Using GIS to calculate the potential for small hydro power plants in Norway

Astrid Voksø, NVE

Olav Kavli, Geodata AS

Hallvard Stensby, NVE

Outline

- Background
- Concept
- The projects aim
- Description of Analysis and conditions
- Results
- Problems solved

Background

- Unknown potential
- Demanding work to do manually
- Manually calculation gives different results
- Newly developed datasets at NVE (river network, DTM, digital runoff map as grid)
- NVEs GIS-expertise

Concept

- Identify slope with a certain derived gradient using DTM and river network.
- Calculate drainage area and runoff
- Identify slope with enough energy potential
- Consultant available Geodata AS v/Olav Kavli with knowledge to implement in ArcGIS

Aim

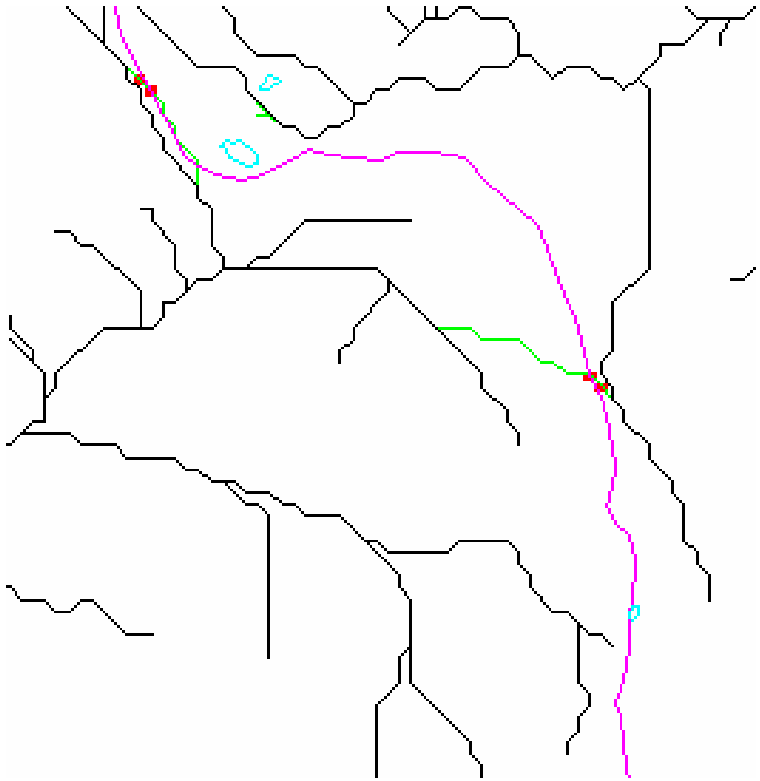
- Calculate small hydro plants energy potential
- Rough estimate
- Automatic using digital maps and GIS, manual correction
- RESULT: the theoretical potential for small hydro power plants .

Steps in the Analysis

- Preparation of DTEM
  - Including hydrologic analysis
- Generate geometric river network from cover to PGDB
- Calculate distance to roads and power lines
- The analyses

Prepare DTEM - 25 x 25 meters

- Compare with digitized watersheds
- Correct errors by elevate terrain 10 m



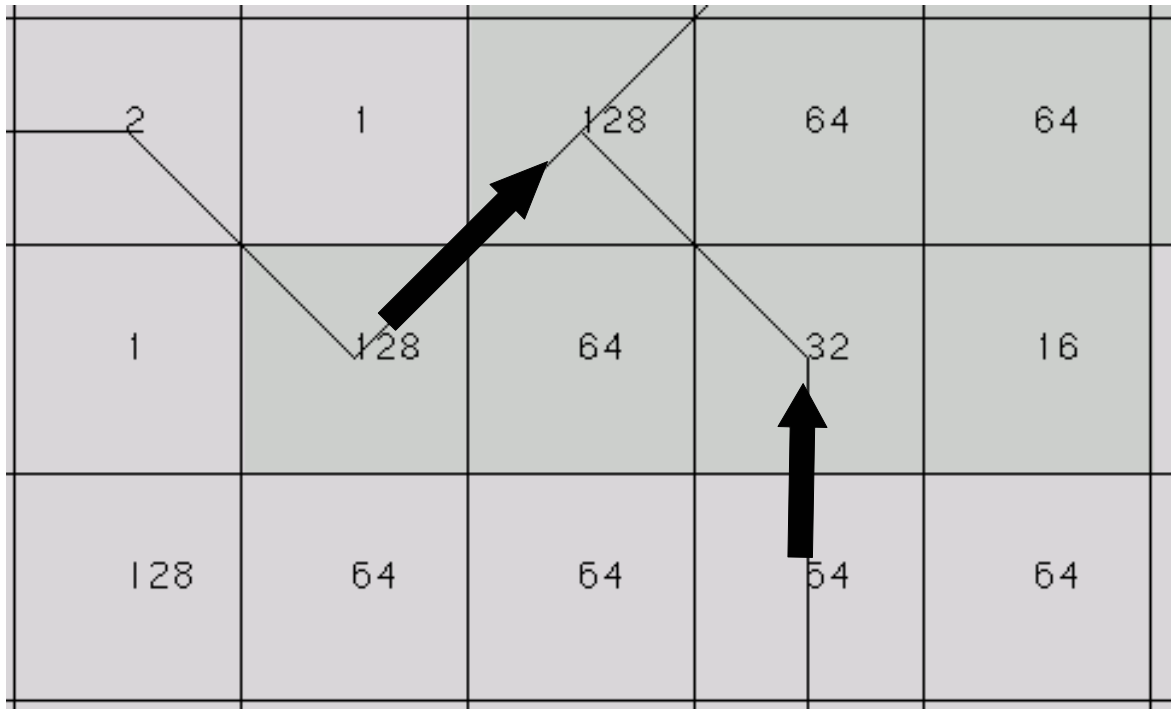
Prepare DTEM

- Compare with digitized watersheds
- Correct errors by elevate terrain 10 m
- New DTEM
  - Get points from DTEM - gridpoint
  - Topogrid - gridpoint and river network as stream

Derive runoff

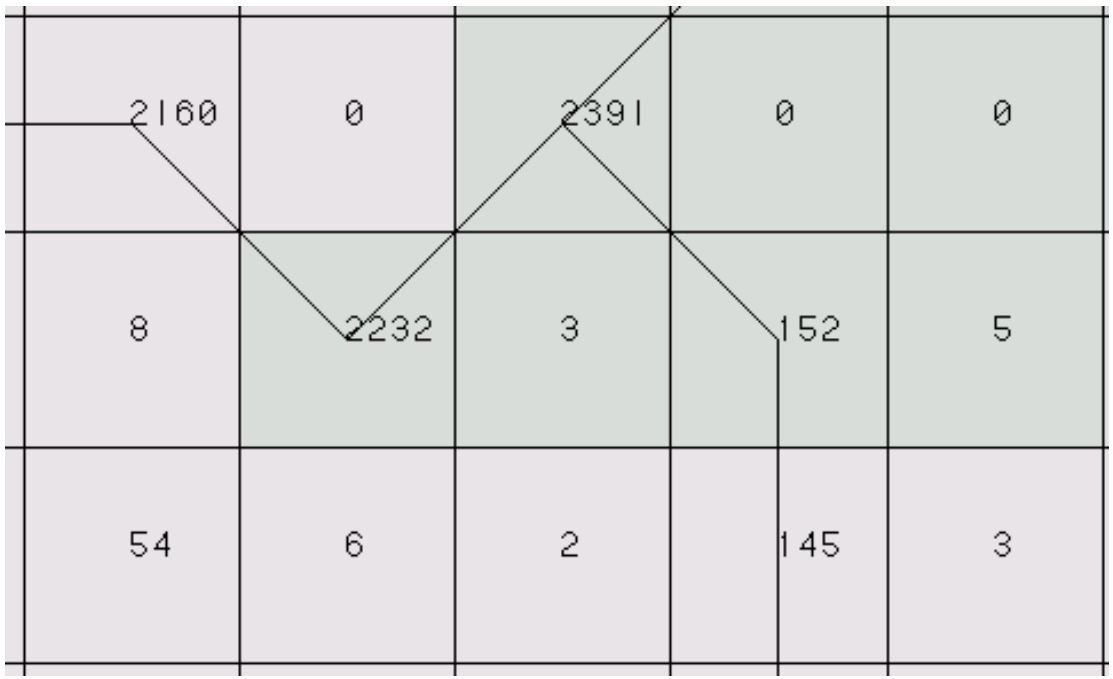
Calculate watershed in all points along river – time-consuming - instead

