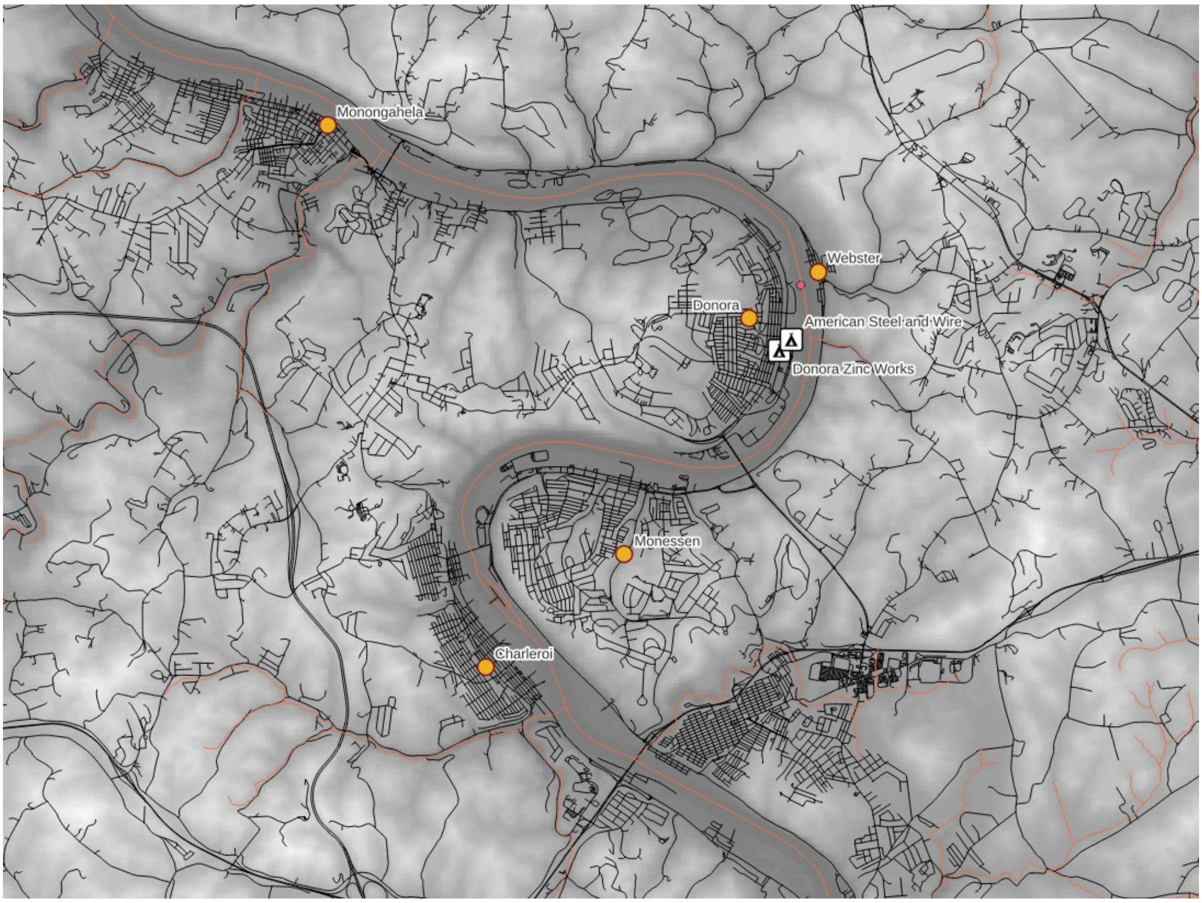
Analysis of the 1948 Donora Smog Disaster with QGIS



Abstract

Donora, Pennsylvania is a mill town appoximately 20 miles south of Pittsburgh, built into a tight bend of the Monongahela River. It is the location of the deadliest acute air pollution event in United States history. In October 1948, a five day temperature inversion trapped emissions from two U.S. Steel plants in the valley, causing the death of 20 people and affecting the health of thousands. Analysis and visualization is done through QGIS by using OpenTopography data to build a Python based Gaussian dispersion model of the two source plants. Roasting and reduction chemistry of the emissions is examined along with engineering controls including wet scrubbing and particulate capture that would have prevented the disaster.

Introduction

Two U.S. Steel facilities anchored Donora's economy: the Donora Zinc Works, opened in 1915 and among the largest zinc smelters in the country, and the neighboring American Steel and Wire Company plant, opened in 1902. Zinc production was not incidental to the town's identity, it was strategically vital to American industry. In the years surrounding the Second World War, zinc from plants like Donora's went into brass for cartridges and artillery shells, into aluminum and magnesium alloys for aircraft components, into galvanized coatings for naval hardware and infrastructure, and into die cast parts for military vehicles, while the neighboring wire plant supplied bullet cores and structural reinforcement. The Zinc Works had operated continuously for over three decades by 1948, releasing sulfur dioxide, hydrogen fluoride, and particulate metal oxides into the valley air as an ordinary byproduct of a process considered essential rather than exceptional.

