Assessment of flood risks for residential areas caused by cloudbursts

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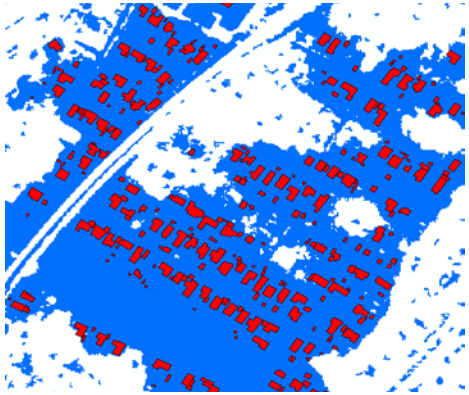
Background

My focus has been on developing some models to estimate the flood risk for existing buildings or planned new developments.

My motivation is driven by a personal experience in July 2011 when Copenhagen got 5" of rain in 75 minutes, so our home's basement was flooded.

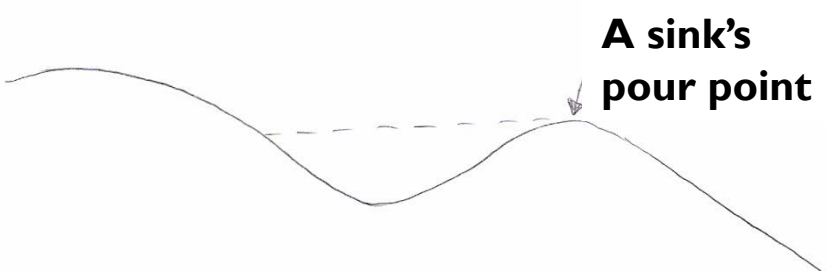
Facing that climate changes is a fact causing more and more heavy rainfalls, the Danish Geodata Agency and Danish Nature Agency issued nationwide so called bluespot maps in 2012 based on a 10 m (32') DEM. They show where buildings are located within sinks in chance of getting flooded. An unfair catagorization in my opinion as a building's flood risk should a.o. be based on its terrain level within the sink.

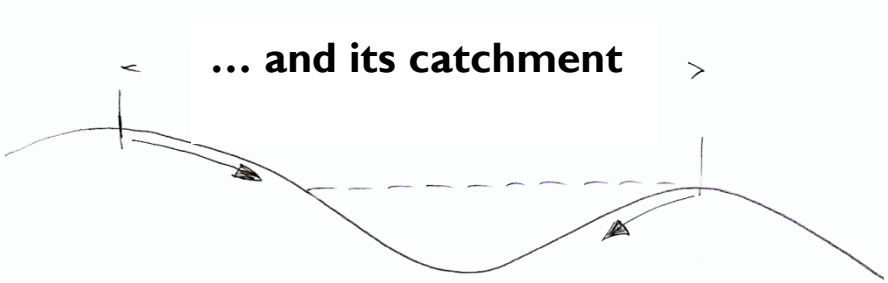


Sinks are all over

During cloudbursts runoff is predominant and the water just flows according to the steepest gradient and may get trapped in a sink – big or small, shallow or deep.

Every sink has a contributing **catchment** and it may be filled to its lowest lying **pour point**, only. If more water is added, it will flow into the next sink and so forth.





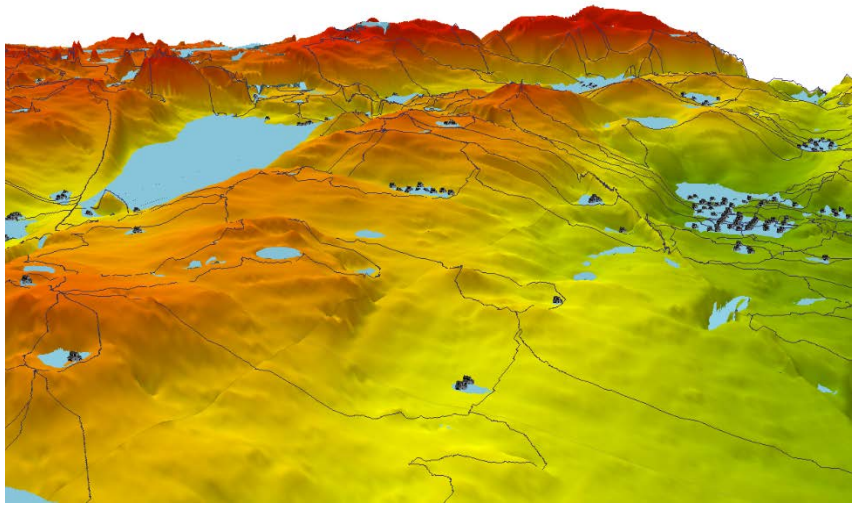
Models and data

So far **4 models** have been developed to estimate flood risks for residential areas:

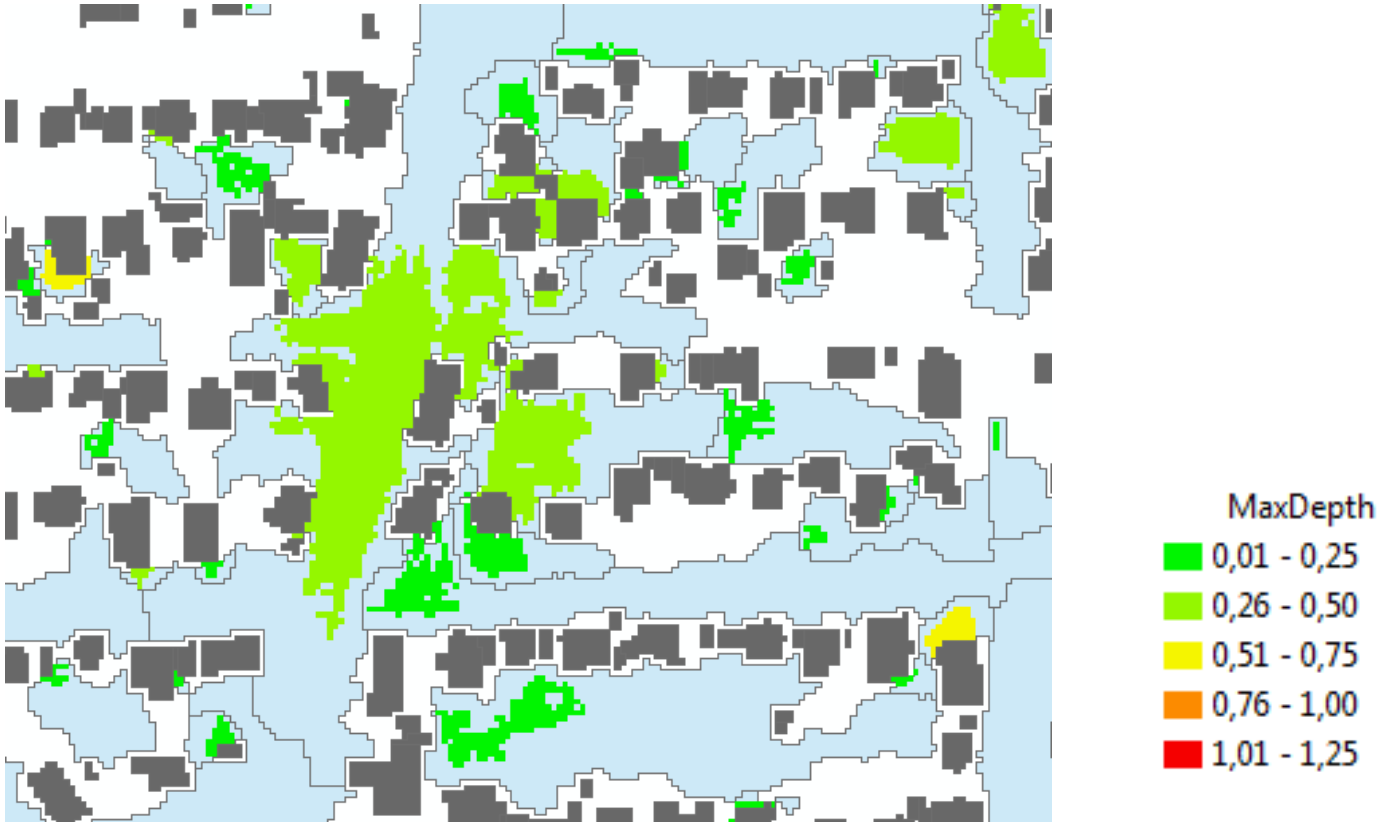
Model 1: Delineations of sinks and their water depths (Blue Spot maps)
Model 2: Estimation of critical precipitation values for the individual sinks to fill them to their pour points assuming perfect runoff conditions
Model 3: Estimation of a critical FillUp value for individual buildings based on their critical water entrance levels
Model 4: Flood risk index for individual buildings based on slope conditions, solid surface %, and flow distances within the sinks' catchments

Data involved:

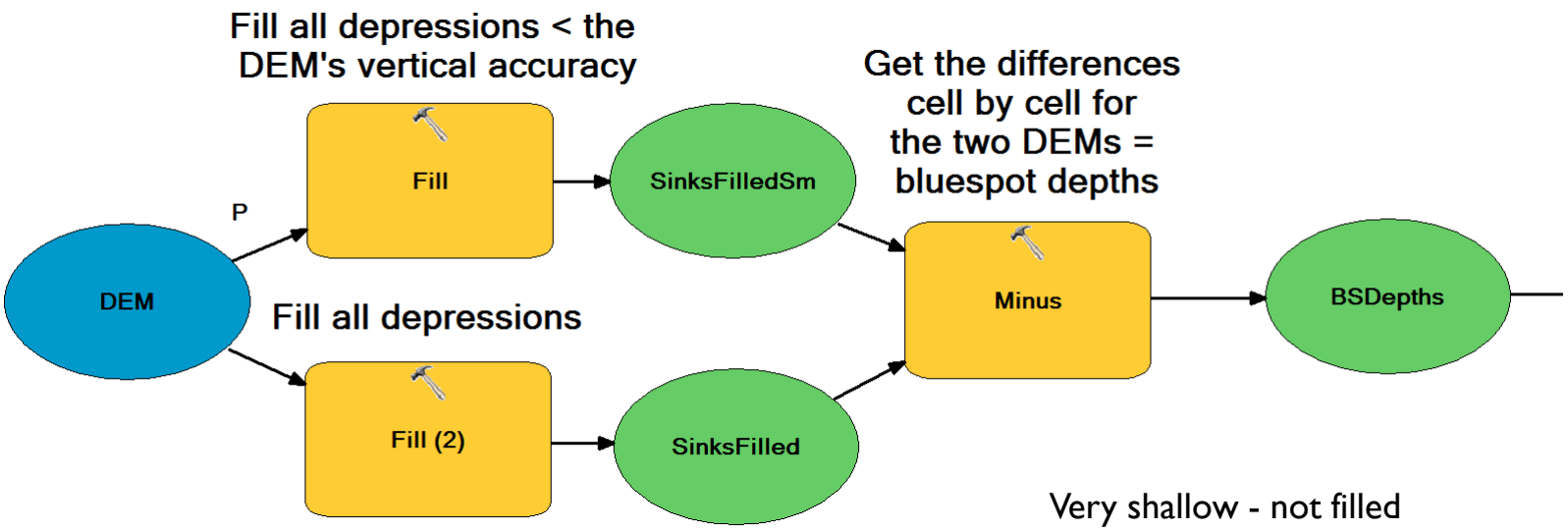
A 1.6 m hydrologically corrected DEM for Denmark
A feature class of building footprints

