Determining upstream/downstream spatial distribution among point sources: Comparison of GIS-based methods

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RESOURCES FOR THE FUTURE

RFF project focuses on environmental risks from shale gas development

- Concerns about shale gas extraction on environment, especially water quality (Olmstead et al., 2013)

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Potential water quality issue #1: Clearing of land, construction of well pads

- Land clearing, well construction have potential implications for stormwater runoff, erosion, etc., which may impact surface water quality.

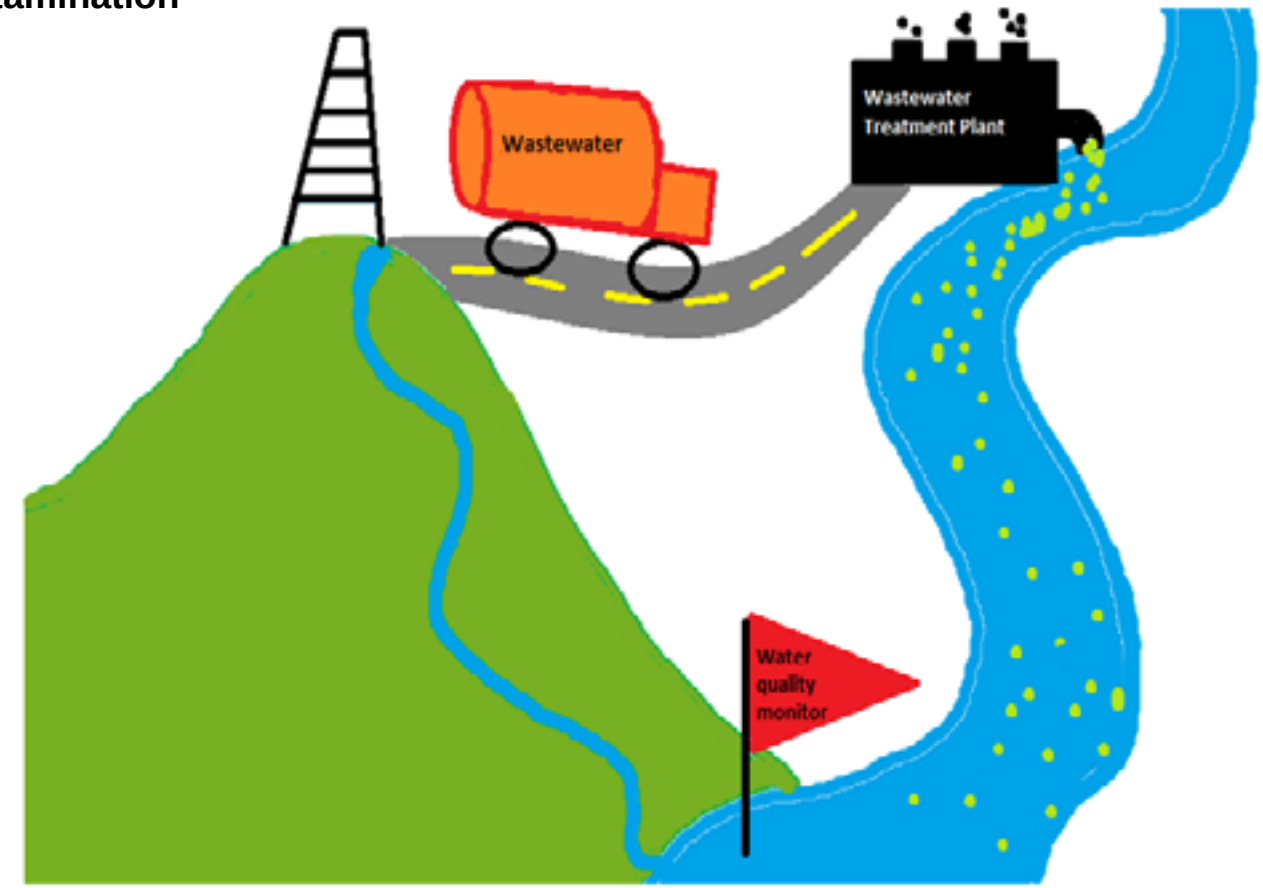
Potential water quality issue #2: Treatment and disposal of shale gas waste

Pittsburgh Post-Gazette

What can be done with wastewater?

