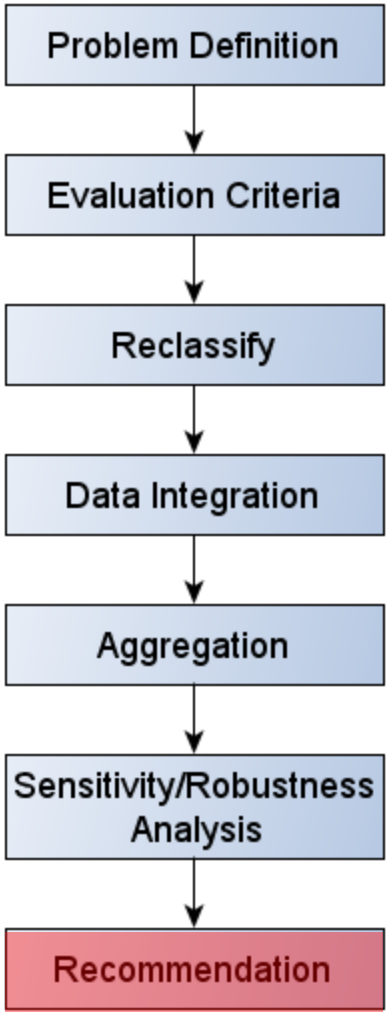


Quality Control:

- Demand for metadata
- Demand for transparency
- Demand for quality report

- Verification based on comparison with reference data (ground truth)

Recommendation

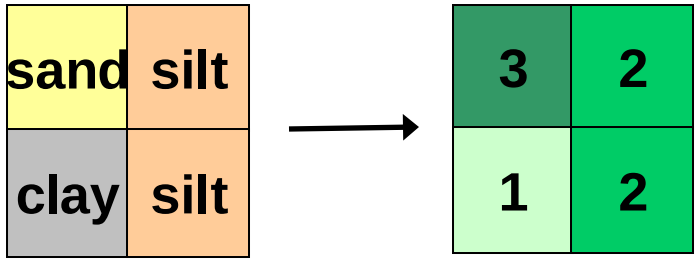


Result: proposed locations/areas

- Suitability/susceptibility map(s)
- Report:
  - recommendations,
  - evaluation of proposed locations/areas,
  - description of process,
  - sensitivity of result,
  - metadata
- Usually: several alternatives

Typical problem sources

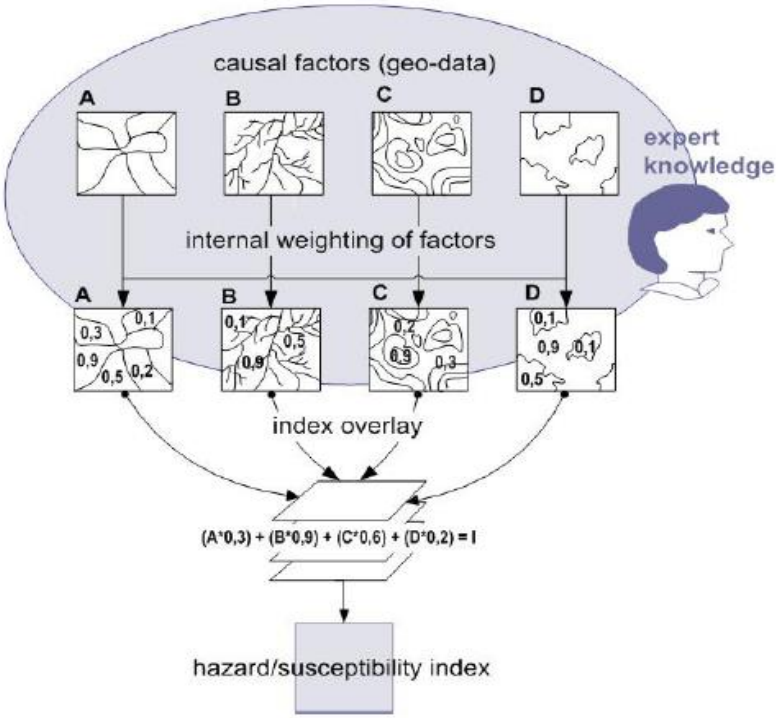
- Choice of criteria: subjective
  - Dependent on the person,
  - project goal (politics?),
  - available datasets
- Raster / Vector?
  - Reclassification
- Assigning weights
- Error Propagation
- Quality Control – how?

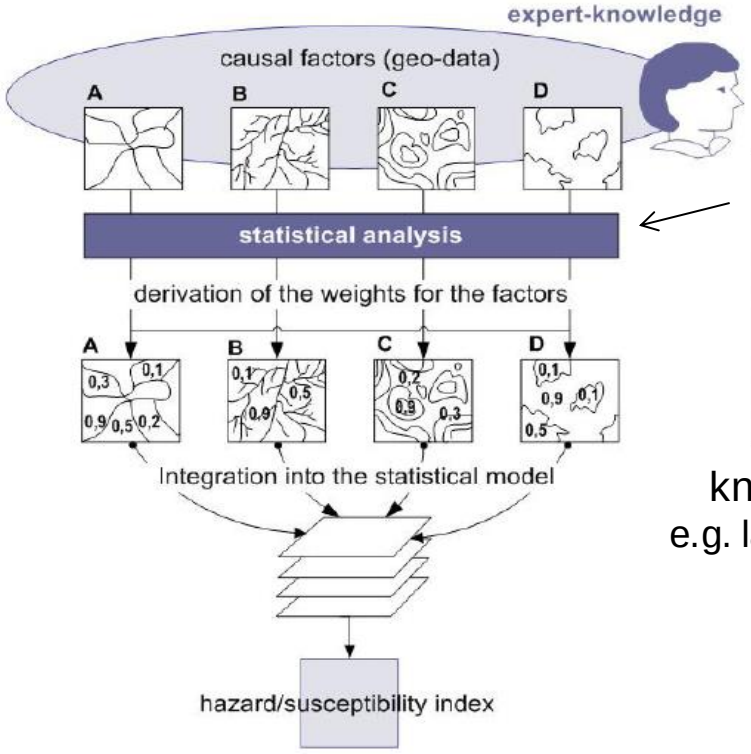


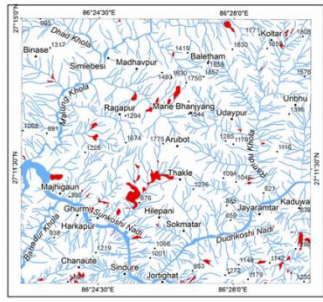
Quality control

- Manual inspection of results
  - By inspecting your recommendations, you might find some clearly bad advice, maybe from a factor that wasn't initially obvious and needs to be considered in the analysis
- Ground truthing
  - See if your process suggests existing entities (depending on your process, you might need to run your analysis a few times after removing a random entity).
- Sensitivity analysis (Is your process robust to small changes)?
  - Change weights (a bit) to see effect
  - Change sampling distance to see scale effects
  - Change source of data if several exist

Use of GIS for susceptibility mapping







known distribution
e.g. landslide inventory

Heuristic methods
(expert judgement)

-> this lecture

Statistical methods (expert judgement + statistical analyses)

-> requires ground truth in area
-> this determines weights

Sources: NGI; Bijoukchen et al (2012), Arab J Geosci

Checkpoint: MCA

You are able to…

1. explain what *suitability analysis, MCA, MOE, susceptibility mapping, and suitability maps* are.
2. describe typical situations – of different types – where a MCE is a useful decision making tool.
3. name and describe the steps of a MCA process.
4. for a given situation, define the problem, find criteria, and operationalise, reclassify and standardise them.
5. explain why data operationalisation and integration are needed, and how this is done.
6. name different aggregation methods, explain the advantages and disadvantages of each, and under what circumstances they are appropriate.
7. explain Boolean operations (using Venn diagrams), and describe the characteristics of a Boolean overlay.
8. describe and explain a weighted data aggregation process and its characteristics.
9. name and explain different methods to assign weights to criteria, and under what circumstances they are appropriate.
10. compute the weights for criteria of a given problem using different methods.
11. characterise the differences between raster and vector overlay, and give examples for each method.
12. explain what the term *sensitivity* means in a MCA process, and why this is important.
13. describe what a typical outcome of a MCE could be, and what it should include.
14. show typical error sources (problems) in a MCA process, and explain how these can be avoided.
15. explain the difference between heuristic and statistical methods for susceptibility mapping.