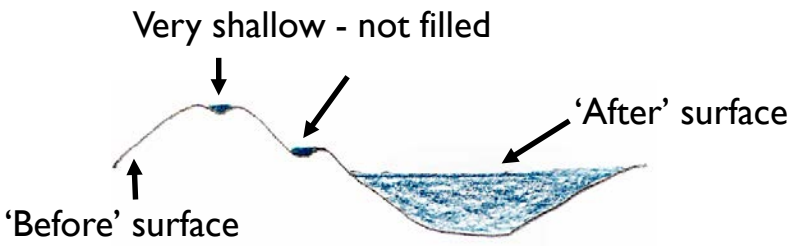


1st model:
Identification of sinks and their max. water depths when filled to their pour points (bluespot map)

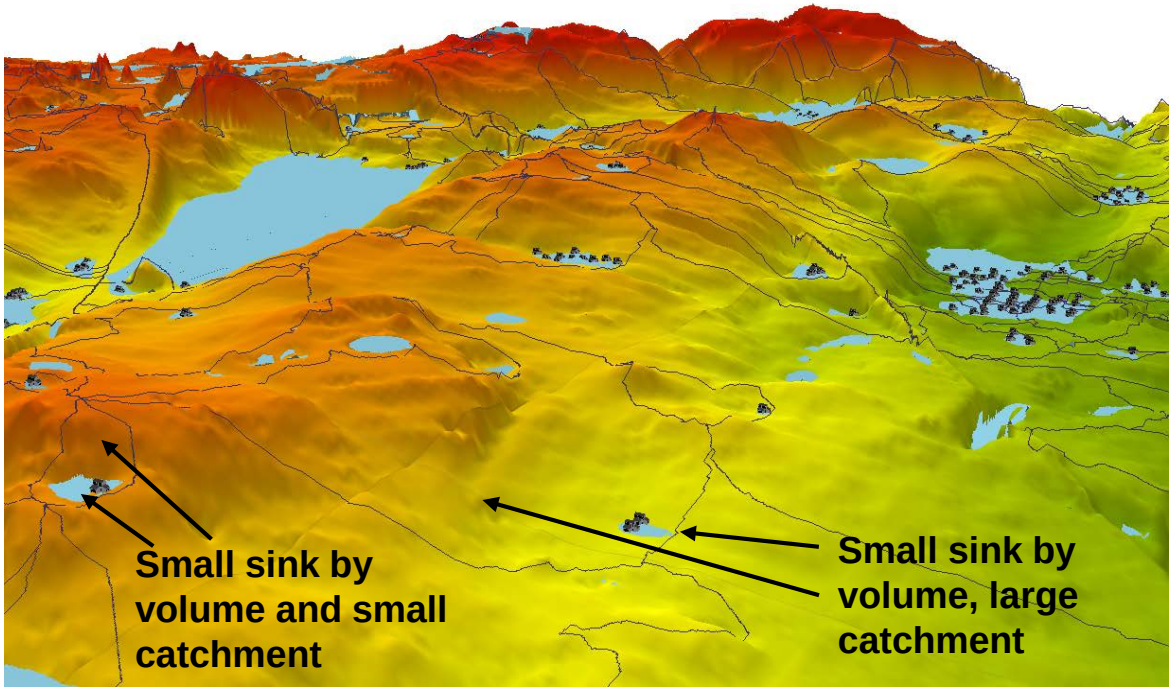


Model 1: Identify bluespots and their depths





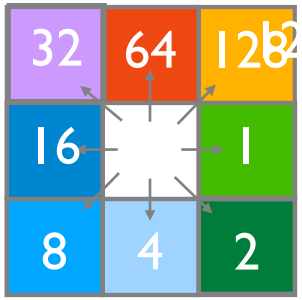
Sinks and their local catchments



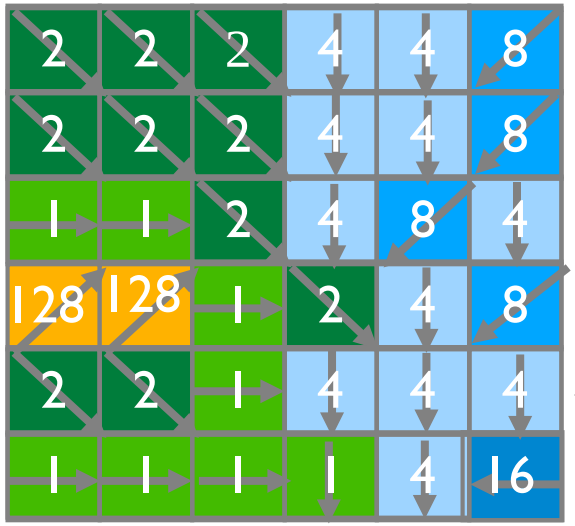
Determination of flow directions

78	72	69	71	58	49
74	67	56	49	46	50
69	53	44	37	38	48
64	58	55	22	31	24
68	61	47	21	16	19
74	53	34	12	11	12