Rapid expansion of gas drilling has led to problems with disposal, contamination

Oct. 4, 2009



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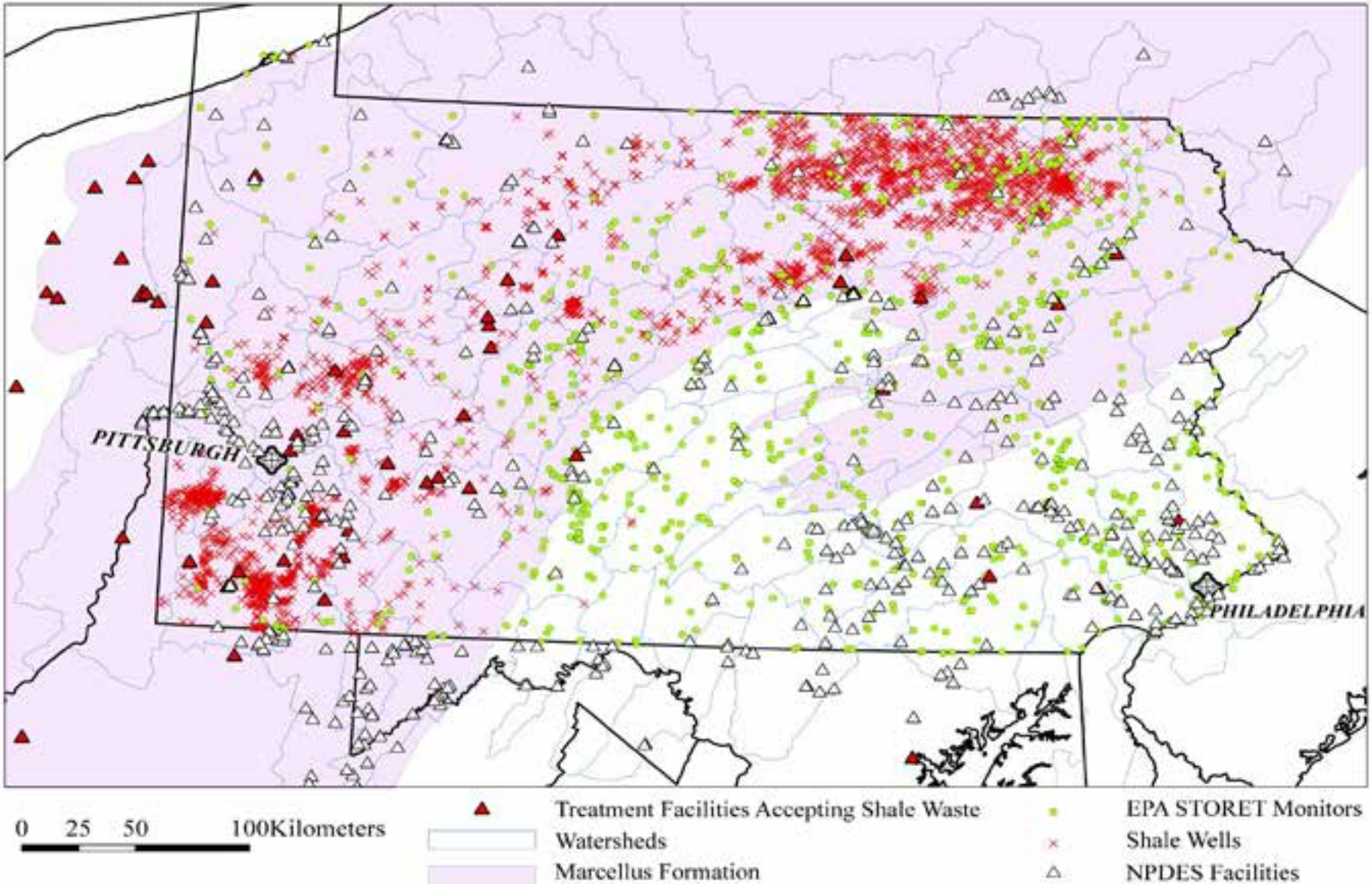
Building a GIS database of water quality monitors, shale gas wells, and waste treatment facilities in PA



Pollution: Upstream to Downstream

- We used Ten GIS-based methods to identify the upstream-downstream relationships and then test several hypotheses related to shale gas development and water quality

- Importance of identification of the linkage between upstream point source pollution and downstream receivers

  - Upstream: shale gas well pads
  - Upstream: shale gas waste disposal facilities and permitted treatment plants
  - Downstream: water quality monitors

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Comparison of different GIS-based methods

Method 1 and Method 2	Method 3 and Method 4	Method 5	Method 6 and Method 7	Method 8 and Method 9	Method 10
Flow (Bottom up, 1km buffer)	Flow (Top down, 1km buffer)	Spatial selection (contributing watershed)	Comparison of flow length in watershed	Comparison of elevation in watershed	USGS Enhanced River Reach File stream linkage as a control group
Flow (Bottom up, 5 km buffer)	Flow (Top down, 5 km buffer)		Comparison of flow length in sub-watershed defined by 8 digits HUC	Comparison of elevation in sub-watershed defined by 8 digits HUC	

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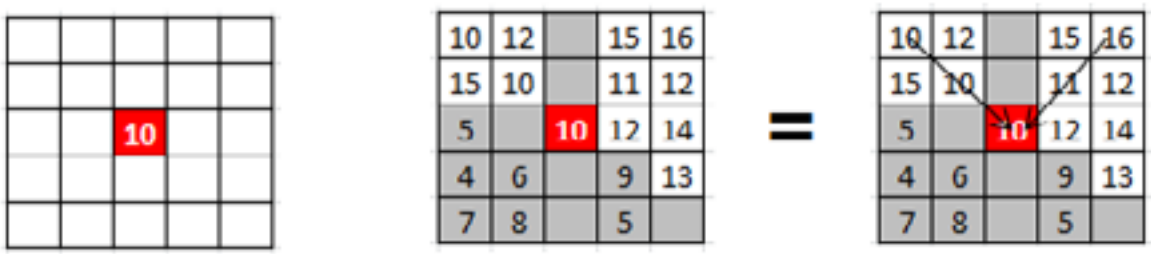
Method 1-2: Bottom – Up: Cost distance tool (1 kilometer & 5 kilometers buffer)