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MCA project

Goals:

- Learn how to take informed decisions (in a geo job)
- Use a wide range of GIS data and tools
- Present the project and write a report just as you would do as a GIS consultant

TUESDAY:

- Make groups:
  - BSc: (up to) 2 people
  - MSc: solo
- Find a project idea

→ Research question

- Find ca. 3 criteria
- Prepare 2-slide presentation for other groups

WEDNESDAY:

- Give presentations!
- 0.5-page project description: Group members, research question, criteria

→ Deadline Sunday (2025-03-16)

→ You'll get feedback

- Find data and start reclassifying and integrating

IF YOU'RE NOT PRESENT FOR THE LAB SESSIONS, BEEF UP YOUR PROJECT DESCRIPTION TO A FULL PAGE

Final output – 40% of course grade

1. A complete report → DEADLINE 2025-05-11
   - Introduction of the question that you are trying to answer
   - Description of your process for each step of the MCA
   - Concluding with your recommendations
2. An online ArcGIS Storymap
3. A poster to advertise your recommendation to the public that it would affect
4. [GEO4460 or voluntarily] 10min presentation targeted at the 'client' in your scenario, 5min Q&A (2025-05-(20|21|27|28))

Grading

The grade follows the *Grade = Ambition * Realization* concept, which encourages choosing a more complicated task.

Realization(GEO4460) =

0.6 * Report + 0.2 * Presentation + 0.1 * Poster + 0.1 * StoryMap

Realization(GEO3460) =

0.7 * Report + 0.15 * Poster + 0.15 * StoryMap

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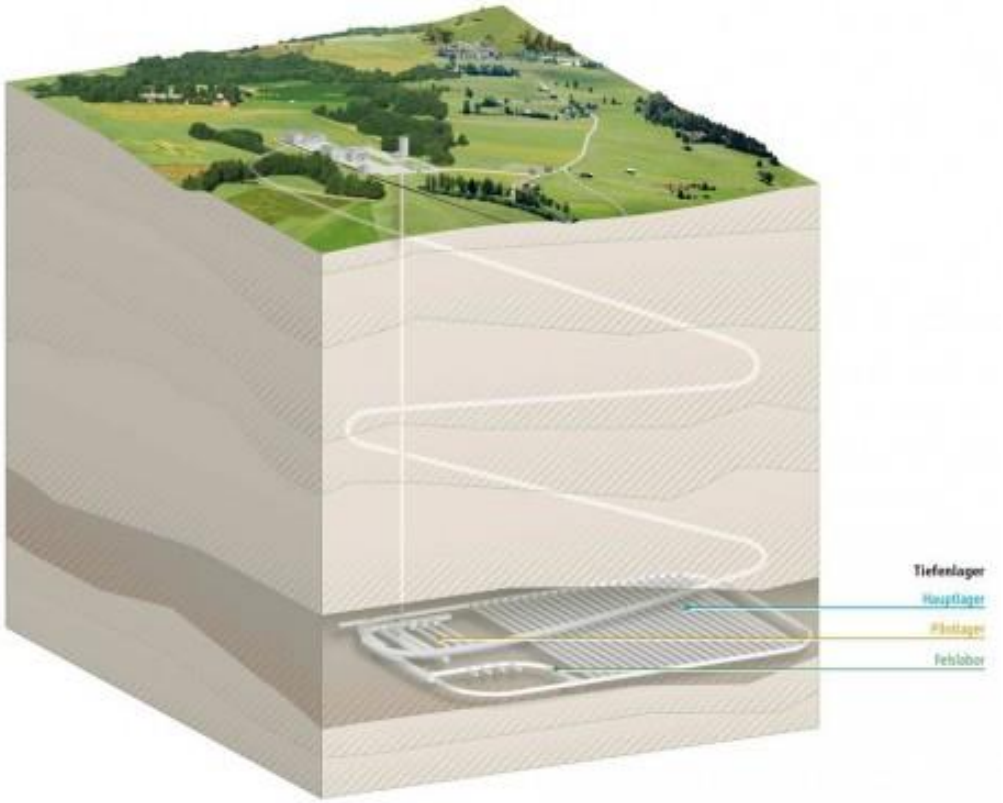
MCA examples

Nuclear Waste storage location – Real world project

Wind Farm suitable location – GEO4460 – 2024

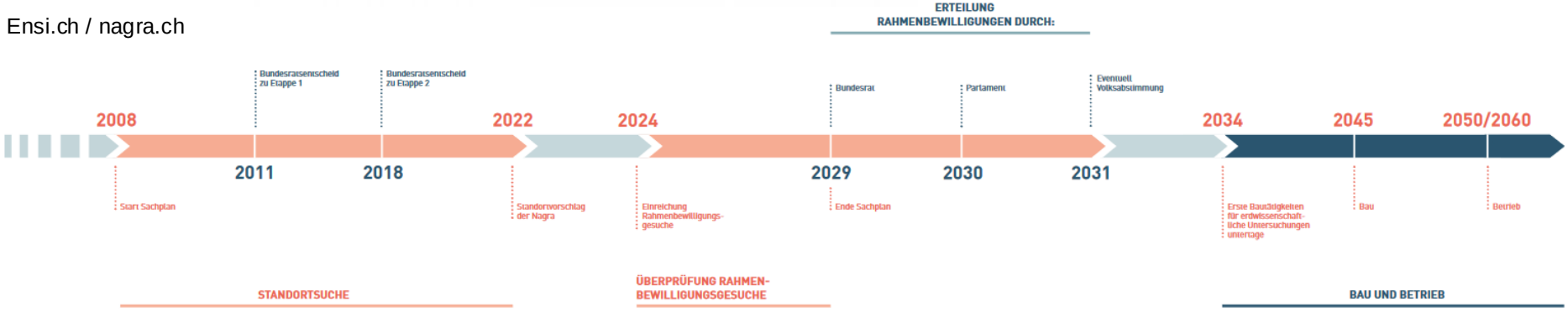
MCA Example: Nuclear waste



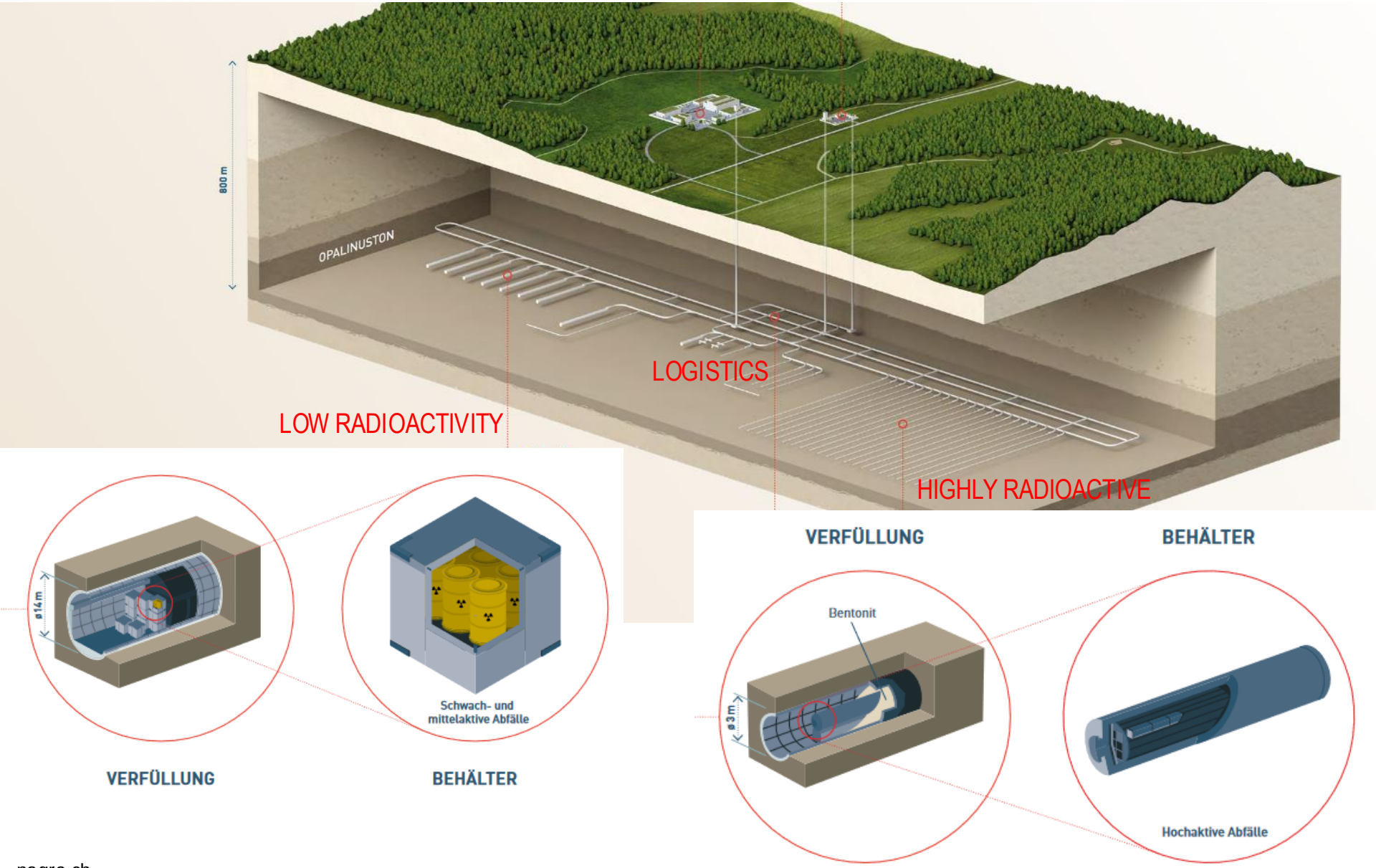
Goal: to find the best place to safely store nuclear waste for 1’000’000 years

-> How?