Elevation values

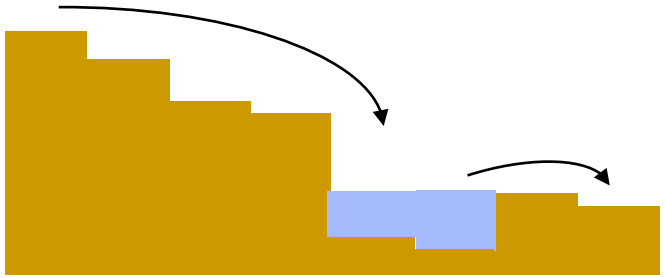


Flow directions



Sink detection

Sink



2nd model: Estimation of critical precipitation values for the individual sinks to fill them to their pour points

The water balance equation:

P = I + E + Ao + Au + M,

where P is the precipitation
I is the interception
E is the evapotranspiration
Ao + Au is the overland and subsurface runoff
M is storage in soils, lakes etc.

M = P – (~~I~~ + ~~E~~ + Ao + Au)

If the rain intensities are extreme, soils' infiltration rates are too slow to let away the water. Also, no sewer systems in Denmark are in general dimensioned to drain off more than 40 mm/hr (1.6"). Thus, when setting **Au** to 40 the formula can be modified as:

$\mathbf{P}_{\text{critical mm/hr}} = \mathbf{M + 40}$ $\qquad$ $(\mathbf{P}_{\text{critical inches/hr}} = \mathbf{M + 1.6})$

Method:

Assuming perfect run-off conditions within the catchment area and no sewer systems to drain off the water, the FillUp value may be estimated by dividing the individual sinks' volumes by their catchment areas.

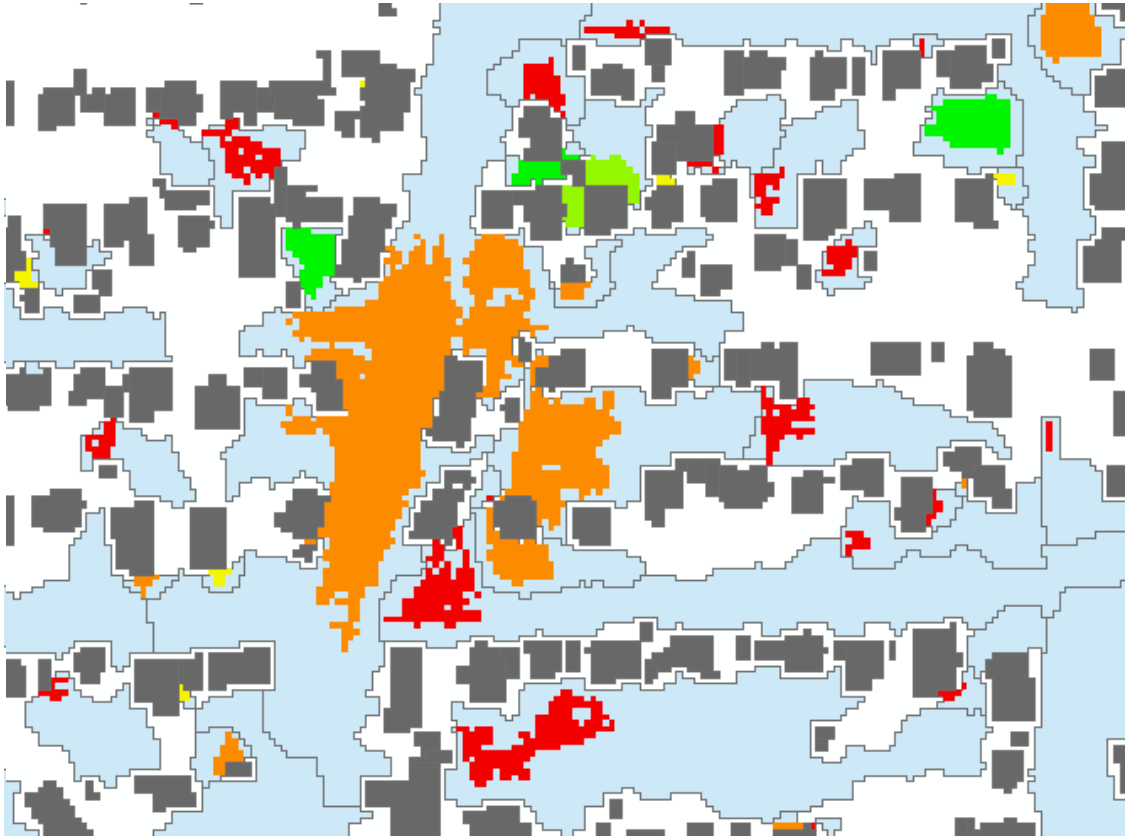
$$\frac{Volume\ of\ local\ sink\ in\ m^3}{Sink's\ catchment\ area\ \ in\ m^2} * 1000 + 40\ \text{mm}$$

$$\frac{Volume\ of\ local\ sink\ in\ cu\ ft}{Sink's\ catchment\ area\ in\ sq\ ft} * 12 + 1.6''$$