For each downstream water quality monitor

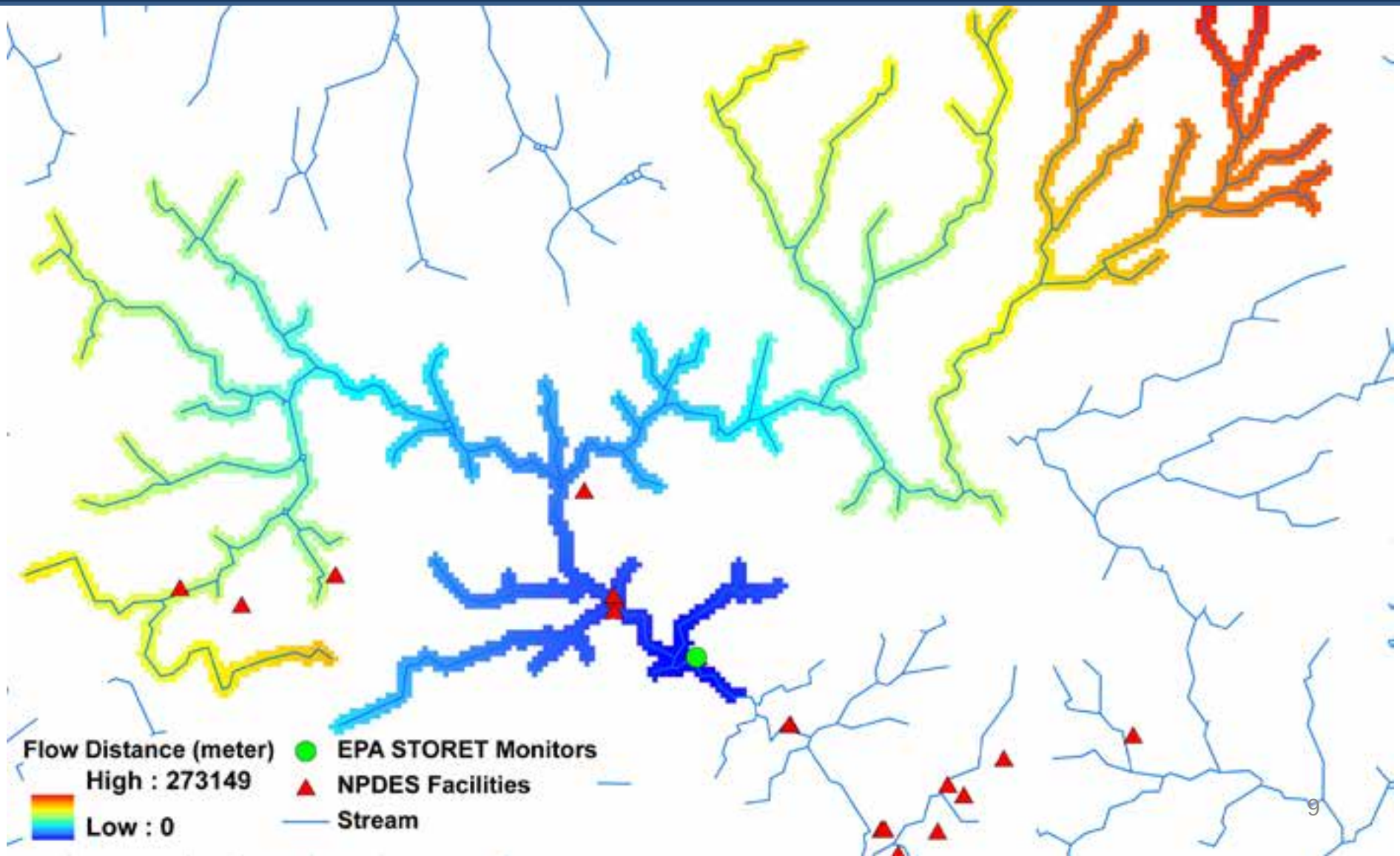
- Keep all upstream river areas
  - Ø Higher elevation than that specific downstream point
  - Ø Within a certain wide buffer from the stream lines

- Run Cost Distance tool for each downstream point: calculate the least accumulative cost distance over a cost surface
  - Ø Cost surface: Elevation (always choose the lowest neighbor to flow)
  - Ø Accumulative cost distance: how many cells it has to flow through



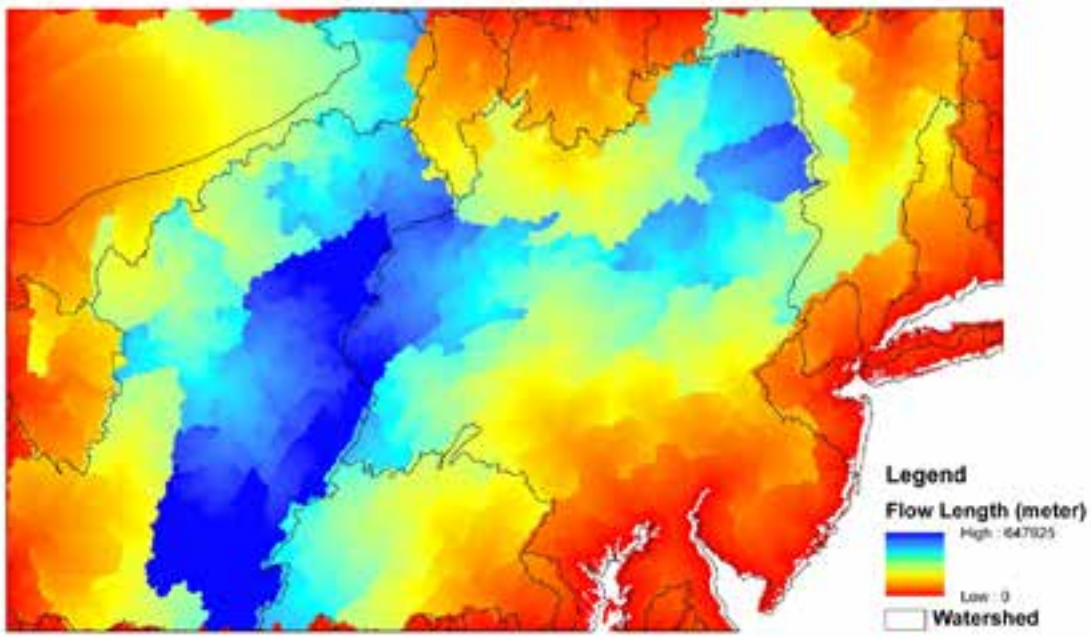
Water Quality Monitor Elevation Surface Accumulative Distance

Method 1-2: Bottom – Up: Cost distance tool (1 kilometer & 5 kilometers buffer)