Ensi.ch / nagra.ch



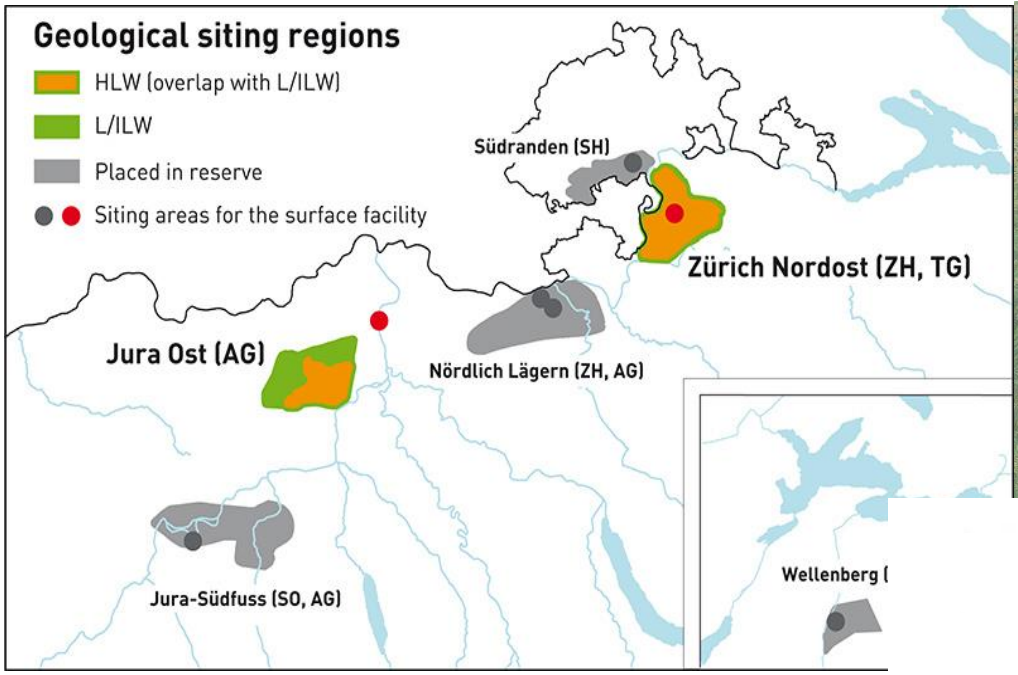
2011: How to find the safest place?

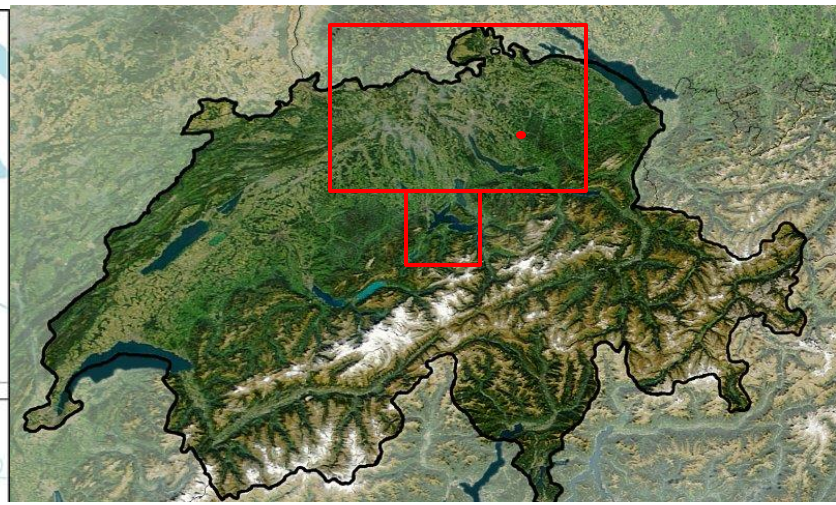


nagra.ch

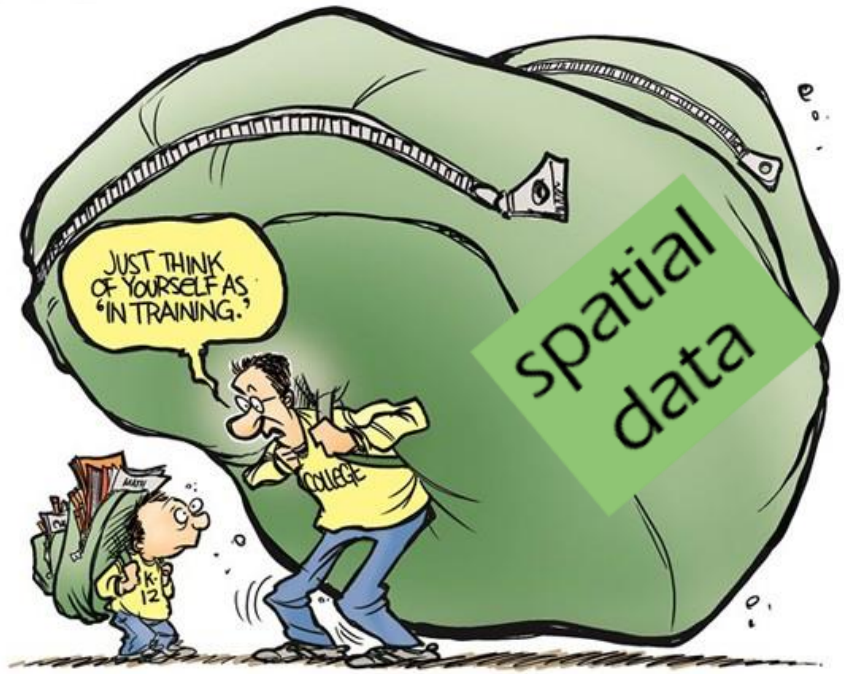
2011: How to find the safest place?

nagra.ch





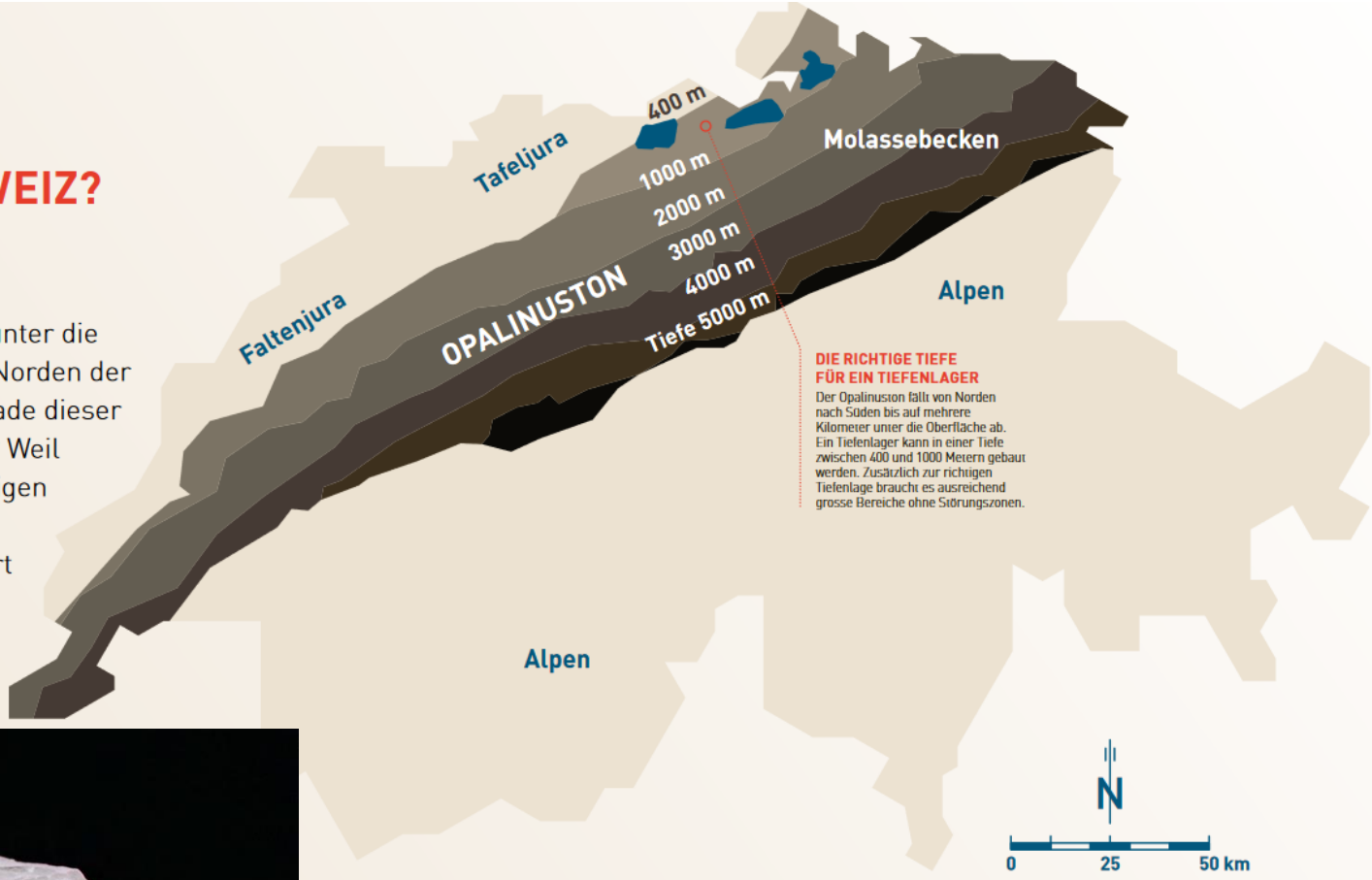
- Long-term project
- GIS central planning tool
- 3D problem: depth of geological layers, faults…
- Socio-economic aspects