<u>Example:</u>
A sink's volume is 10 m^3
The sink's contributing catchment is 200 m^2
The FillUp value is 10/200 m = 0.05m = 50 mm (2")

If a sewer system is present add 40 mm (1.6") → 90 mm (3.5")

2nd model:
Critical precipitation values to fill individual sinks to their pour points



Catchments

Buildings

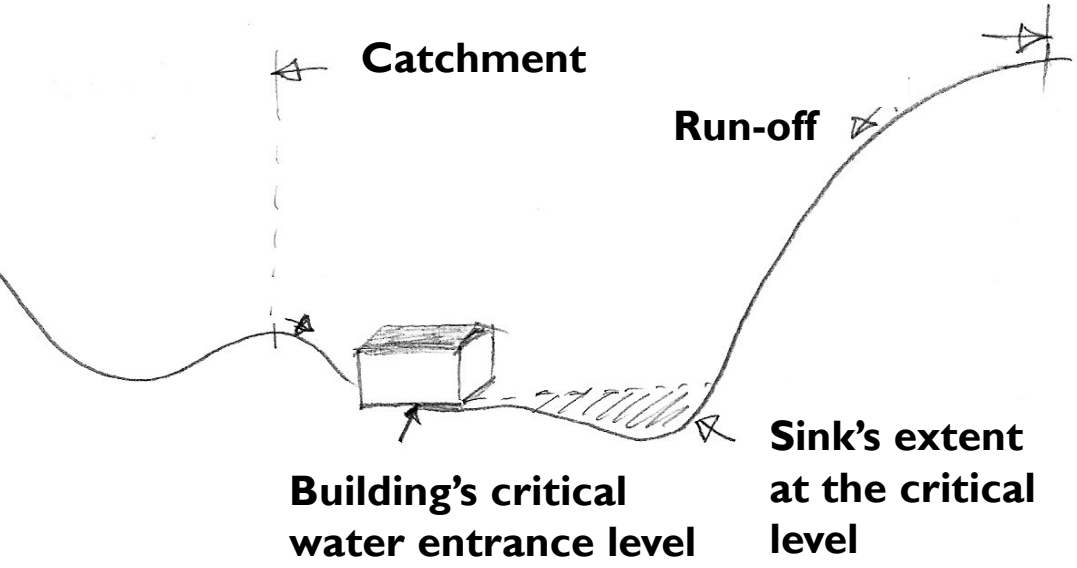
Critical precipitation to fill up the sinks to their pour points.

- P 40-60 mm
- P 60-80 mm
- P 80-100 mm
- P 100-120 mm
- P 120-140 mm

If a sewer system is present add 40 mm to the above values.

3rd model: Estimation of a critical FillUp value for individual buildings based on their water entrance levels

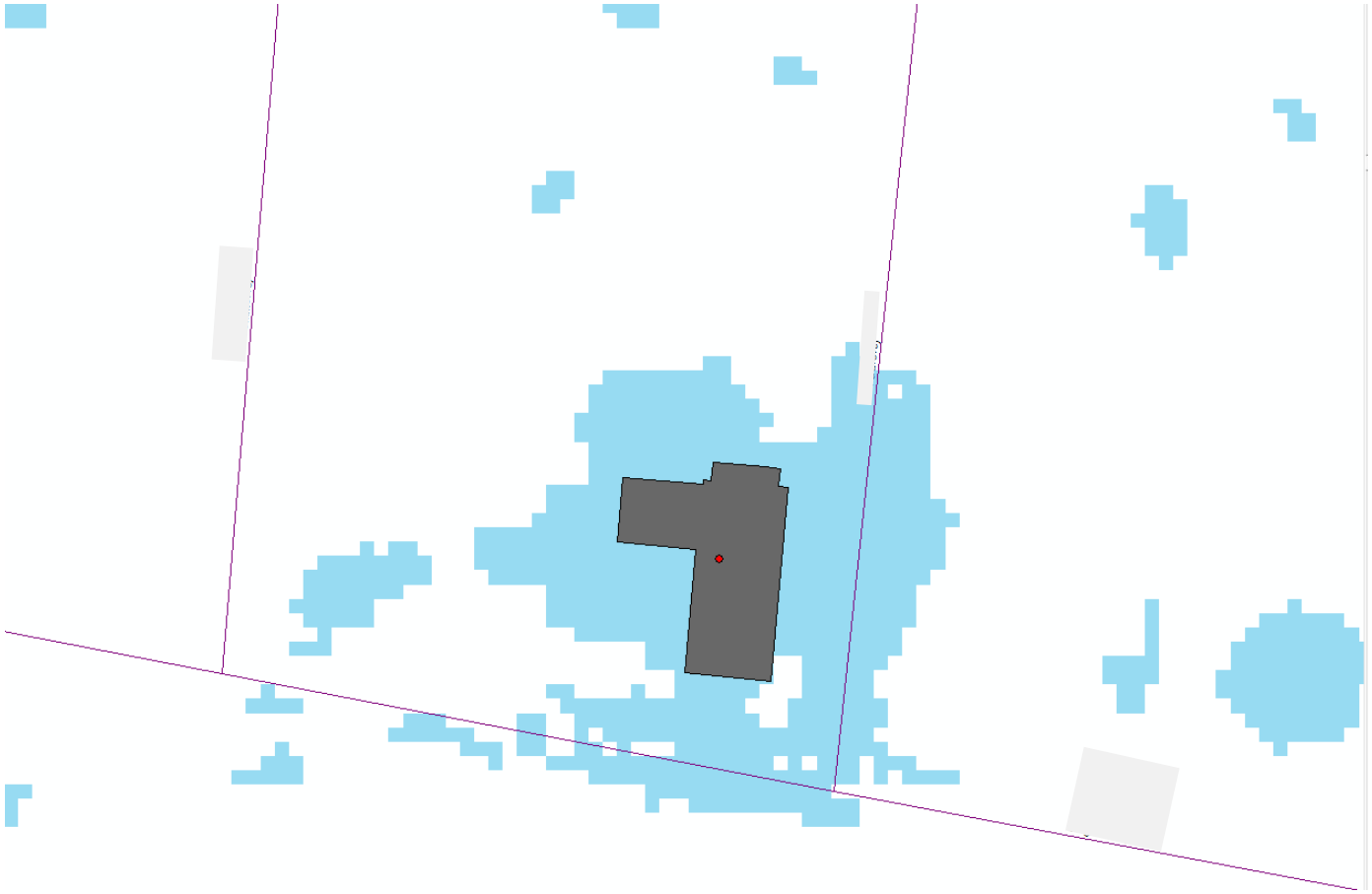
What is the critrical amount of precipitation for a building located in a sink before it gets flooded (worst case scenario)?