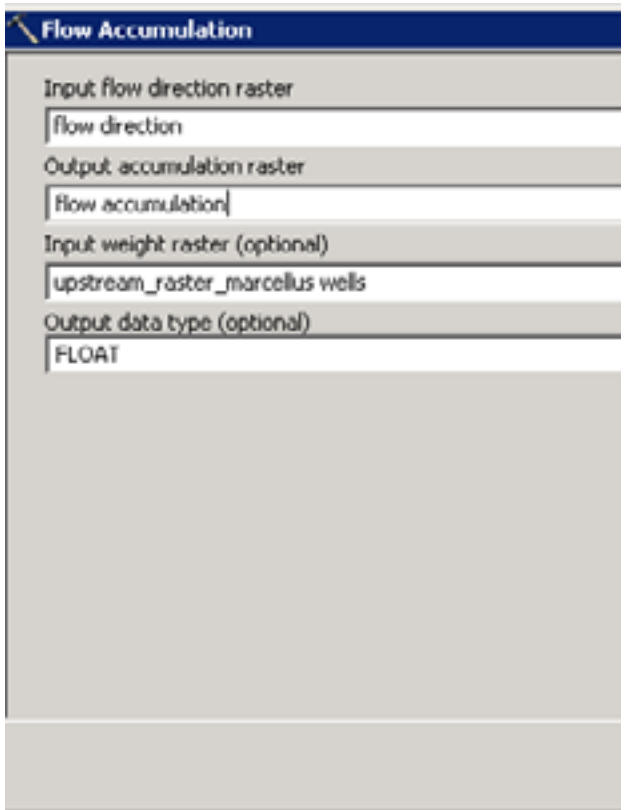
Method 3-4: Top-Down : Flow Length Tool (1 kilometer & 5 kilometers buffer)

- Flow Length: Calculates downstream distance along the flow path for each cell.
  - Ø Flow direction raster: created using elevation raster
  - Ø Direction: Downstream

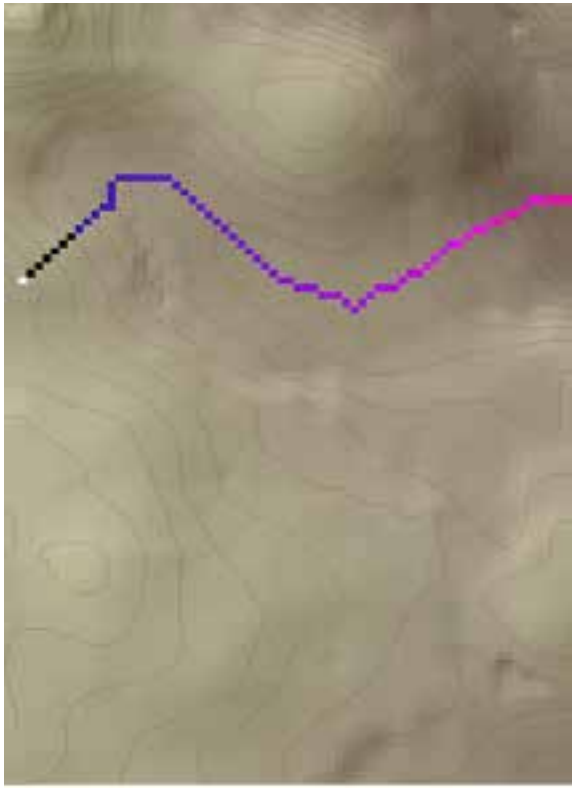


Method 3-4: Top-Down : Flow Length Tool (1 kilometer & 5 kilometers buffer)

- Flow Accumulation with upstream pollution point as in_weight_raster: get the flow line from that specific point
- Flow accumulation * Flow length = the flow length from that specific point