- Arc/Info standard hydrologic analyses
  - Flow direction – determine the direction of flow from every cell in the raster



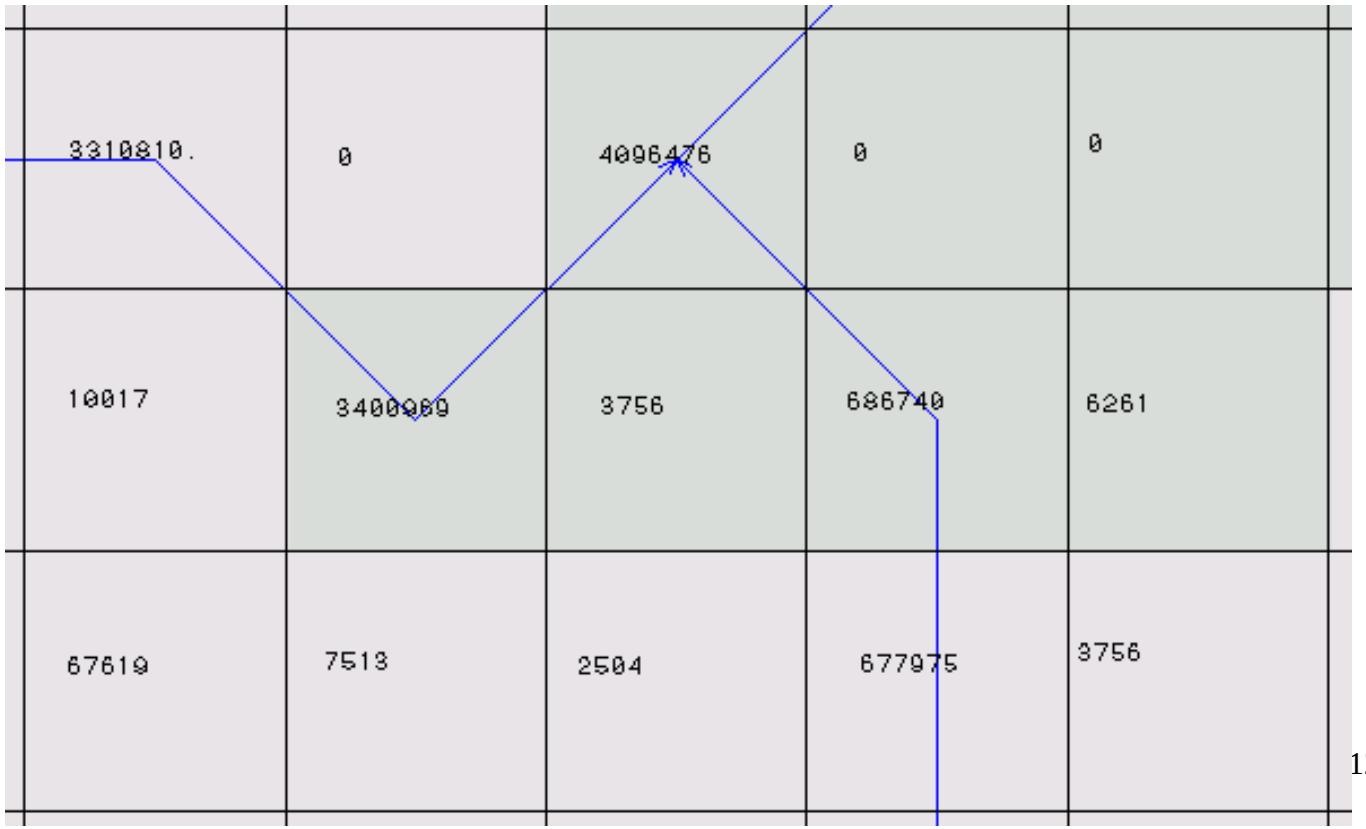
Derive runoff

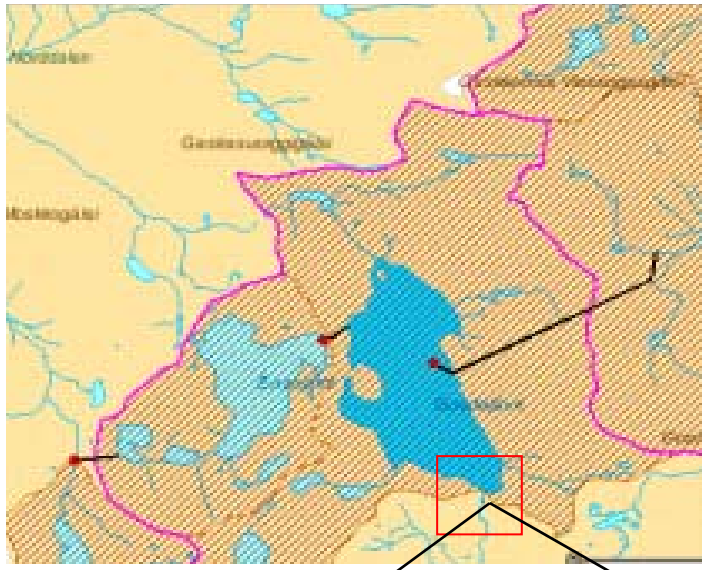
- Arc/Info standard hydrologic analysis
  - flow direction - determine the direction of flow
  - flow accumulation - calculates accumulated flow as the accumulated number of all cells flowing into each down slope cell in the output raster.



Derive runoff

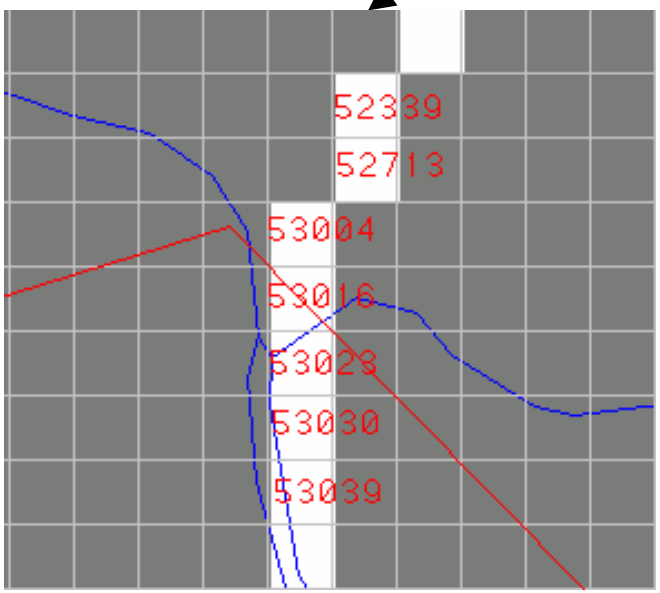
- Arc/Info standard hydrologic analysis
  - flow accumulation with runoff as a weight raster - accumulated weight of all cells flowing into each down slope cell in the output raster.