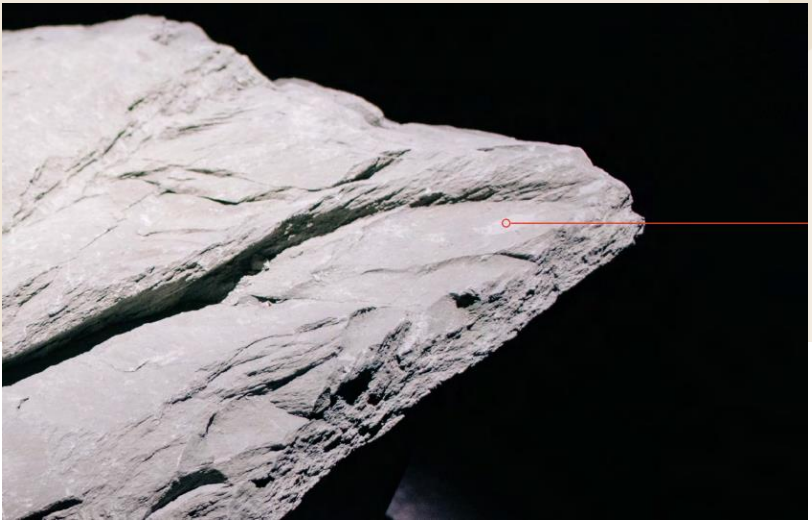


Most suitable geology

WIESO DIE NORDSCHWEIZ?

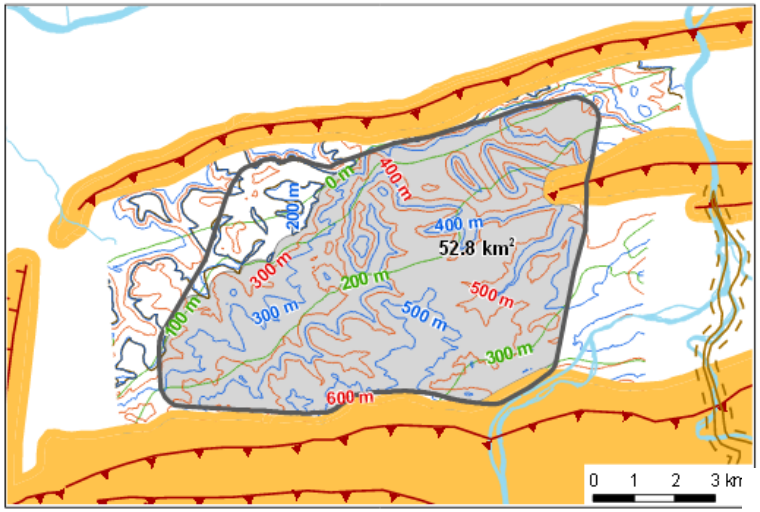
Alle drei Gebiete, die die Nagra unter die Lupe genommen hat, liegen im Norden der Schweiz. Warum eignet sich gerade dieser Bereich der Schweiz am besten? Weil dort der Opalinuston in der richtigen Tiefe, Qualität und Ausdehnung sowie verhältnismässig ungestört vorliegt.





Opalinus clay

Jura Ost: Geological setting



reg. tekt. Elemente
- reg. Störungszonen
- Abschiebung
- Überschiebung

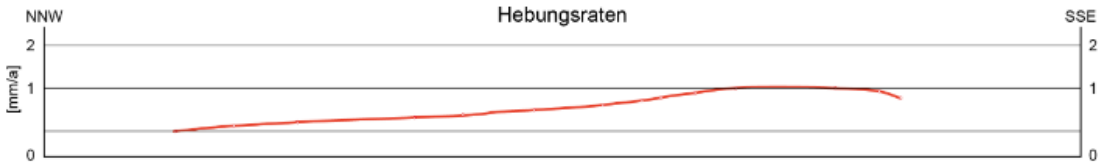
Tiefe Lagerebene
- bzgl. m u.T.

Tiefe Top WG
- bzgl. m u.T.
- bzgl. m u.E.
- 200 m u.F.