× Flow length raster →



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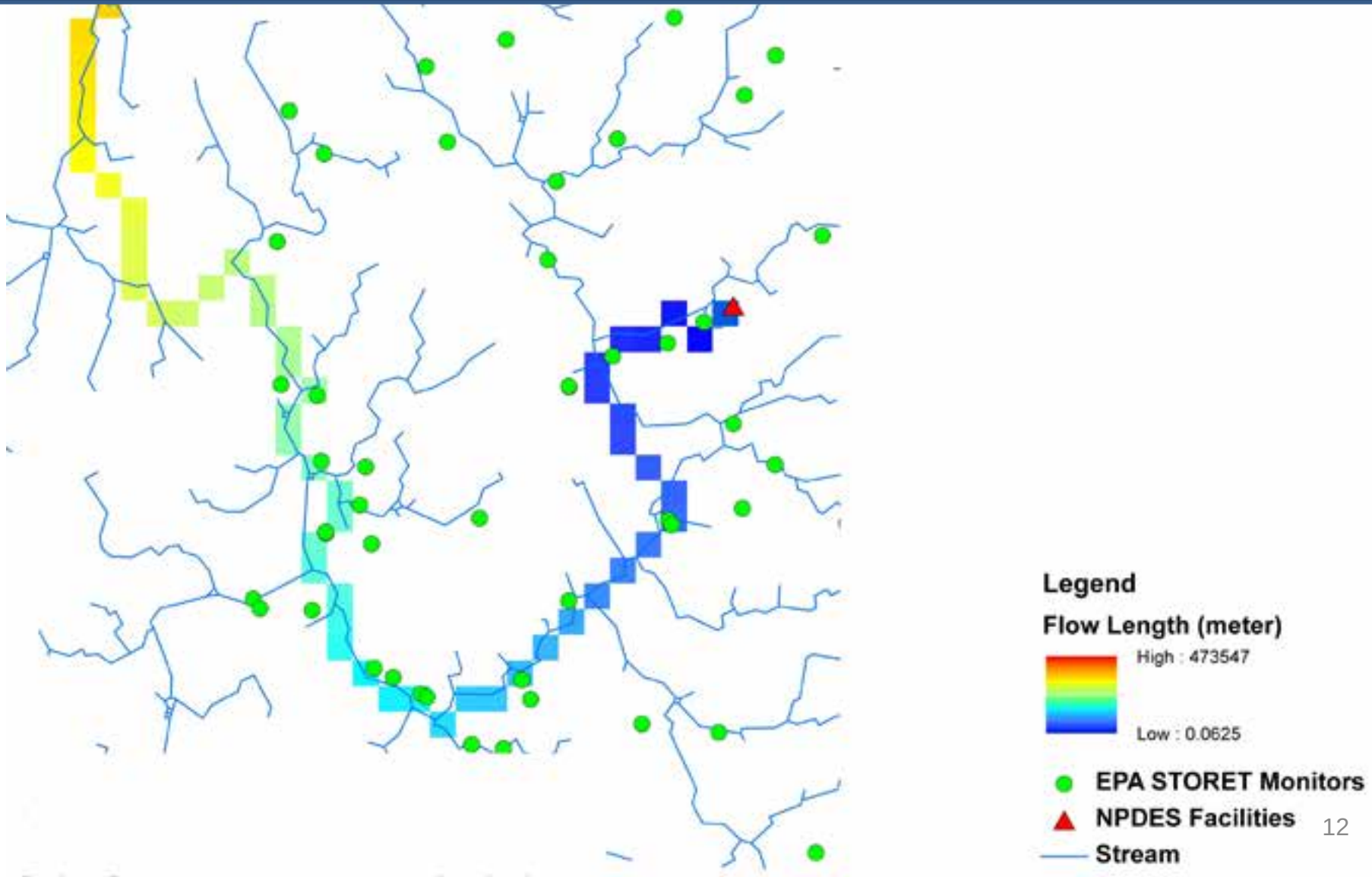
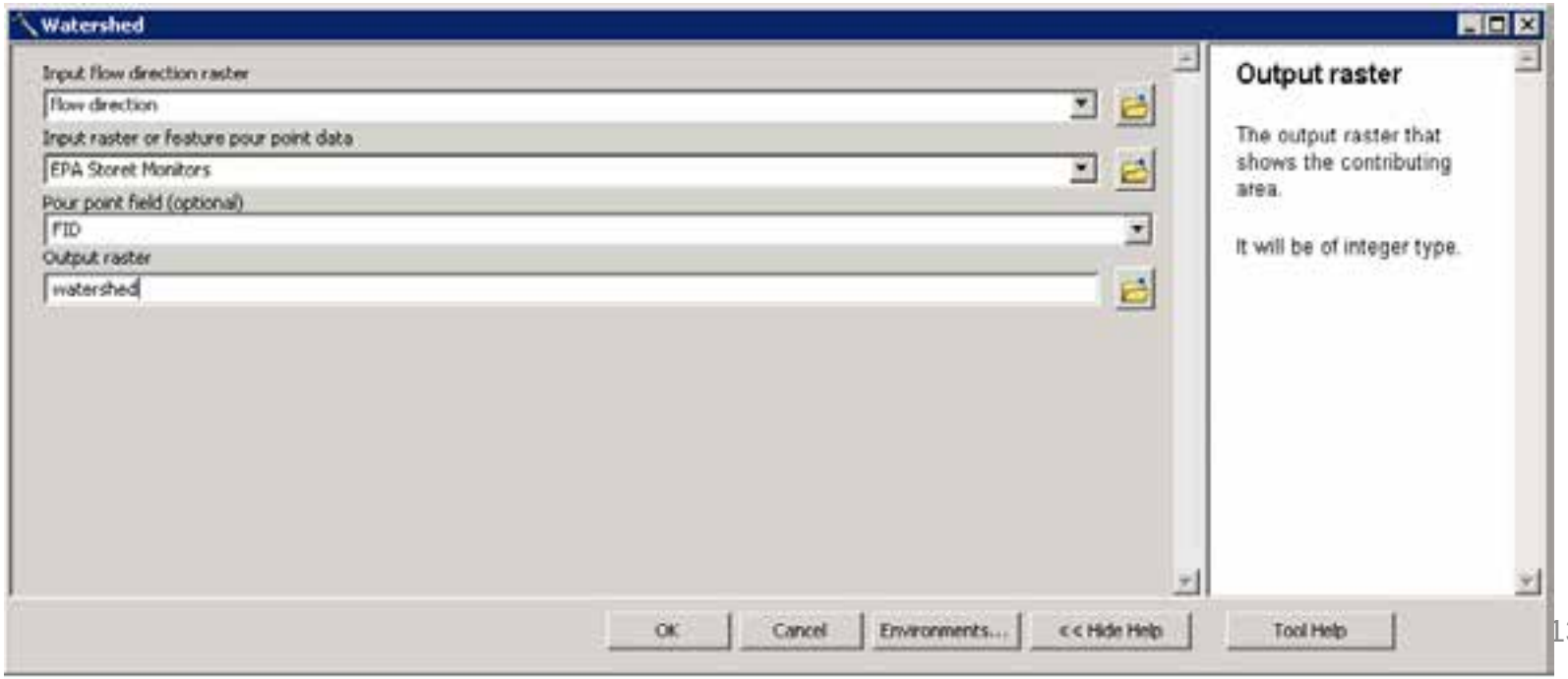


Method 5: Watershed Delineation

- Hydrology -> Watershed: determine the contributing area above each EPA STORET water quality monitor