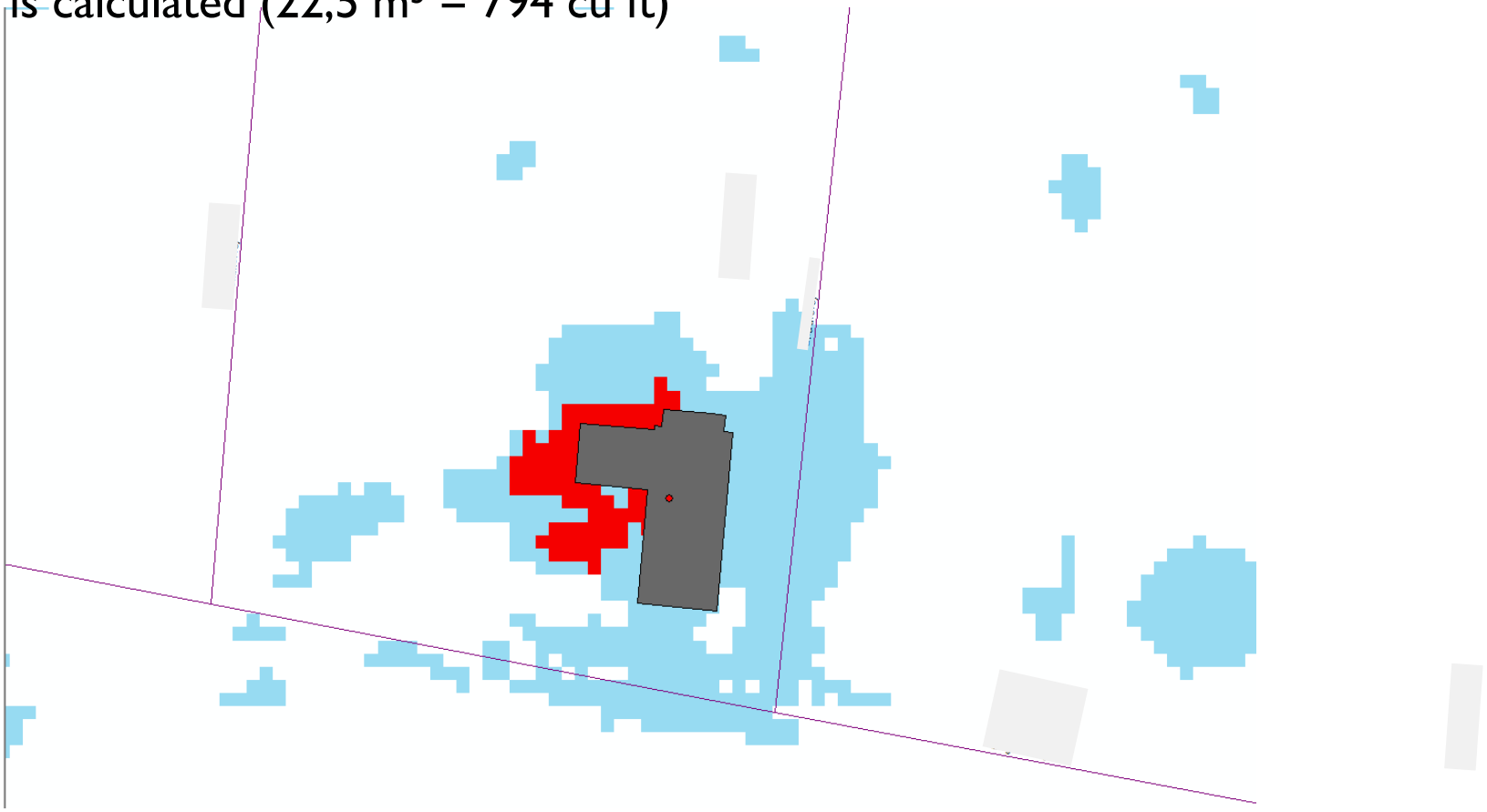
Calculate the sink's volume up to the critical water entrance level and divide it by the catchment's area. Optionally add 40 mm (1.6") to the result if the sewer system is efficient.