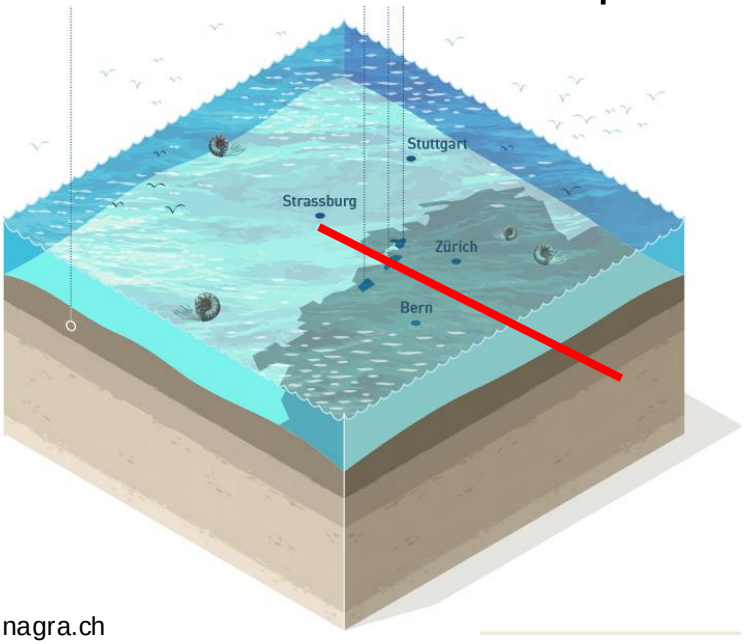
Standortgebiet
- SMA-JO

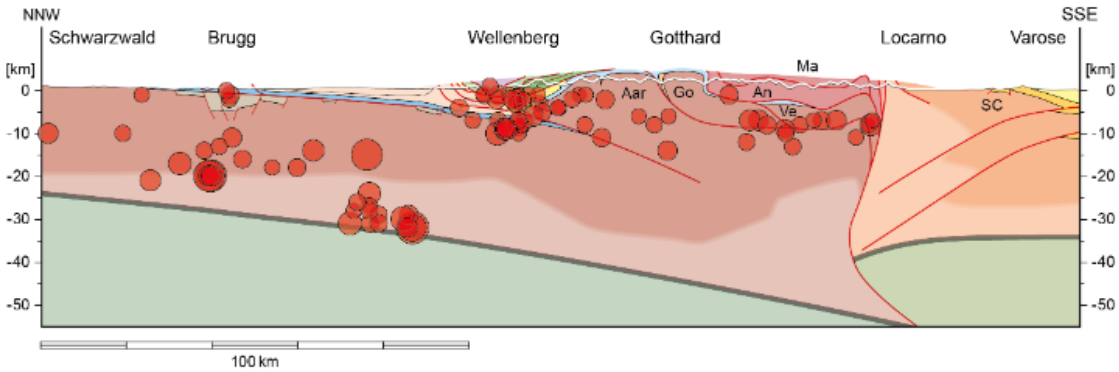
Lagerperimeter
- MA/VA

übertiefte Felsrinnen
- Top Fels > 50 m u.E.
- + 200 m Abstand



N-S transect across Alps





Erdbeben 1975-2012: Instrumentell (M_L)
- 2
- 3
- 4

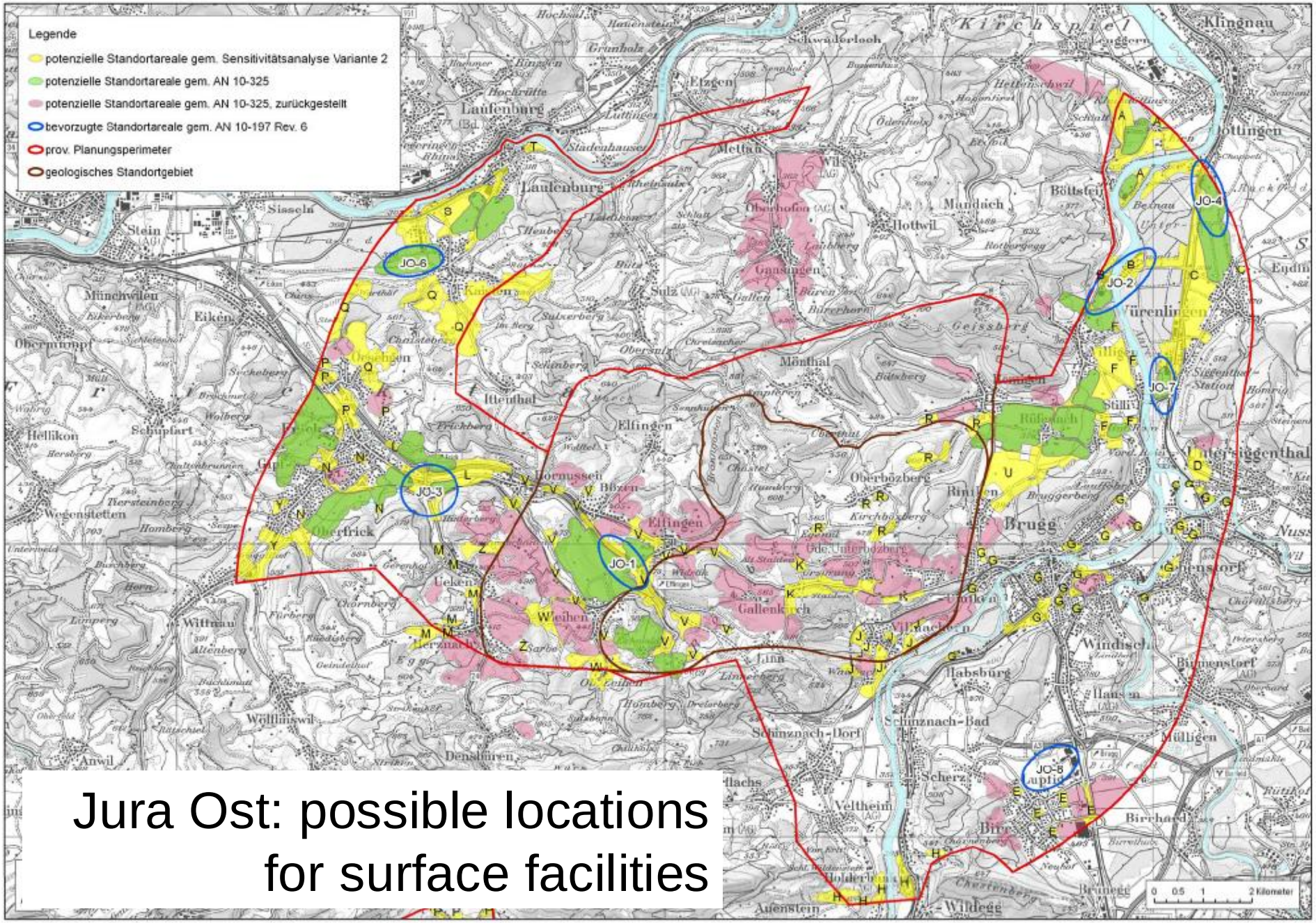
Vorland
- Subalpiner Flysch
- Molasse
- Mesozoikum
- Permokarbon

Helvetikum
- Nordhelvetischer Flysch
- Drusberg-Decke
- Axen-Decke
- Autochthon
- Perm (Verrucano)
- Oberkruste (Kristallin)
- Unterkruste
- Erdmantel
- Ve Verampic
- Go Gotthard

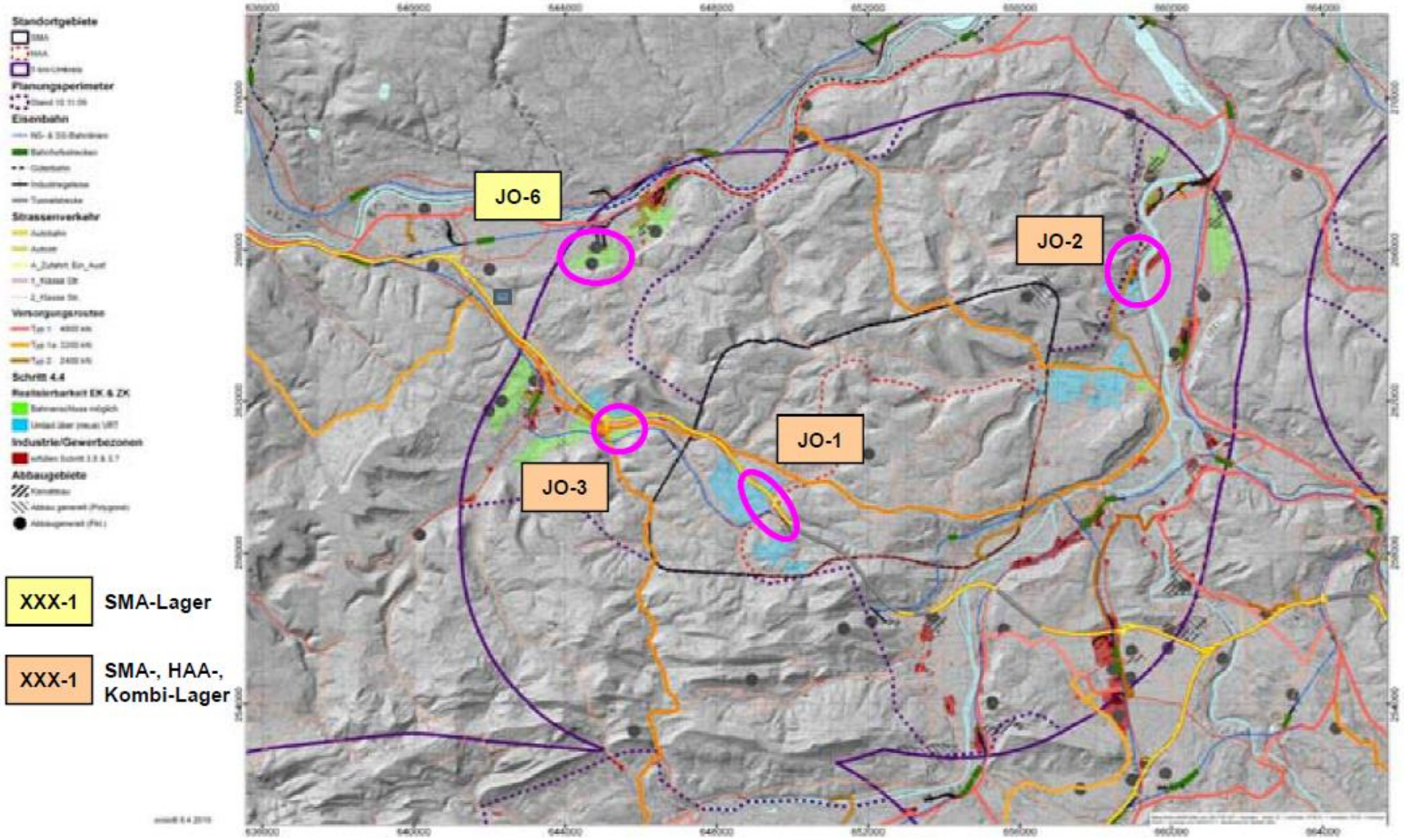
Penninikum
- Mesozoikum
- Oberkruste (Kristallin)
- Ma Maggia
- An Antigorio

Ostalpin/Südalpin
- Känozoikum
- Mesozoikum
- Oberkruste (Kristallin)
- Unterkruste
- Erdmantel
- SC Strona-Ceneri