- Identify which upstream polluting points within each watershed



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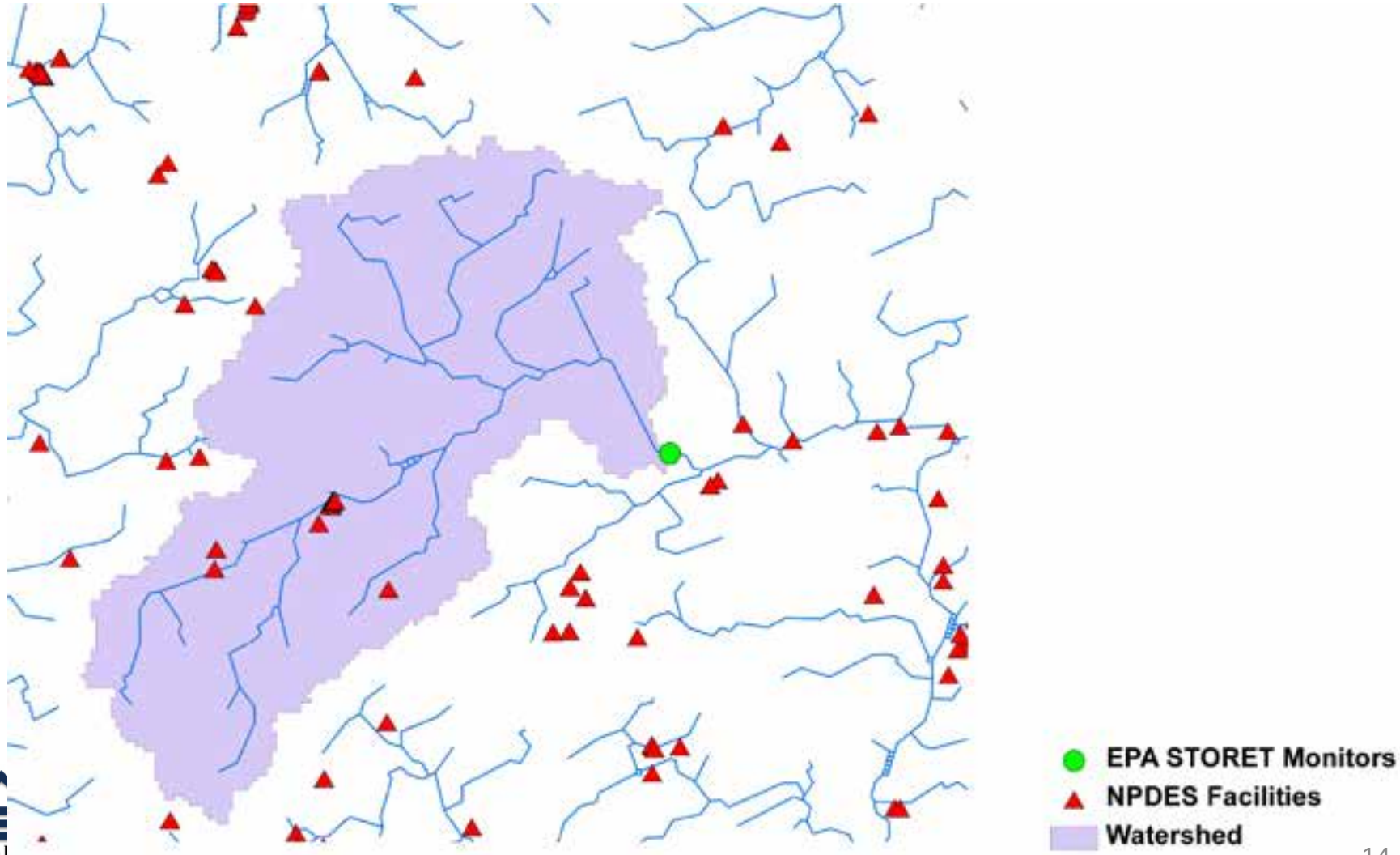

Method 6 - 9: Compare Flow Length and Elevation within Watershed and Sub-watershed

- 61 Watersheds defined by USGS Enhanced River Reach File
- 119 Sub-watersheds defined by 8-digits Hydrological Unit Codes (HUC)
- Compare the flow length and elevation between each upstream-downstream pair within watersheds and sub-watersheds

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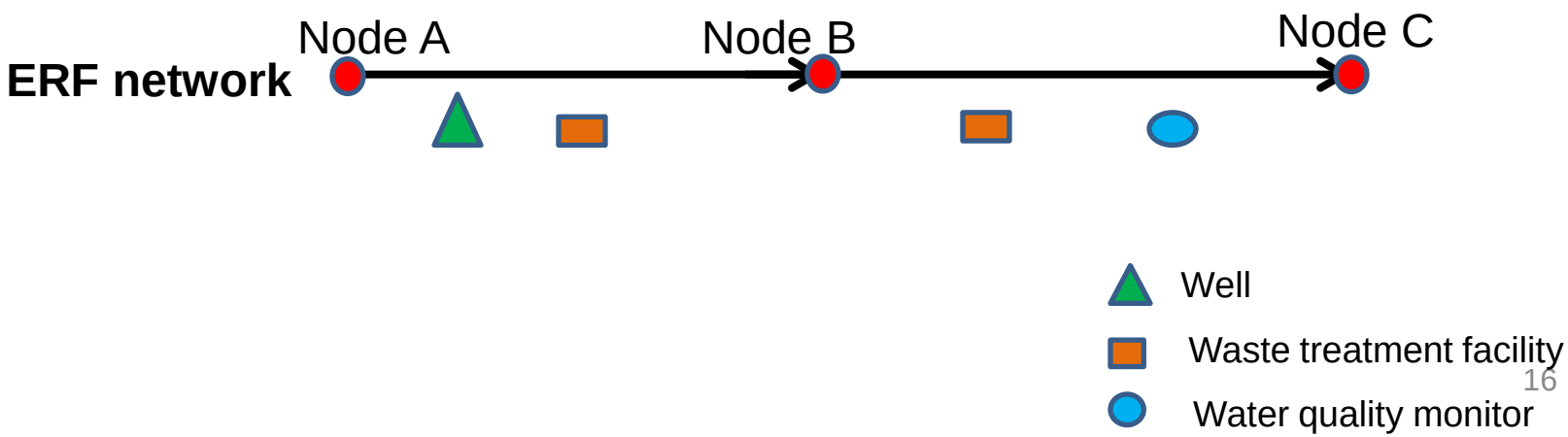
Control Group M10: USGS ERF stream network