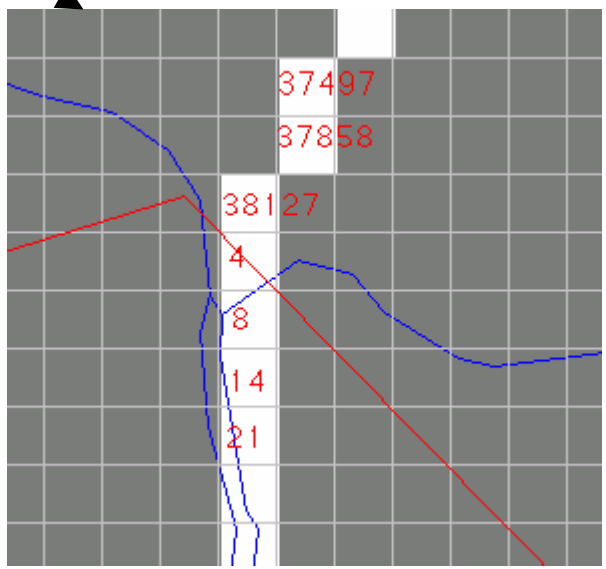




Change flowdir and flowacc for regulated rivers

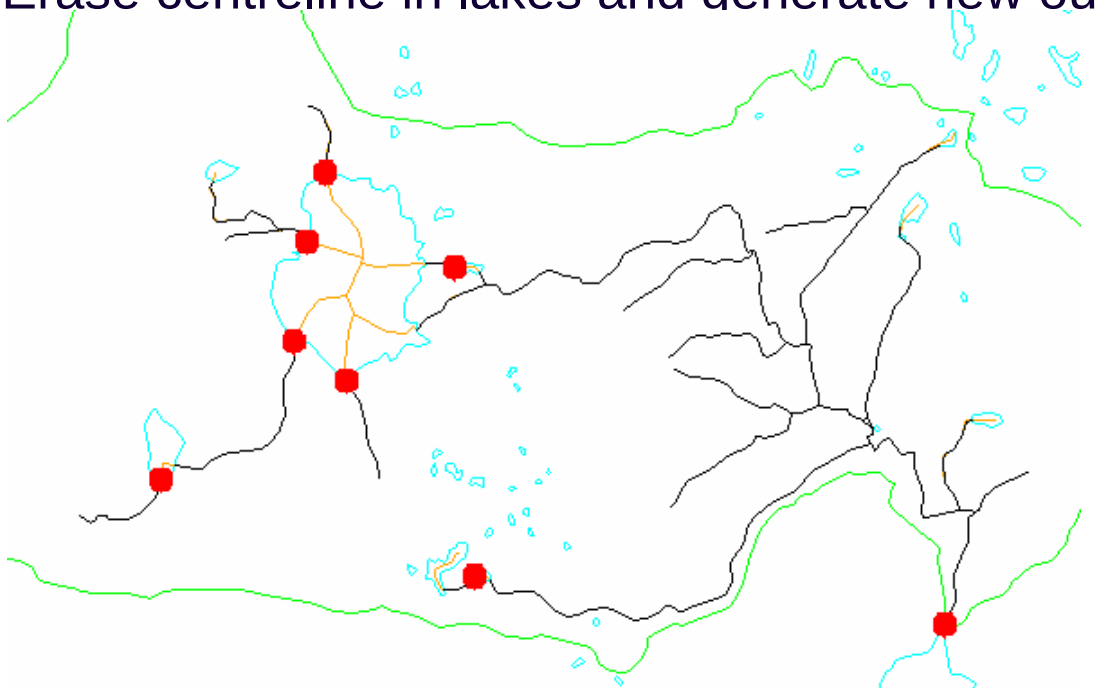
Use setmask when flowacc is generated





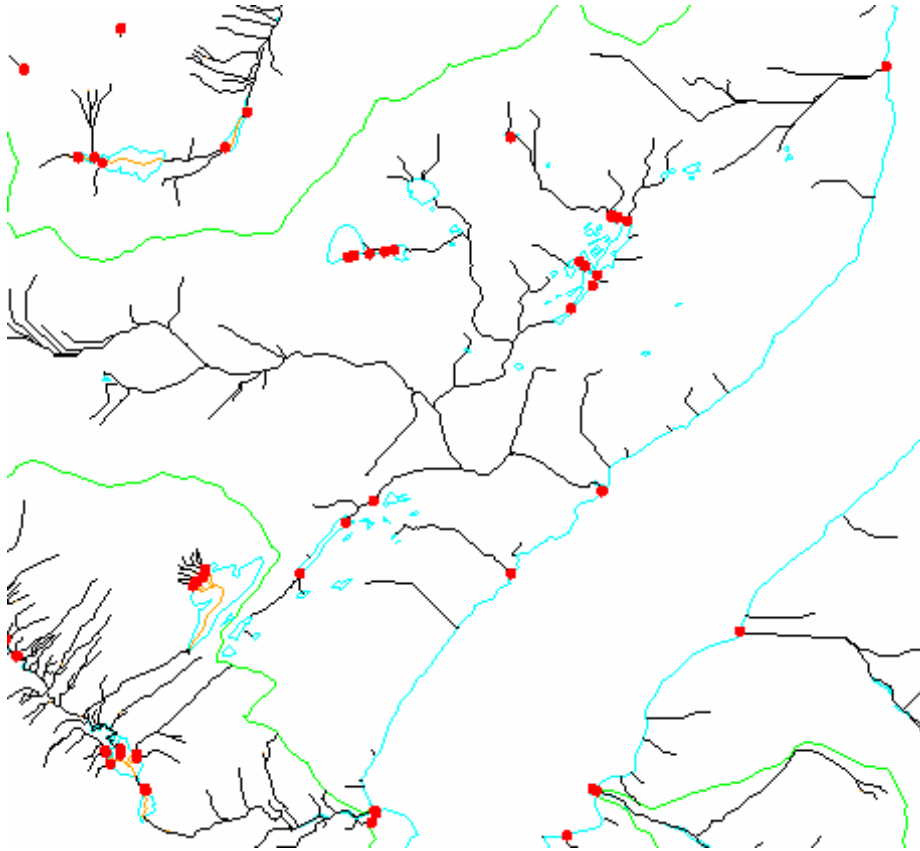
River network

- Centre line generated for all rivers defined in REGINE
  - Joined in nodes and given direction towards outlet – river network on cover
- Irrelevant with power plant where intake and power plant on each side of lake
  - Erase centreline in lakes and generate new outlet points



Rivers outside river network

- Generate automatic from DTEM
- 300 cells in flowdir to define a river comparable to 1:50.000
- Join both datasets
- New outlet points