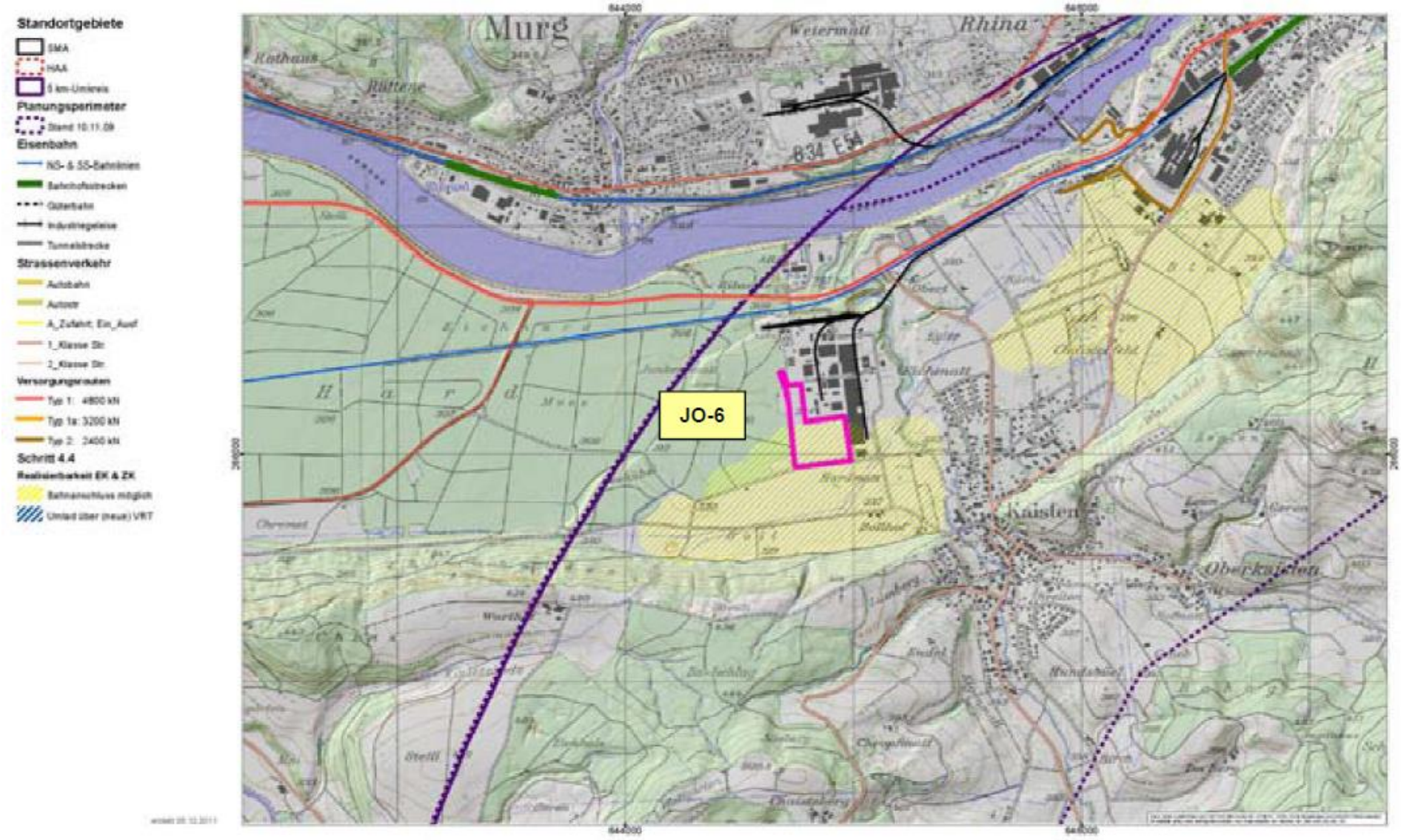
Beilage 2.4: Resultat der Sensitivitätsanalyse Variante 2 – Jura Ost



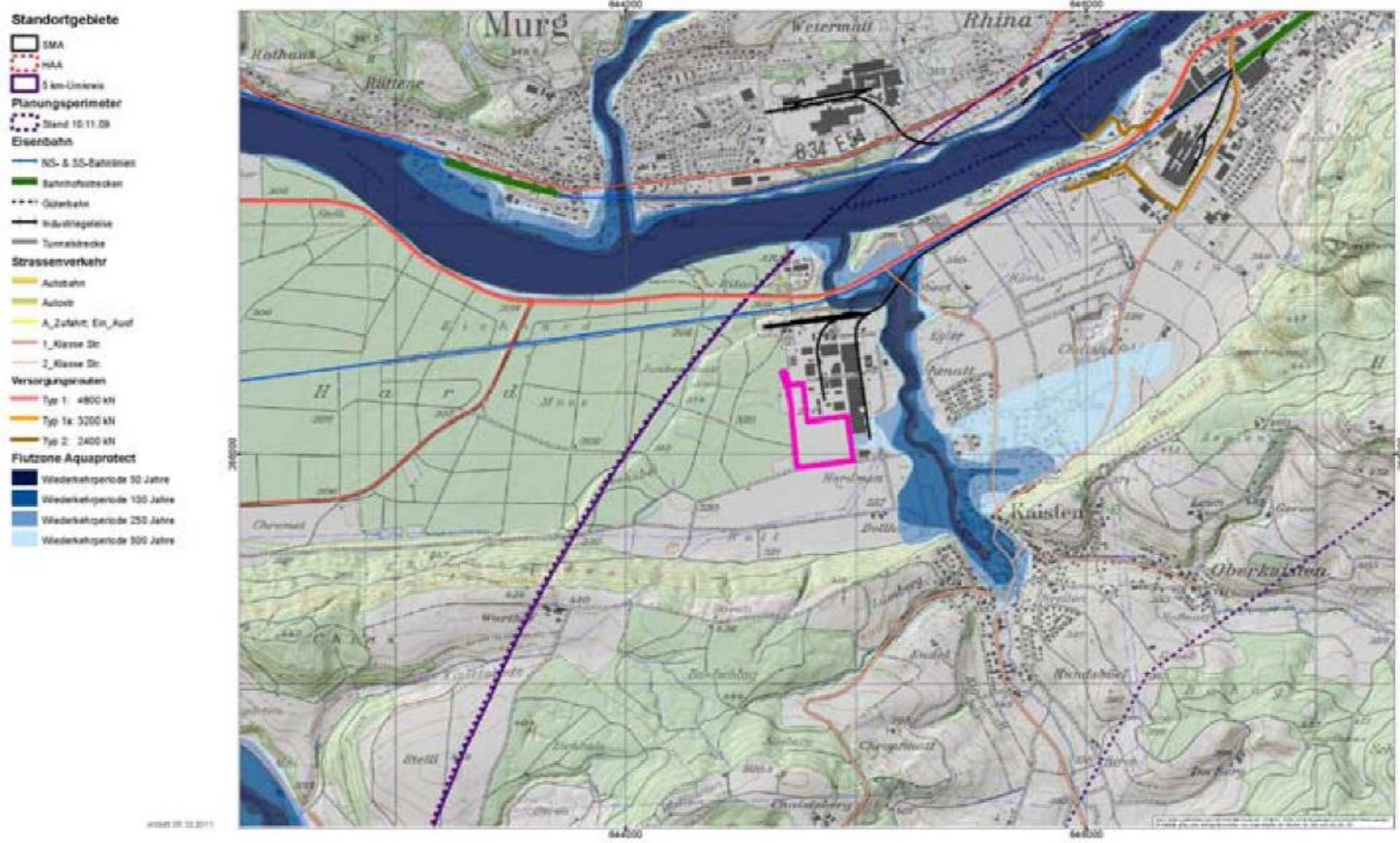
Nagra, AN11-227



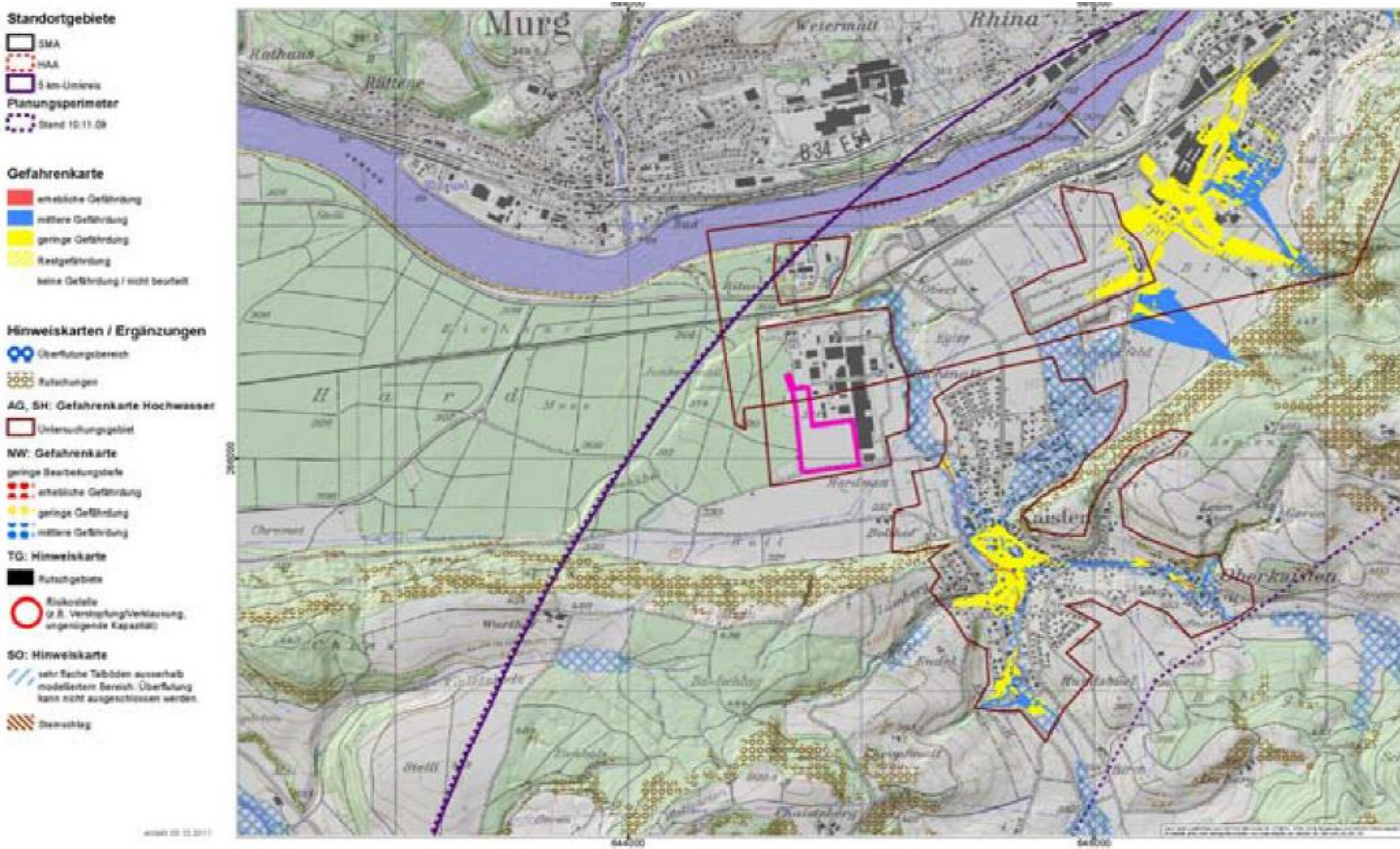
Four selected surface facility locations