- Used Stata to identify the linkage between each stream segment (from node -> to node)
- ArcGIS -> Near Tool to assign each point (i.e. upstream wells, waste treatment facilities, downstream water quality monitors) to a specific stream segment



Results: Comparison by different scenarios

	Monitor Elevation <=300m				Monitor Elevation > 300m		
	Success percentage (%)	Type I Error (%)	Type II Error (%)		Success percentage (%)	Type I Error (%)	Type II Error (%)
M1 vs M10	91.11%	0.22%	8.67%		93.40%	0.04%	6.56%
M2 vs M10	85.76%	13.86%	0.38%		88.95%	6.71%	4.34%
M3 vs M10	90.99%	0.38%	8.63%		93.36%	0.06%	6.57%
M4 vs M10	89.16%	4.74%	6.10%		92.64%	2.98%	4.39%
M5 vs M10	91.24%	0.05%	8.71%		93.38%	0.04%	6.58%
M6 vs M10	18.81%	78.00%	3.19%		42.06%	55.34%	2.60%
M7 vs M10	90.53%	1.30%	8.17%		89.77%	5.21%	5.02%
M8 vs M10	11.41%	88.41%	0.18%		31.80%	66.05%	2.15%
M9 vs M10	90.27%	1.77%	7.96%		92.46%	2.56%	4.97%

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Results: Comparison by different scenarios

	Monitor Distance to Stream <= 400m				Monitor Distance to Stream > 400m		
	Success percentage (%)	Type I Error (%)	Type II Error (%)		Success percentage (%)	Type I Error (%)	Type II Error (%)
M1 vs M10	93.45%	0.18%	6.37%		90.44%	0.10%	9.45%
M2 vs M10	83.71%	13.27%	3.02%		86.55%	8.27%	5.18%
M3 vs M10	93.32%	0.41%	6.27%		90.41%	0.07%	9.52%
M4 vs M10	89.98%	5.50%	4.52%		91.25%	2.33%	6.41%
M5 vs M10	93.59%	0.06%	6.35%		90.43%	0.03%	9.54%
M6 vs M10	28.07%	69.69%	2.24%		28.58%	67.66%	3.76%
M7 vs M10	91.33%	3.38%	5.29%		88.96%	2.35%	8.70%
M8 vs M10	18.81%	80.37%	0.82%		20.80%	78.03%	1.17%
M9 vs M10	91.45%	3.45%	5.10%		88.61%	2.77%	8.62%

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Results: Regression on distance measurement

VARIABLES	(1) Distance_ Method1	(2) Distance_ Method2	(3) Distance_ Method3
Distance_Method10	0.801***	0.602***	0.744***
	(0.00562)	(0.000978)	(0.00393)
Constant	-24,239***	-9,247***	-15,049***
	(1,296)	(256.0)	(612.7)
Observations	3,070	116,754	3,739
R-squared	0.869	0.765	0.905

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

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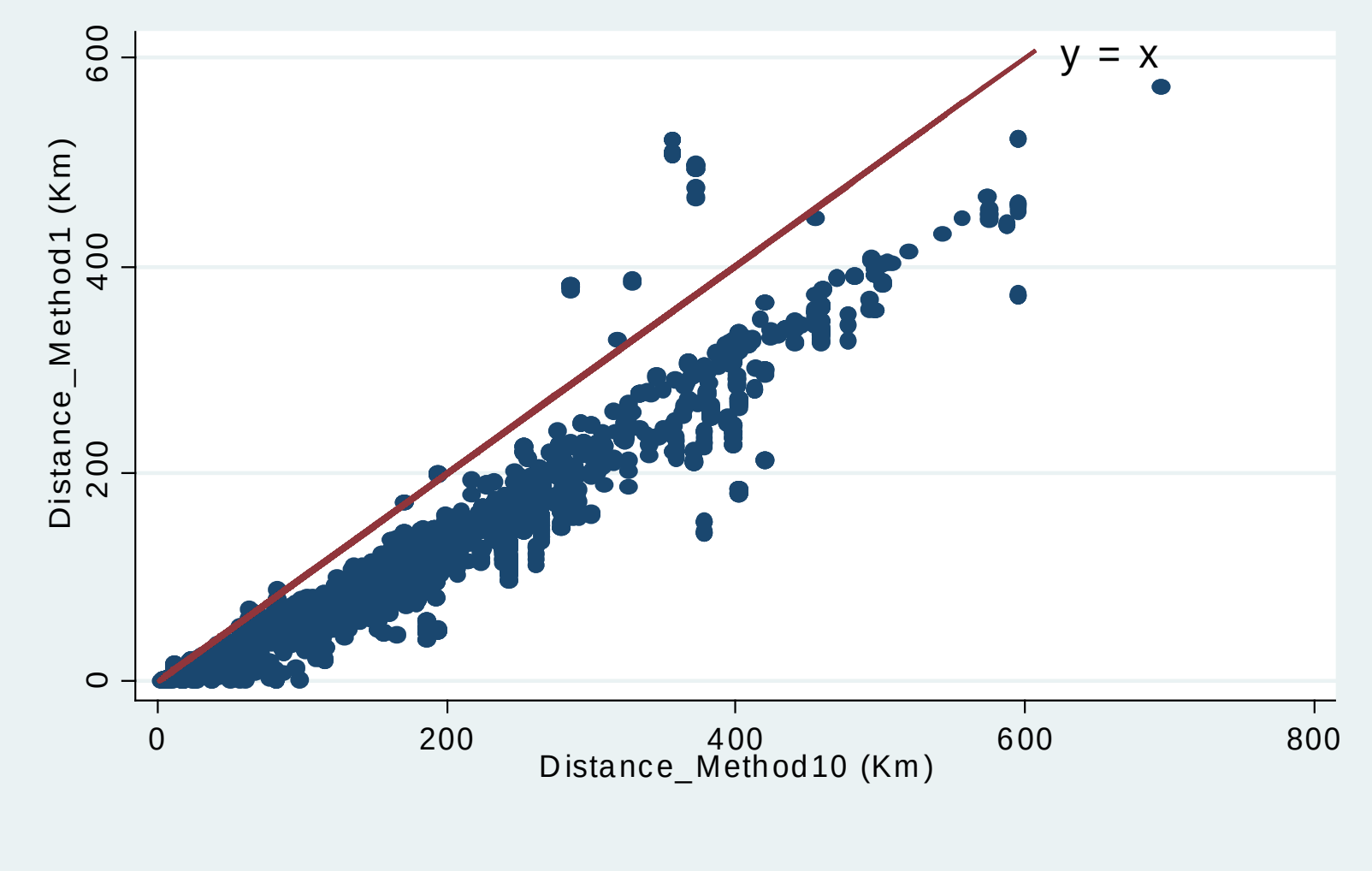