That ordinary output became lethal only when it met an extraordinary atmospheric condition. The Monongahela valley's steep, enclosing walls, well suited for concentrating a workforce near river transport and raw materials, offered no natural avenue for pollutants to escape once a temperature inversion capped the air above the town. This project treats that combination, an established industrial process and a confined valley, as separable variables, and builds a spatial model to test how much of the disaster's severity can be attributed to geometry alone, independent of the plants' unremarkable emission rate on an ordinary day of production.

Theory and Analysis

Atmospheric dispersion of a continuous point source is commonly modeled with the Gaussian plume equation, which gives ground level concentration downwind of a stack as a function of distance, wind speed, and two dispersion coefficients, sigma y and sigma z, that depend on atmospheric stability class. Under normal daytime conditions, turbulent mixing spreads a plume both horizontally and vertically and concentration falls off quickly with distance. Under a stable, low wind inversion, vertical mixing is strongly suppressed, both dispersion coefficients shrink, and a plume that would otherwise thin into the open sky instead stays close to the ground and travels further before diluting. This project uses stable class dispersion coefficients paired with a light wind speed to represent the inversion conditions recorded at Donora.

A standard Gaussian model assumes an open half space above flat ground and does not account for a plume colliding with terrain. To capture the valley's role, the model adds a terrain constraint: an inversion lid height is set relative to the valley floor, and any cell whose elevation exceeds that lid is treated as outside the trapped air mass and assigned zero concentration. This simplifies a real inversion, which caps a horizontal atmospheric layer rather than following ground contour exactly, but it reproduces the key effect for a narrow valley. Pollutant that would otherwise pass over low hills is instead retained below the ridgeline, mirroring how the real trapped air mass was bounded by the surrounding terrain.

The source term for the model is grounded in the plant's actual unit operations. The Donora Zinc Works processed zinc sulfide ore in two stages. The first, roasting, is a gas solid reaction in which the ore is heated in a stream of air, oxidizing the sulfide to an oxide and releasing sulfur dioxide as the off gas:

$$2\ ZnS(s) + 3\ O2(g) \rightarrow 2\ ZnO(s) + 2\ SO2(g)$$

The zinc oxide produced by roasting is an intermediate, not the final product. It proceeds to a second unit operation, reduction, in which it is heated with carbon at high temperature. This drives off zinc as a vapor, which is condensed to liquid and then solid metal outside the retort, while releasing carbon monoxide gas:

$$ZnO(s) + C(s) \rightarrow Zn(g) + CO(g)$$

Both roasting and reduction were standard, long-established steps in zinc production and routine for this plant. At Donora, reduction in horizontal retorts also released carbon monoxide, unburned carbon particles, and zinc fume that escaped condensation, in addition to the SO_2 from roasting. he main hazard was not the reactions themselves but what happened to the exhaust gases once released into humid, stagnant air. SO_2 oxidized further and combined with fog moisture to form sulfuric acid aerosol, which deposits in the lungs far more readily than SO_2 gas alone.

$$2\ SO2(g) + O2(g) \rightarrow 2\ SO3(g)$$

$$SO3(g) + H2O(g) \rightarrow H2SO4\ (aerosol)$$

Fluoride bearing impurities in the ore also release hydrogen fluoride under these conditions:

$$CaF2(s) + H2SO4(l) \rightarrow CaSO4(s) + 2\ HF(g)$$

The model captures this trapping effect geometrically, not chemically. Rather than simulating the conversion of SO2 to sulfuric acid aerosol or hydrogen fluoride, it computes a Gaussian plume concentration field from both point sources and zeroes out any cell whose elevation exceeds the inversion lid height, so pollutant that would otherwise disperse over the surrounding hills is instead held at valley floor concentrations. The chemistry described above explains why that trapped concentration was hazardous. The model itself only reproduces where and how strongly the plants' output accumulated.

Methods and Procedures

A digital elevation model of the Monongahela valley was obtained through QGIS using the OpenTopography data source, which provides free, no login access to the Copernicus GLO-30 Digital Elevation Model, a 30 meter resolution global dataset derived from the TanDEM-X radar satellite mission. A region of interest was drawn over Donora and the surrounding valley towns, and a GeoTIFF elevation raster was downloaded and extracted from the delivered archive.

Figure 1: Regional map of the Monongahela River valley, showing the five affected towns and the two industrial plants.