Perimeter for surface facility



Flood risk: dark blue 10y floods, light blue 500y floods

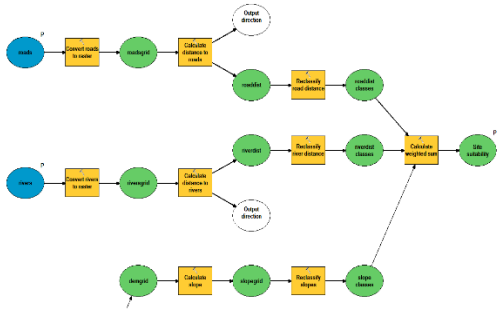


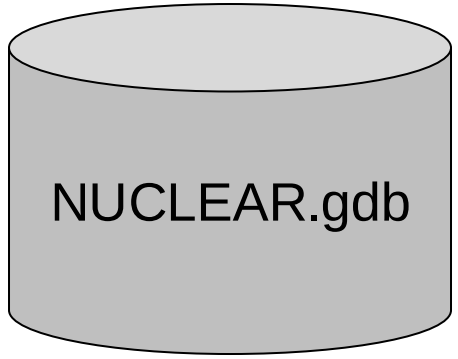
Natural hazards – red/blue/yellow: substantial/middle/low risk

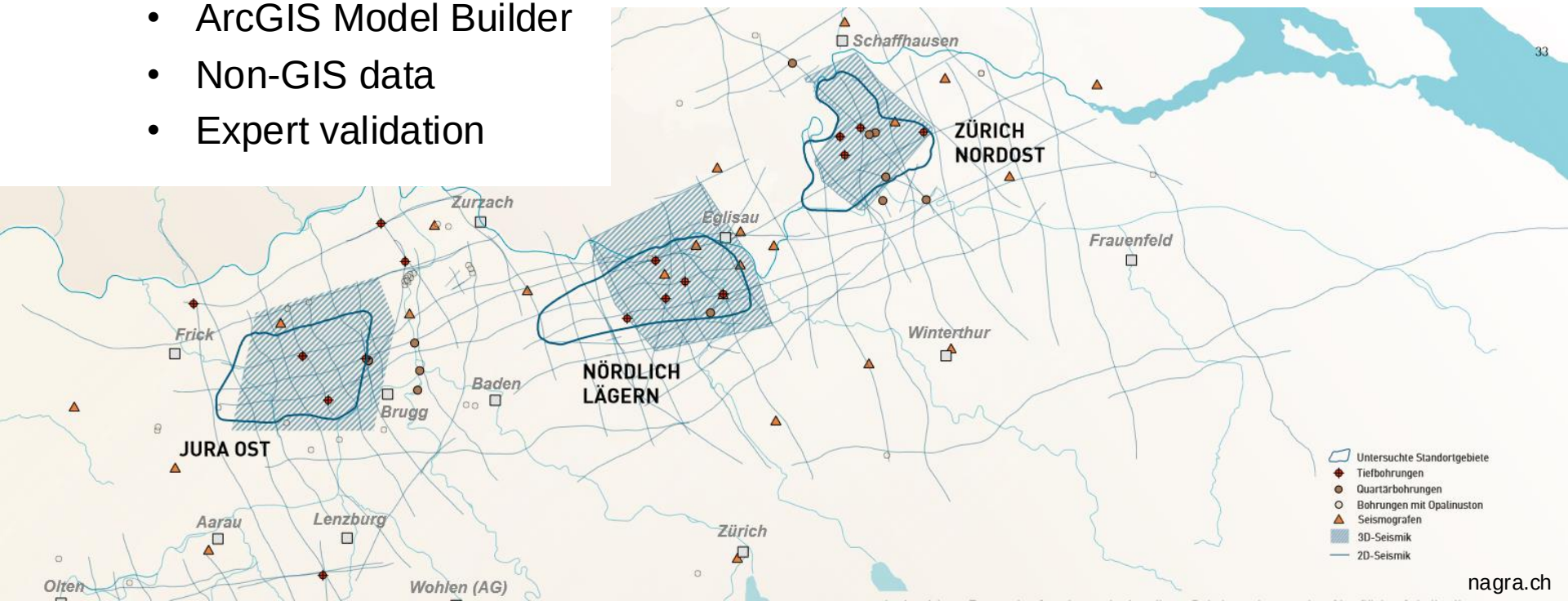
Nagra, AN12-30

Implementation – Overview

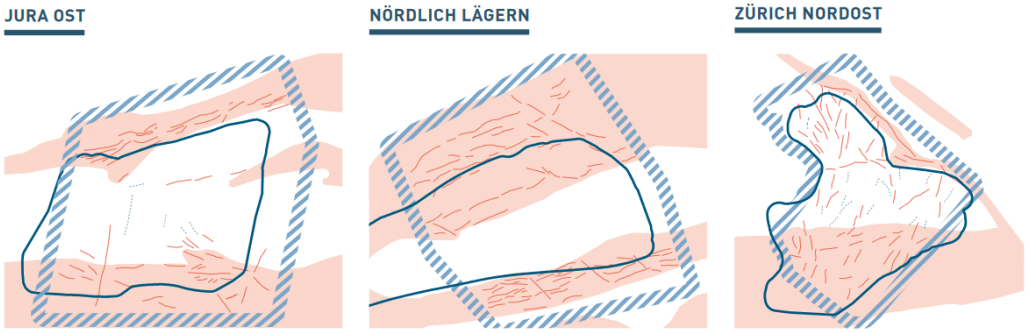
- Data integration: Spatial databases
  - Database modelling
  - ESRI geodatabases
  - Metadatabases
- Cartographic Modelling
  - Many MCAs
  - ArcGIS Model Builder
  - Non-GIS data
  - Expert validation