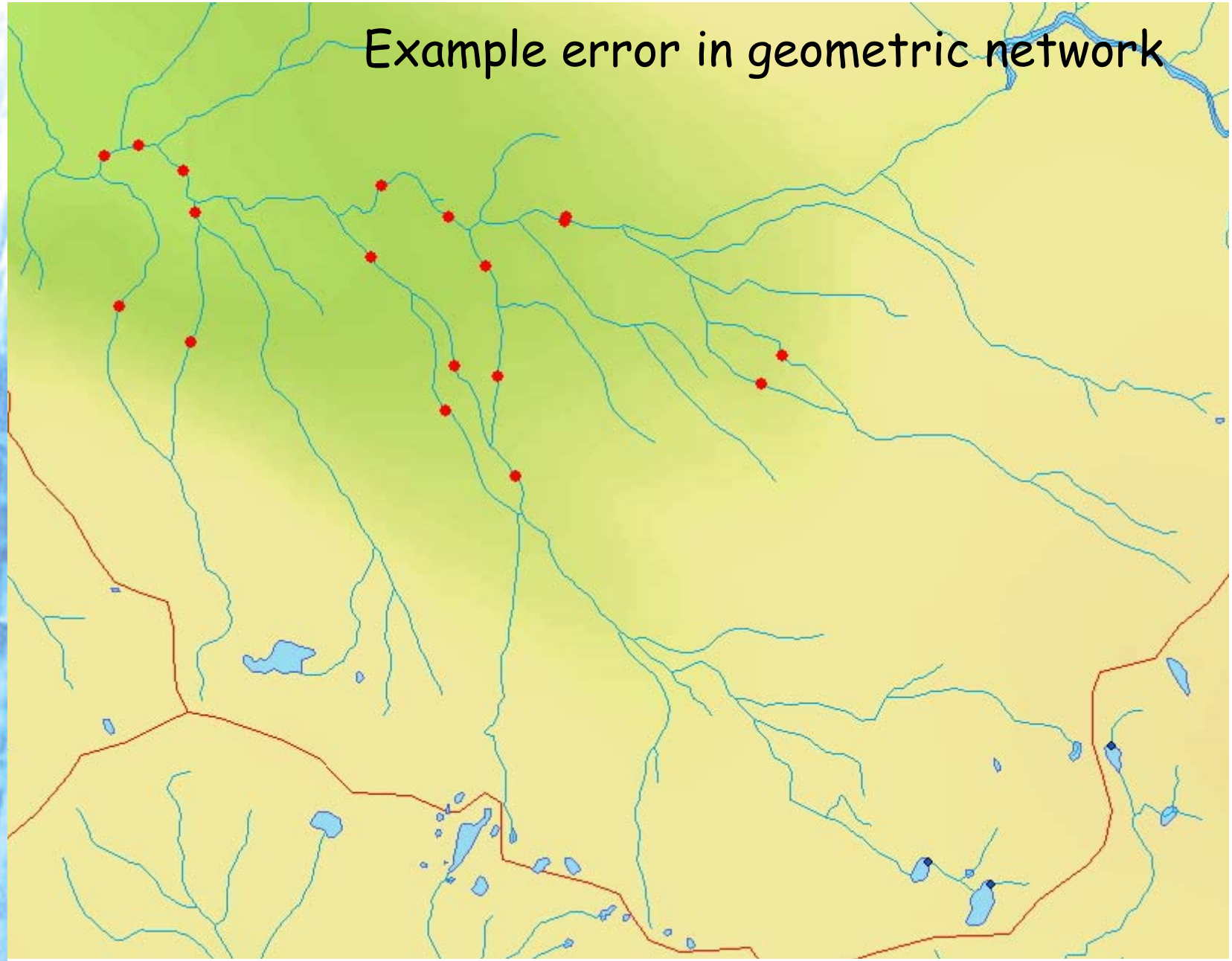


So fare analyse in Arc/Info workstation

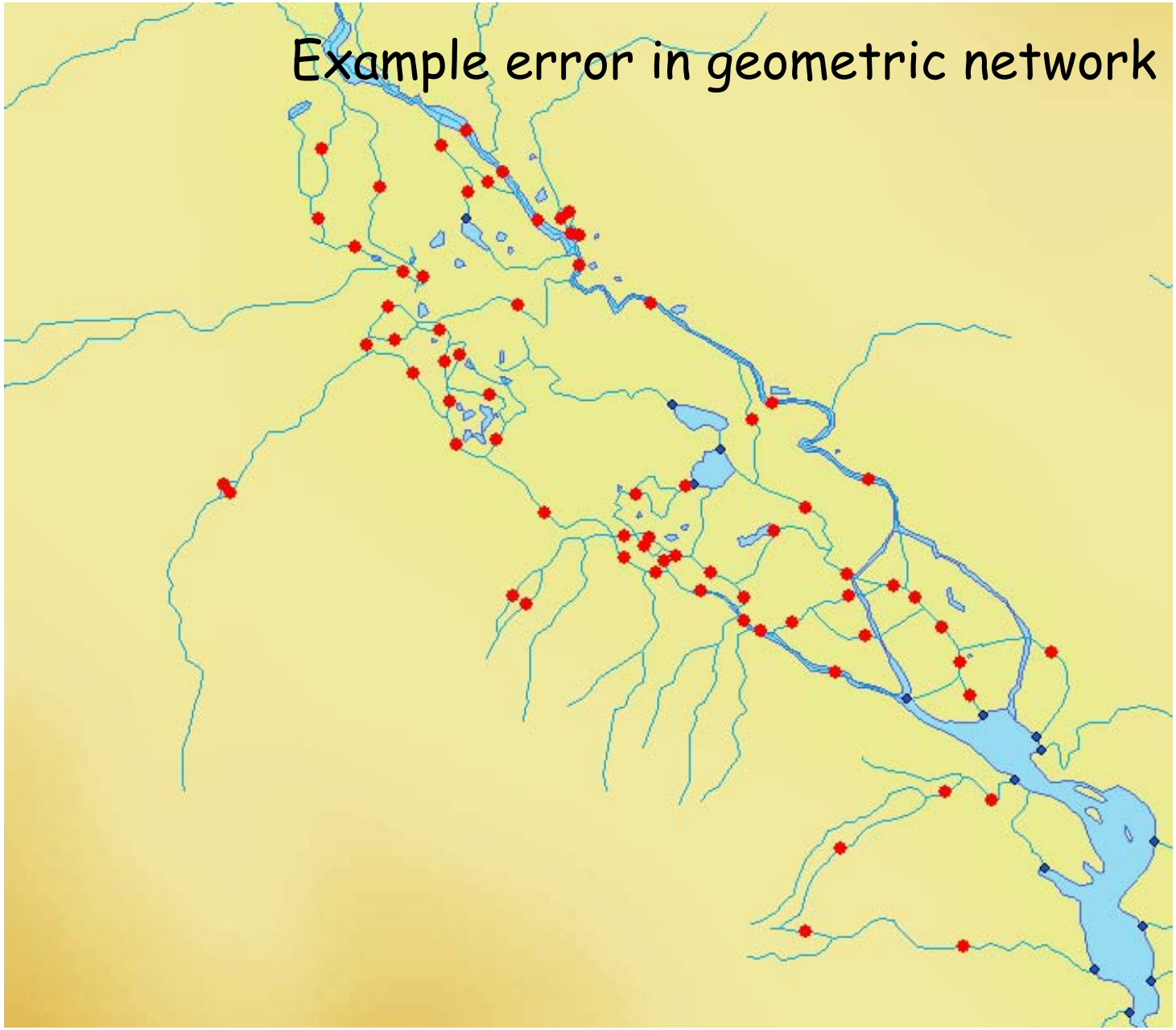
Prepare datasets in ArcGIS

- Convert centreline of river and outlet points to PGDB.
- Generate topology and correct errors.
- Convert river network and outlet points to 3D.
- Generate geometric network
- Find and correct network errors