Example:

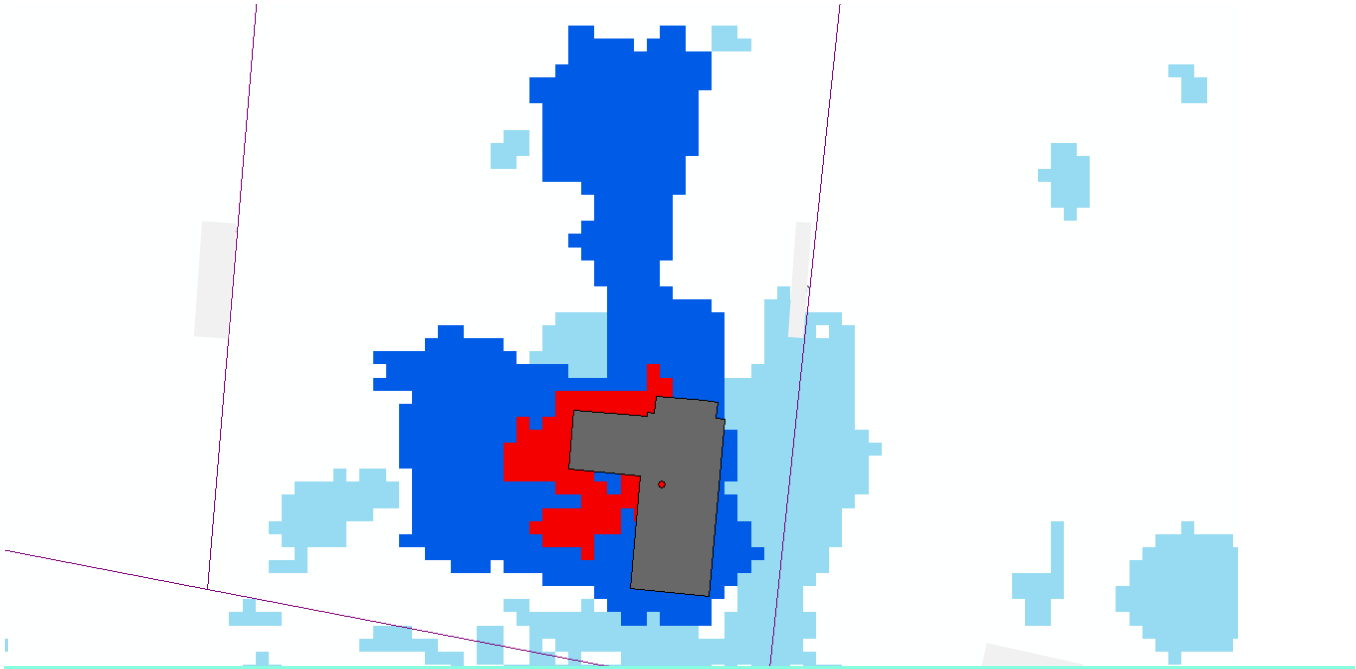
A building (gray) located within a sink (blue)



The building's base level is extracted (ZonalMean of elevations within the building's footprint). Next, the sink's extent (in red) and volume at that level is calculated (22,5 m^3 = 794 cu ft)



The sink's catchment area is calculated (1774 m^2 = 19,095 sq ft)



$$\text{Critical precipitation, mm/hr} = \frac{22.5}{1774} * 1000 + 40 = 53$$

$$\text{Critical precipitation, mm/hr} = \frac{794}{19095} * 12 + 1.6 = 2.1''$$

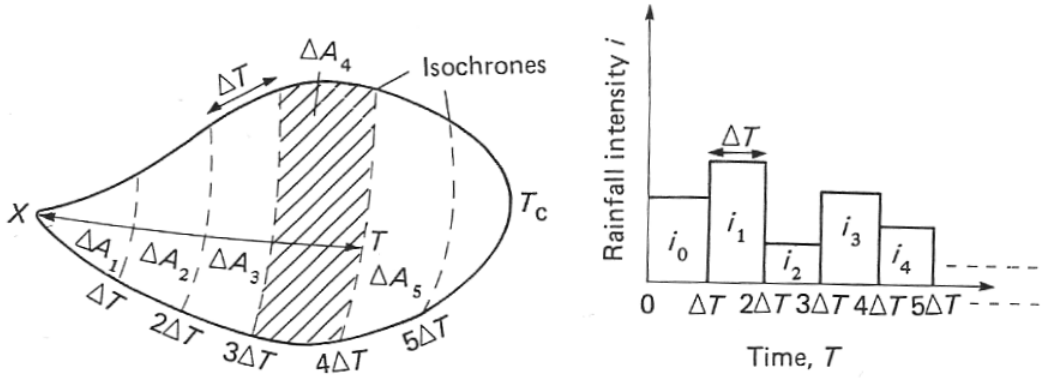
Critical precipitation values for a residential area

4th model: Risk factor index

Calculate a risk index for each building based on

a) Response times due to max. flow length, L, within the catchment, and slope, S,
b) % surface cover
c) The FillUp rate