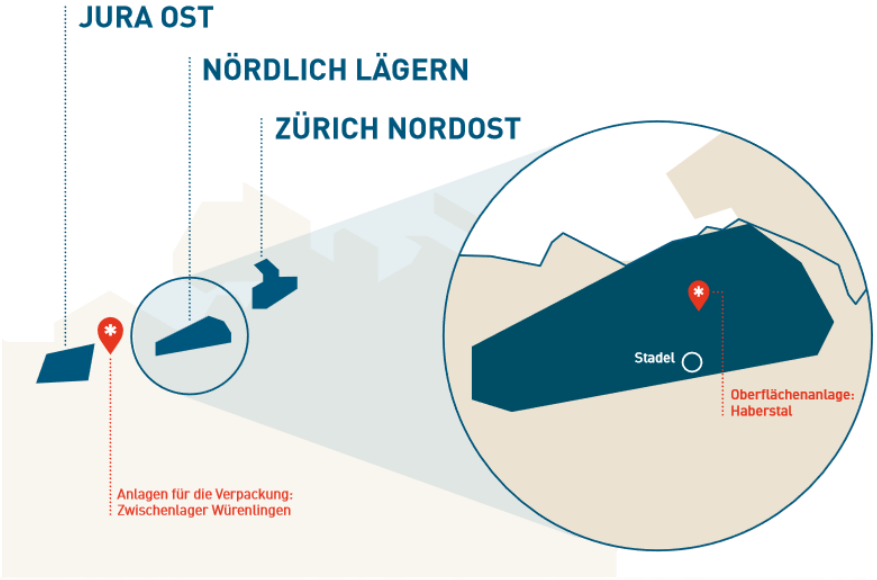


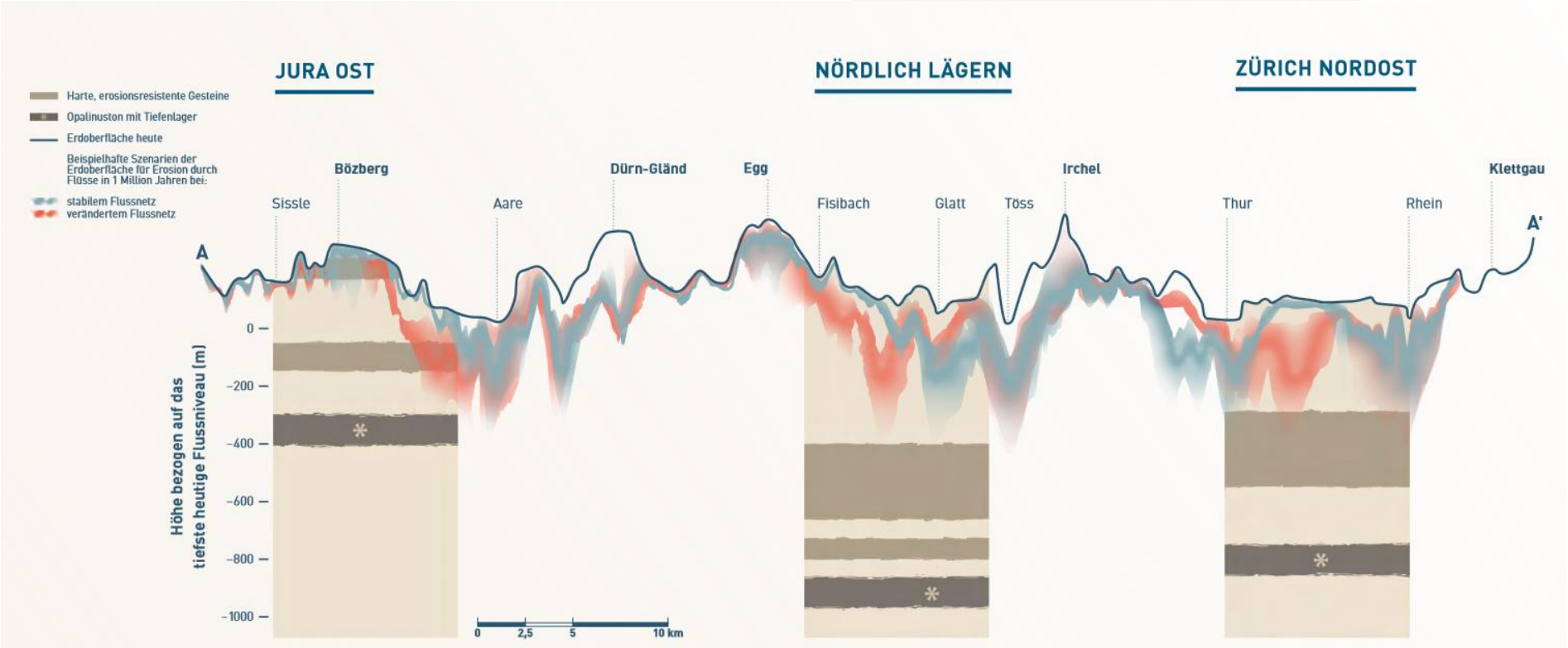




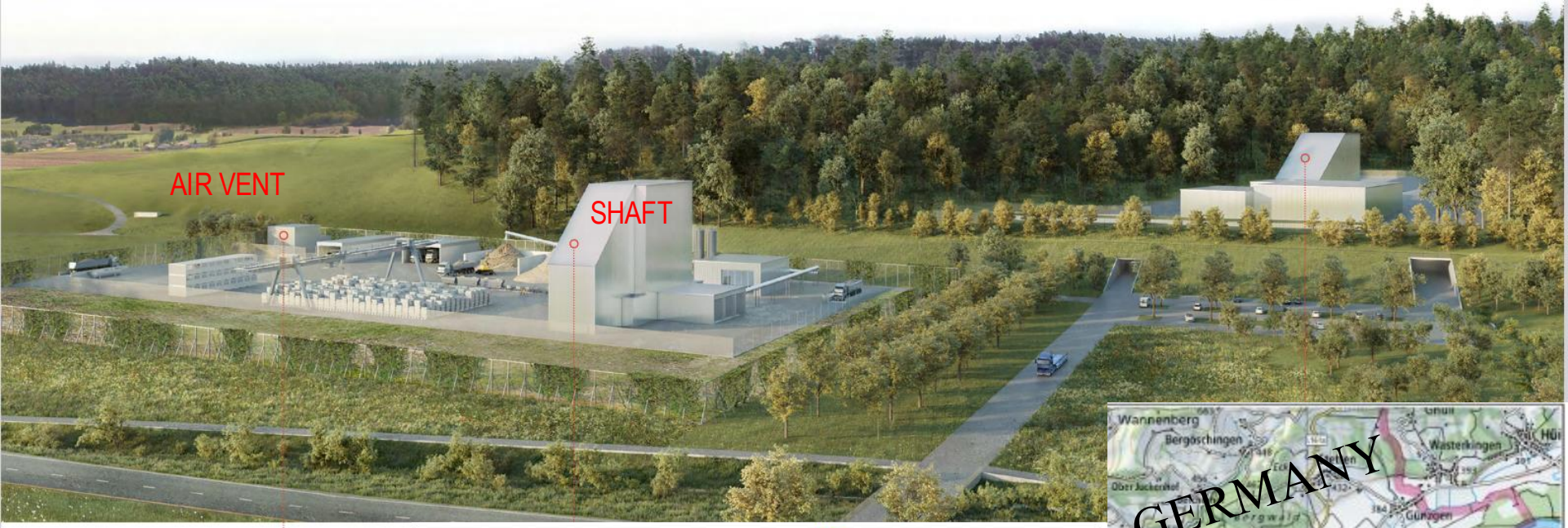
2022: Decision

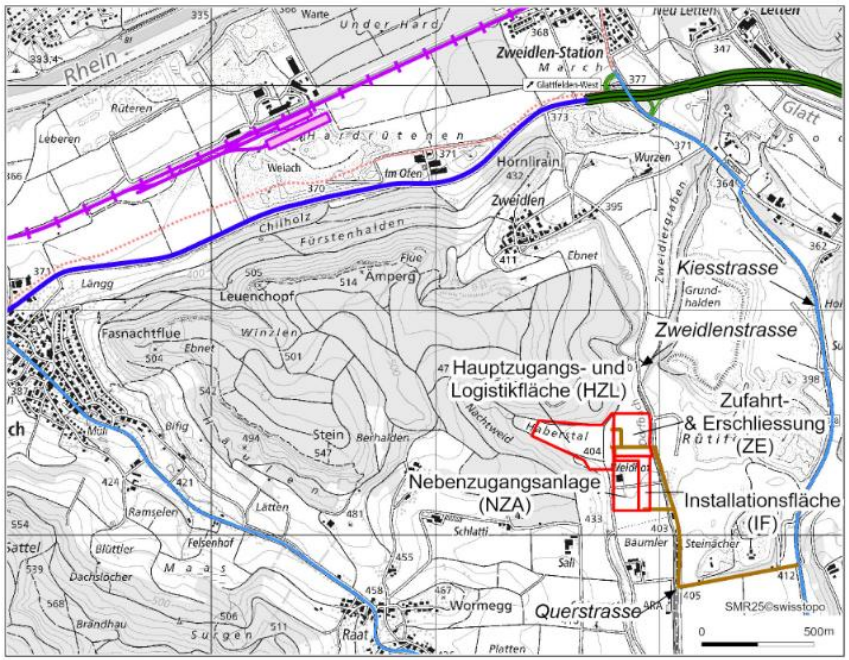






VISUALISIERUNG DER OBERFLÄCHENANLAGE

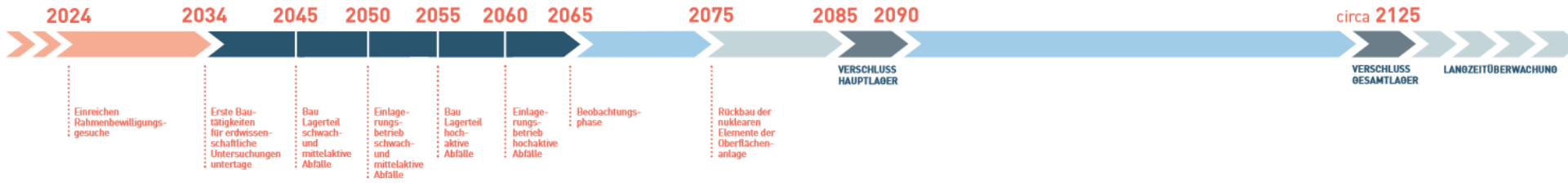




Surface facility

VISUALISIERUNG DER OBERFLÄCHENANLAGE

Bureaucracy phase



Building phase

Observation phase