Example error in geometric network



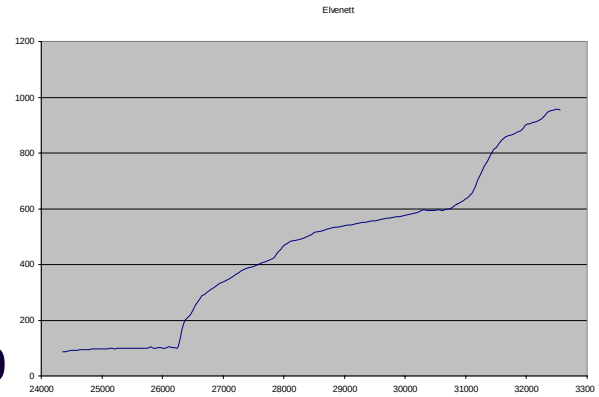
Example error in geometric network



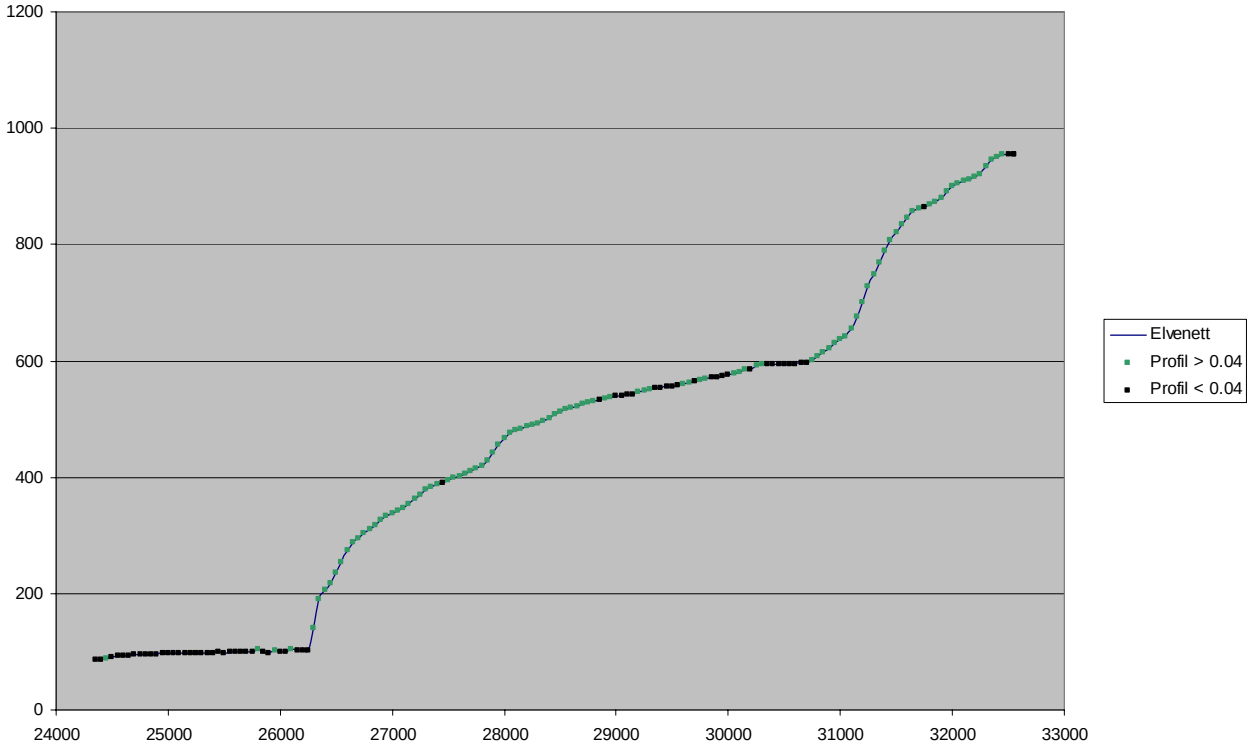
Steps in the analyse

- Identify downfall
  - Calculate longitude profile
  - Identify downfall with gradient > 1:25
  - Find top and bottom of each downfall
  - Calculate attribute to top of each downfall
- Identify small hydro power plants which are within the conditions
- Calculate cost for each plant

Calculate profile



- Use ”utility network analysis” to trace all rivers from outlet to top
  - Each trace – longitude profile stored temporary
  - Dived profile in 50 meter sections – define point for each section (represent at top)
    - Attributes: difference of height, dH/dL.

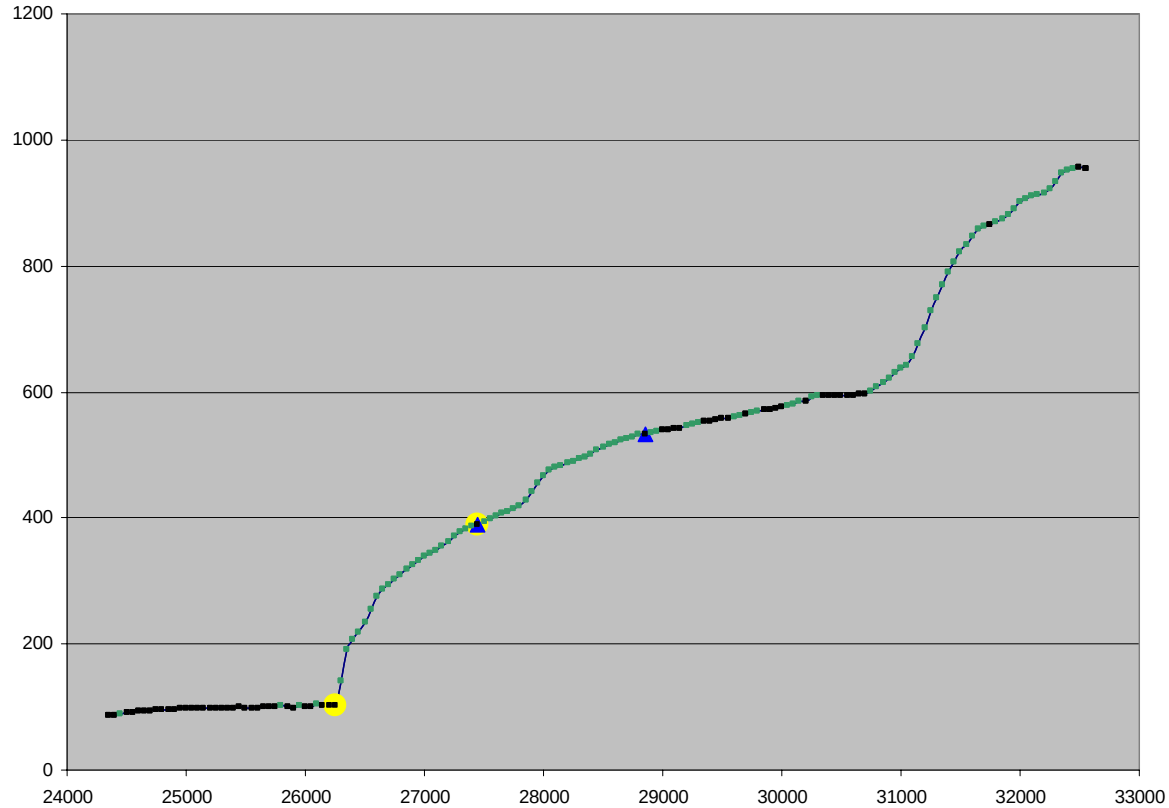


dH/dL for each 50 meter

< 0.04 - black vs. 1:25

> 0.04 - green

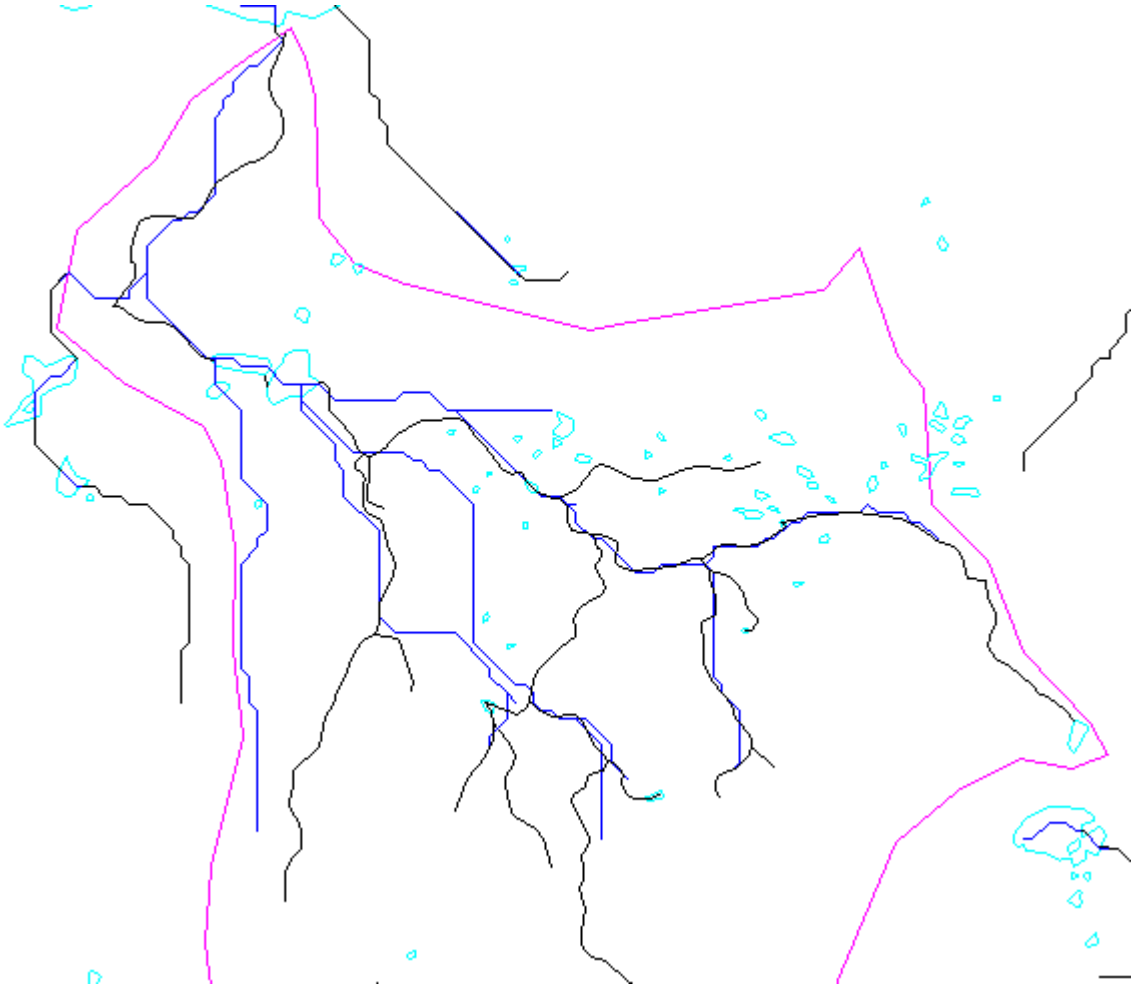
- Identify downfall
  - from outlet trace all profile points and start a downfall where dH/dL > 0.04 and end where dH/dL gets < 0.04.