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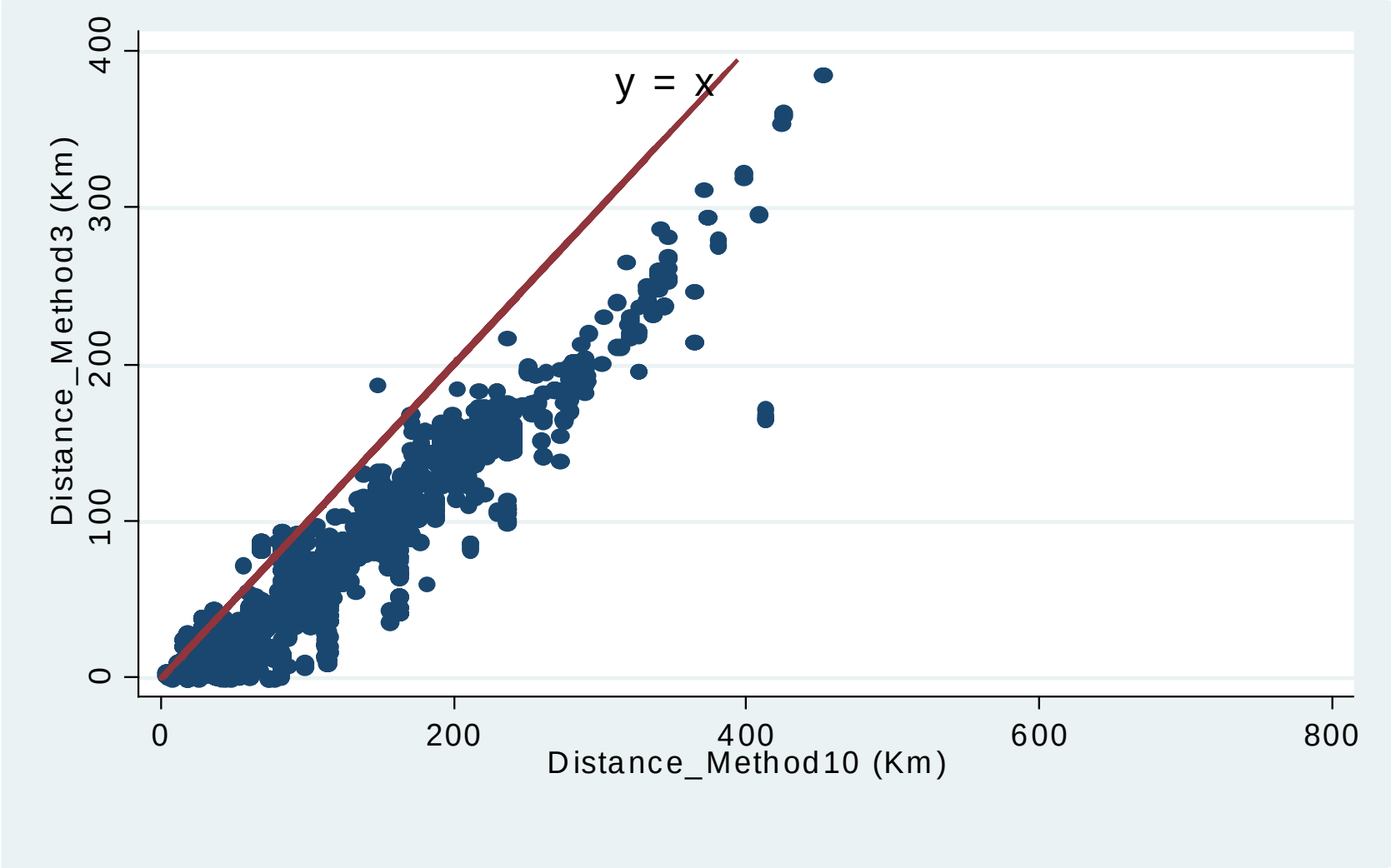

Conclusion and a way forward

- **Cost distance and flow length calculations perform better when the elevations of downstream monitors are higher**

- **Comparison methods perform better at smaller scale rather than whole watershed level**

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Conclusion and a way forward

- **Next step in the project:**
  - q **Run separate econometric models to estimate the effect of shale gas activities on observed downstream concentrations of chloride (Cl–) and total suspended solids (TSS)**

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Thank you!

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