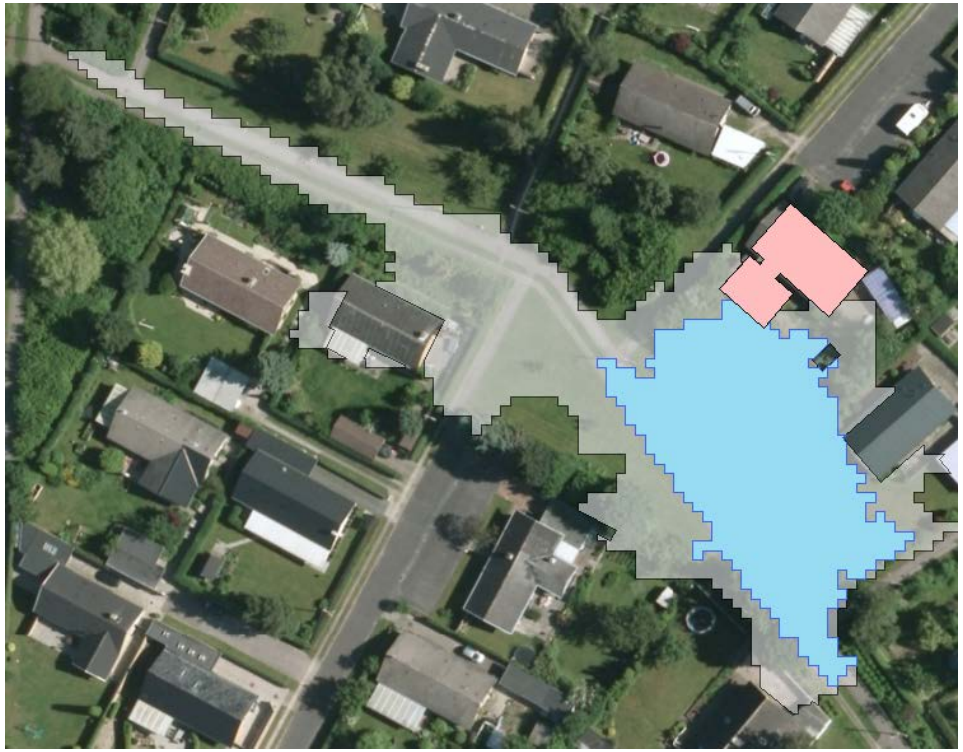
Ad 1) Kirpich (1940): $Tc = 0.00025 * \left(\frac{L}{\sqrt{S}}\right)^{0.8}$



(a) Rainfall bar graph and catchment showing isochrones of travel time

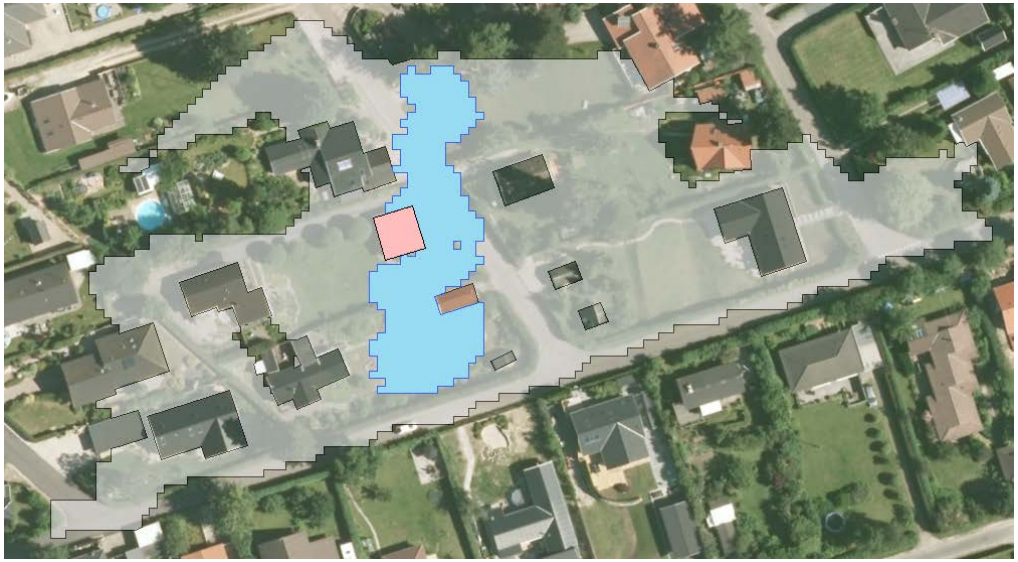
Risk factor example 1:

Sink volume: 61 m^3 (5,685 cu ft)
Catchment area:
4270 m^2 (45,962 sq ft)
FillUp value: 78 (38) mm /
3” (1.5”)
Average slope: 2.7 %
Max. flow length: 124 m (356 ft)
Solid surface: 37 %
Risk factor: 20



Risk factor example 2:

Sink volume: 180 m^3 (6,355 cu ft)
Catchment area: 9832 m^2
(105,830 sq ft)
FillUp value: 58 (18) mm /
2.3” (.7”)
Average slope: 9%
Max. flow length: 144 m (472 ft)
Solid surface: 55 %
Risk value: 85



Risk factor example 3:

Sink volume: .7 m^3 (24 cu ft)
Catchment area: 3400 m^2 (36597 sq ft)
FillUp value: 40 (0) mm / 1.6” (0”)
Average slope: 4.4 %
Max. flow length: 136 m (512 ft)
Solid surface: 55%
Risk value: 6274

In the pipeline:

- Improve risk index
- Tune up performance: Models 3 and 4 may be converted to Python scripts or tried in ArcGIS Pro to perform faster
- Awaiting bug fixes for iterations causing memory leaks
- Add knowledge about base heights for buildings, and information about presence of basements from a national building and dwelling register
- The consequences of changing flow paths near critically located buildings

- Release models 1 and 2 on the learn.arcgis.com site in the fall of 2015

Thank you for your attention!

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