Blue triangle → intake

Yellow circle → power plant

- Calculate parameters at top of each downfall
  - Drainage area (flowacc)
  - Runoff (flowacc weighted with runoff grid)
  - Total difference of height
  - NB! - flowacc is calculated from the DTEM, that means that basis is the generated river



Blue river - generate from DTEM

Red boundary – REGINE's watersheds

Conditions

- All rivers with downfall down to 1:25
- Relevant elevation limits (H) is 10 m - 600 m.
- Runoff 0.05 m^3/s – 25 m^3/s
- The turbine's maximum useable flow - (Q) = 1,5 x Q_{av} (average runoff).
- Installed power - N = 8,0 x Q x H
- Installed power limits - 50 kW-10000 kW.
- Production - 70 % of water can be used
- Production = 8,0 x (Volume pr year) x 0,7 x H x / 3600

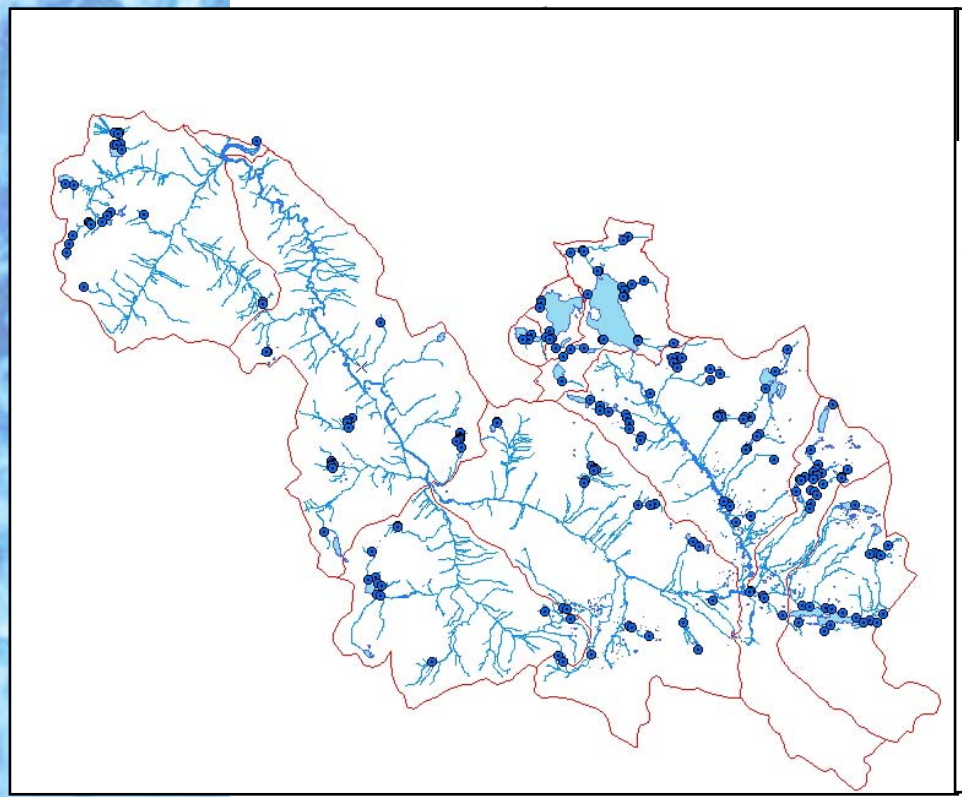
Erase plants outside defined limitations

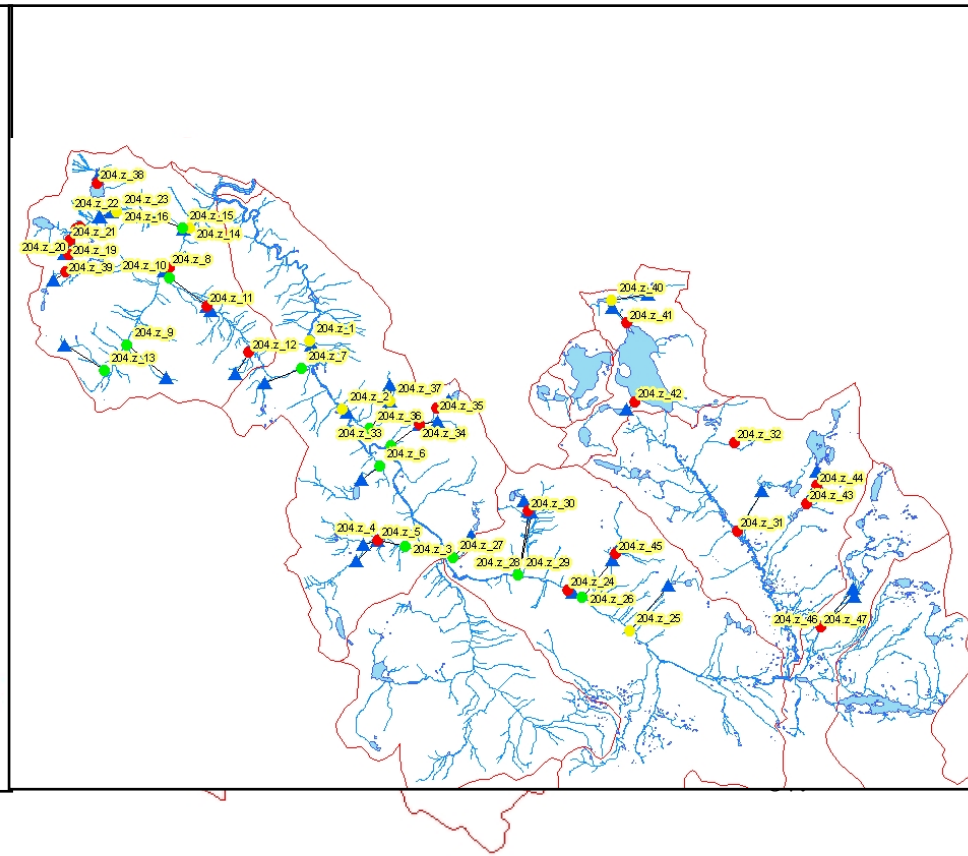
Cost accounting

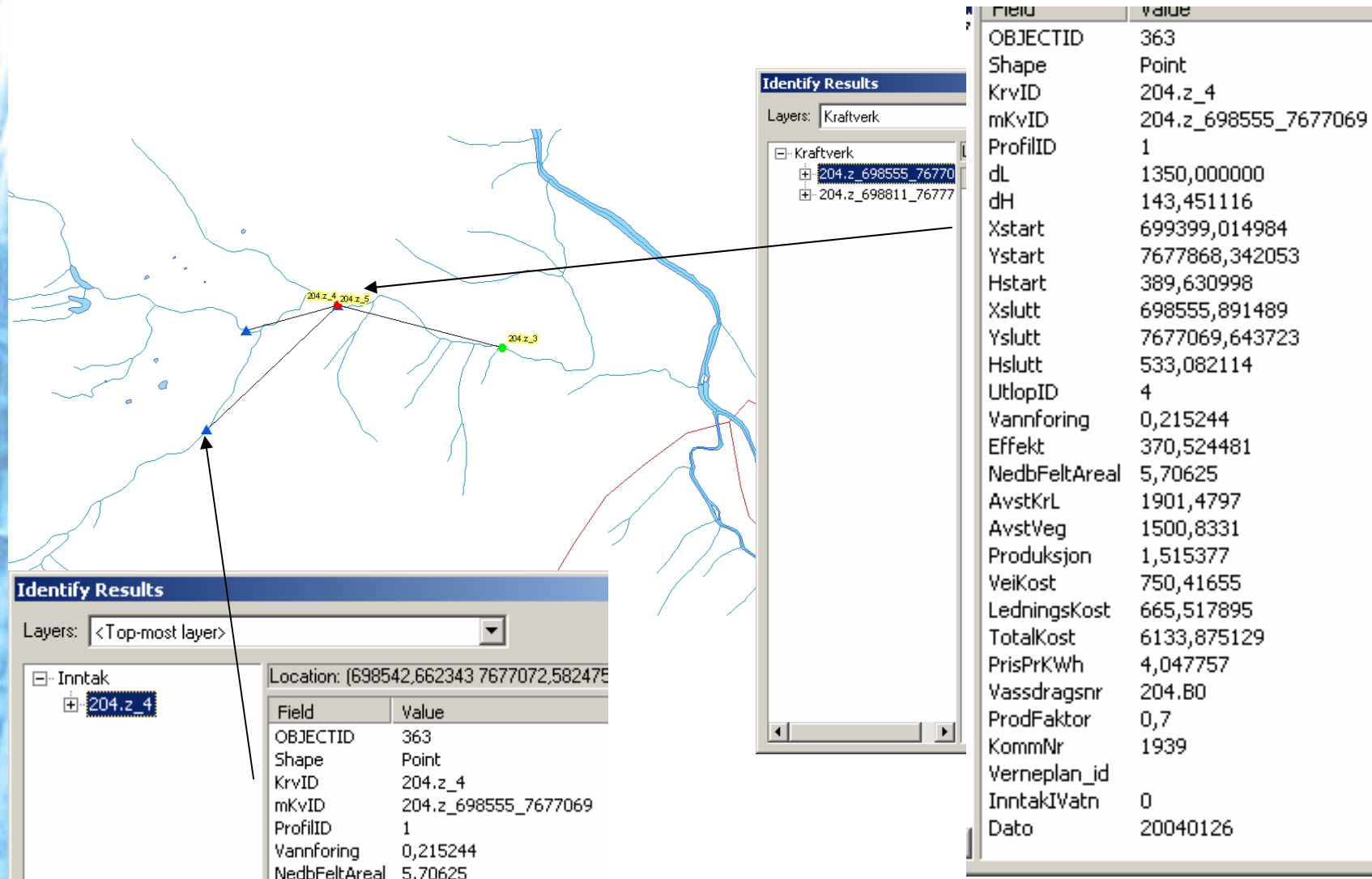
- Formula developed for small hydro plants
- Calculated based on
  - Elevation
  - Length of pipeline
  - Maximum useable flow
  - Distance to roads and transmission lines
  - Power

Results

Calculate for each drainage basin



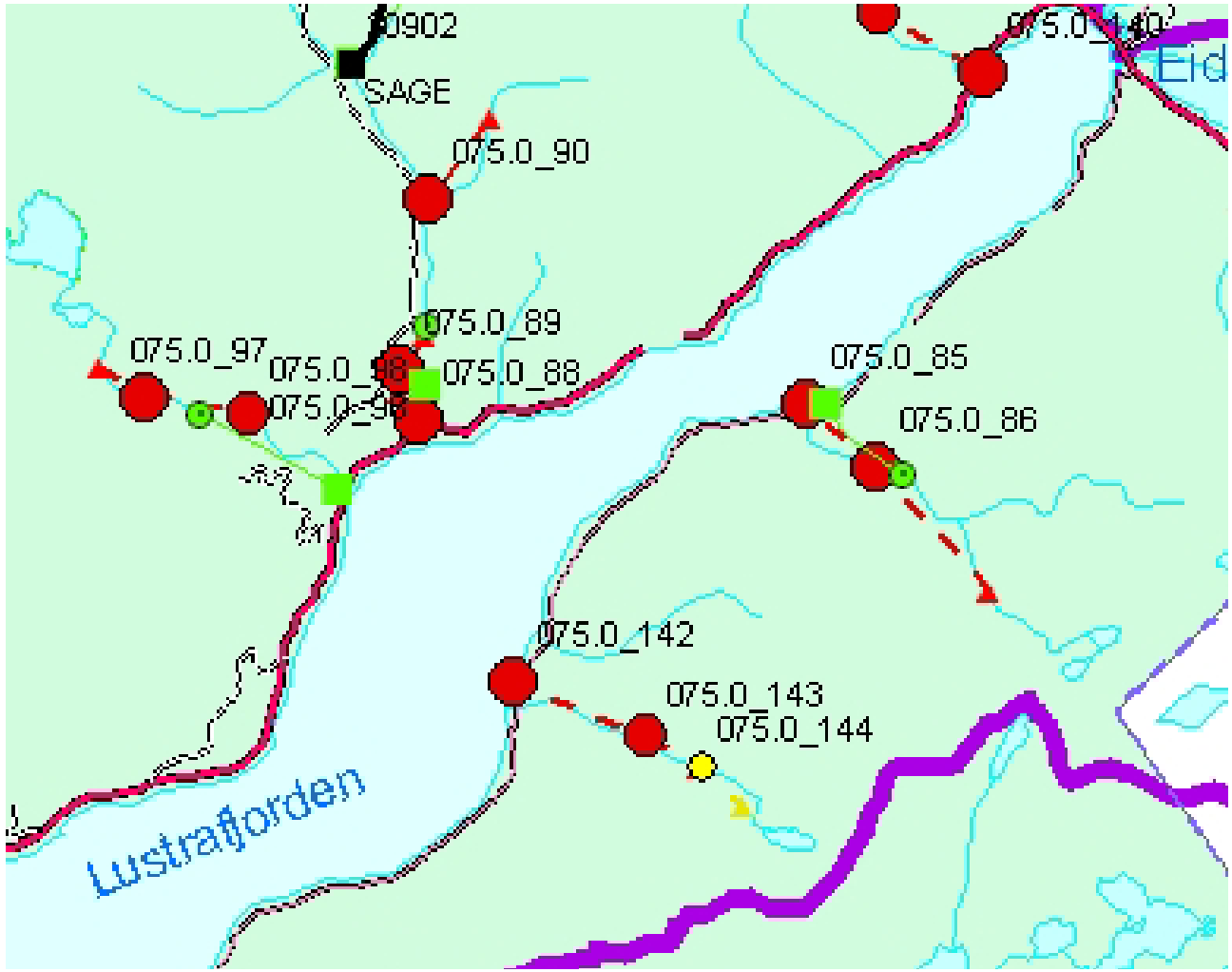



Identify Results
Layers: Kraftverk
Kraftverk
204.z_698555_76770
204.z_698811_76777
Field
Value
OBJECTID 363
Shape Point
KrvID 204.z_4
mKvID 204.z_698555_7677069
ProfilID 1
dL 1350,000000
dH 143,451116
Xstart 699399,014984
Ystart 7677868,342053
Hstart 389,630998
Xslutt 698555,891489
Yslutt 7677069,643723
Hslutt 533,082114
UtlopID 4
Vannforing 0,215244
Effekt 370,524481
NedbFeltAreal 5,70625
AvstKrL 1901,4797
AvstVeg 1500,8331
Produksjon 1,515377
VeiKost 750,41655
LedningsKost 665,517895
TotalKost 6133,875129
PrisPrKWh 4,047757
Vassdragsnr 204.B0
ProdFaktor 0,7
KommNr 1939
Verneplan_id
InntakIVatn 0
Dato 20040126
204.z_4
204.z_5
204.z_3
Identify Results
Layers: <Top-most layer>
Inntak
204.z_4
Location: (698542,662343 7677072,582475
Field
Value
OBJECTID 363
Shape Point
KrvID 204.z_4
mKvID 204.z_698555_7677069
ProfilID 1
Vannforing 0,215244
NedbFeltAreal 5,70625
ProdFaktor 0,7
InntakIVatn 0

Method of production

- Calculate for each drainage basin
  - Divide depending of size
- Append in a seamless PGDB
  - Use ”load data”
- Quality control in ArcView
  - Manuel check
  - The results from the automatic method pass a manual quality control before acceptance and the method and its results are approved by experts.

Outcome


0902
SAGE
075.0_90
075.0_89
075.0_97
075.0_88
075.0_85
075.0_86
075.0_142
075.0_143
075.0_144
Lustrafjorden

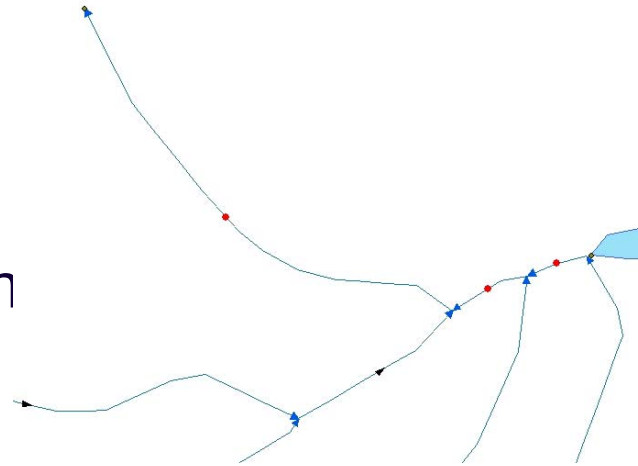
Comments

- Location are accurate, but does not give a correct location for planning new power
- **Gives the theoretical potential for small hydro power plants.**
- Is **NOT** a map showing where new power plant are going to be build
- An development will take other factors into account and will nearly always end in a different location of both intake and plant.

Experience

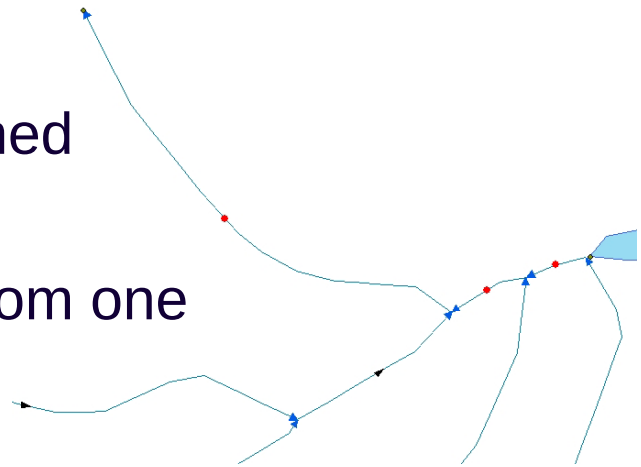
Correct river network essential

- Important that all river reaches hav direction towards outlet
- Parallel river reaches – Some OK other not OK
- Topology in network before buildin geometric network – ensure no topologic errors
  - No double lines
  - no intersections
  - Outlet snapped to river



Geometric river network

- Most frequent errors
  - Wrong direction
  - Rivers are connected at watershed divide
  - More than one outlet in a lake from one river



A problem arise in the future calculations if the data is not correct

Further work

- Quality control by surveying some regions by foot
- Better data with transmission lines
- Develop an interactive method for calculate parameters depending of set location of intake and power plant.

Weakness

- DTEM
- Transmission lines
- Horizontal distance to rivers and lines
- Should have set limits on steep river slopes (maximum)

Automatic method

- ArcMap document with relative paths and set structure of catalog's
  - Easy to calculate a new area
- Programmed in VBA and stored in the mxd-file.
- The Program can run in steps or total automatic.

Parameters


Beregning av potensiale for mikrokraft...
Vassdragsnr
204.z
DeltaLengde
50
Slukeevne
1.5
Min dH/dL
0.04
MinVannføring
0.05
MaksVannføring
25
Minimumseffekt
50
Maksimumseffekt
5000
Min. fallhøyde
10
Maks. fallhøyde
600
Effektfaktor
8
Varighetsfaktor
0.7
Antall valgte utløpspunkter: 197
Beregn profil
Beregn fall
HydroBeregning
TotalBeregning
Avbryt

Challenges in the programming

- Efficiency
- Sturdy program
- Advanced use of ArcObjects
- Integration with MS Office

Challenges in the programming

- Efficiency
  - One analyse can run for more than one 24-hour period
  - No calculations are done more than once. Data are temporary saved in memory
  - Use small analyse area when running some of the raster calculations. (3x3 cells)

Challenges in the programming

- Sturdy program
- Stops because of unknown reasons
  - The Program can continue whiteout losing already calculated data

Challenges in the programming

- Advanced use of ArcObjects
  - Spatial analyst
    - Upstream area
    - Runoff in point of intake
    - Distance to transmission lines/roads
  - Utility network analyst
    - Make profiles along all rivers from outlet all the way to the source of each tributary

Challenges in the programming

- Integration with MS Office
  - Use cost accounting formula in excel
  - Store the result report in excel

Inndata fra GIS		
Brutto fallhøyde	255.100826	m
Lengde rørgate	2 003	m
Slukevne	0.49	m3/s
Lengde veg	10408.6504	m
Lengde linje	12124.4844	m
Effekt	1004	kW
Konstanter i konstnadsfunksjoner		
Vannhastighet	3.0	m/s
Rente	8 %	
Byggetid	8	mnd
Kostnader	Tusen kr	
Totalkostnad	20979	
herav:		
Linje	4 244	
Veg	5204.3252	

Potensial for Mikrokraftverk

KrvID	Fallhøyde	NedbFeltAre	Vannføring	Effekt	Produksjon	AvstKrL	AvstVeg	Totalkost	Linjekost	Vegkost	PrisPrkWh
204.z_1	11.1	103.86	3.191	423	1.7	293	230	7266.2	102.4	115.2	4.20
204.z_2	11.3	90.07	2.807	380	1.6	190	90	7009.6	66.6	45.1	4.52
204.z_3	287.1	11.21	0.393	1354	5.5	1107	584	9870.3	387.5	291.8	1.78
204.z_4	143.5	5.71	0.215	371	1.5	1901	1501	6133.9	665.5	750.4	4.05
204.z_5	97.3	3.92	0.140	163	0.7	1901	1501	4330.8	665.5	750.4	6.48
204.z_6	434.3	4.97	0.150	783	3.2	425	79	6595.3	148.8	39.5	2.06
204.z_7	406.3	2.99	0.113	552	2.3	474	25	4620.2	166.0	12.5	2.05
204.z_8	14.3	24.91	0.841	144	0.6	0	112	3452.1	0.0	55.9	5.85
204.z_9	601.7	1.15	0.082	595	2.4	195	0	5015.9	68.3	0.0	2.06
204.z_10	305.2	9.86	0.420	1538	6.3	230	50	11306.5	80.7	25.0	1.80
204.z_11	13.4	9.14	0.393	63	0.3	2085	1145	2891.3	729.8	572.5	11.15
204.z_12	93.7	1.21	0.071	79	0.3	2524	1981	4404.5	883.5	990.6	13.58