The project was built in QGIS. A new project was set to a metric coordinate system, UTM Zone 17N, since distance based calculations require meters rather than degrees, and the DEM was reprojected into this system. A set of site points was built next: the five towns along the river, Donora, Webster, Monessen, Charleroi, and Monongahela, and the two emission sources, the Donora Zinc Works and the American Steel and Wire Company plant, entered from a coordinate CSV rather than hand clicked, to guarantee exact placement. These points were reprojected alongside the DEM and their exact meter coordinates were read out for use in the dispersion model.

Figure 2: Close-up map of Donora and Webster with the Donora Zinc Works and American Steel and Wire plants marked. Arrow on lower right corner points North.

With the geography established in QGIS, a Gaussian dispersion model was written and run in Python, outside QGIS, using the rasterio and numpy libraries. Python was used because the calculation requires evaluating the same equation over tens of thousands of grid cells simultaneously, a task outside the scope of QGIS's built in tools. The DEM exported from QGIS was read into Python as a numeric grid, and the two plants were defined as point sources on that same grid using the exact coordinates read from QGIS, each source given its own stack height and relative strength, similar to how multiple emission points are defined in a facility plot plan. For every cell, the model computed downwind concentration using stable, low wind dispersion coefficients, and summed the contribution of both plants. The terrain constraint was then applied: any cell whose elevation exceeded the inversion lid height was set to zero. The resulting field was scaled to the documented historical peak of about 5,000 micrograms per cubic meter and saved as a raster. A second, unconstrained version with the terrain cap removed was generated as a flat ground control run, isolating the effect of terrain from the effect of emission rate alone. Both rasters were brought back into QGIS and styled on a grayscale elevation ramp, white marking the lowest points of the valley floor and black marking the highest terrain, so the concentration results could be read directly against the shape of the land.

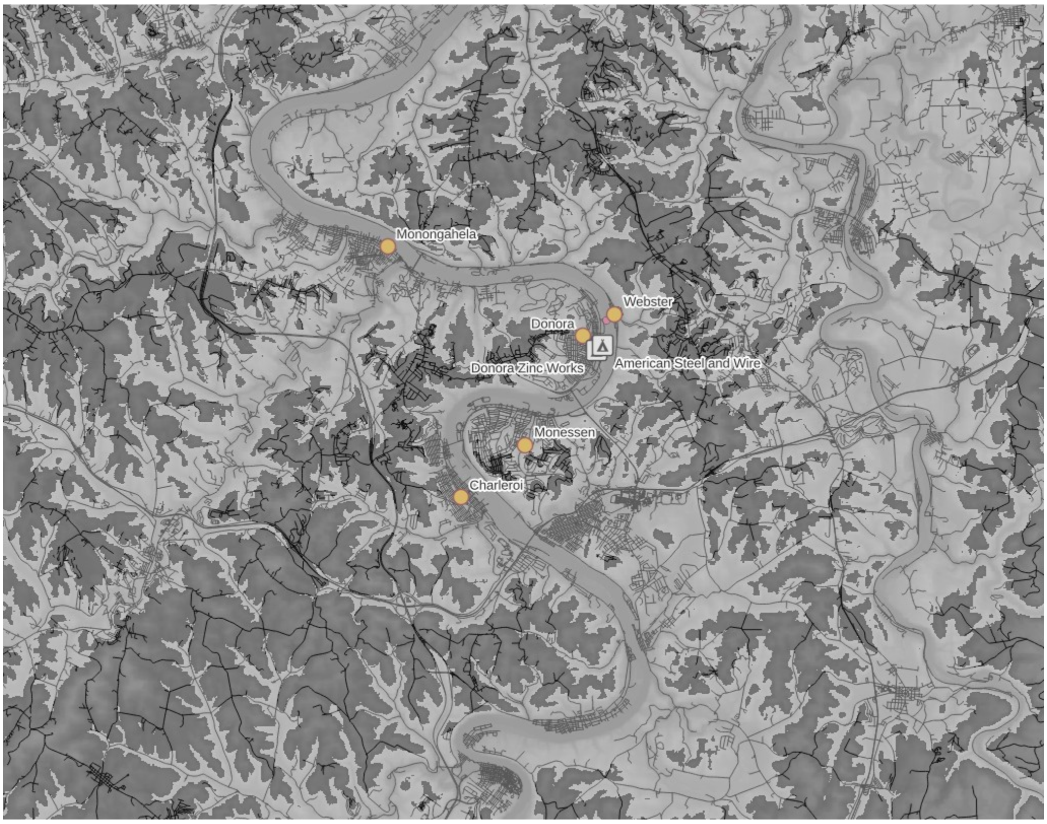


Figure 3: Elevation model of the Monongahela River valley terrain surrounding Donora.

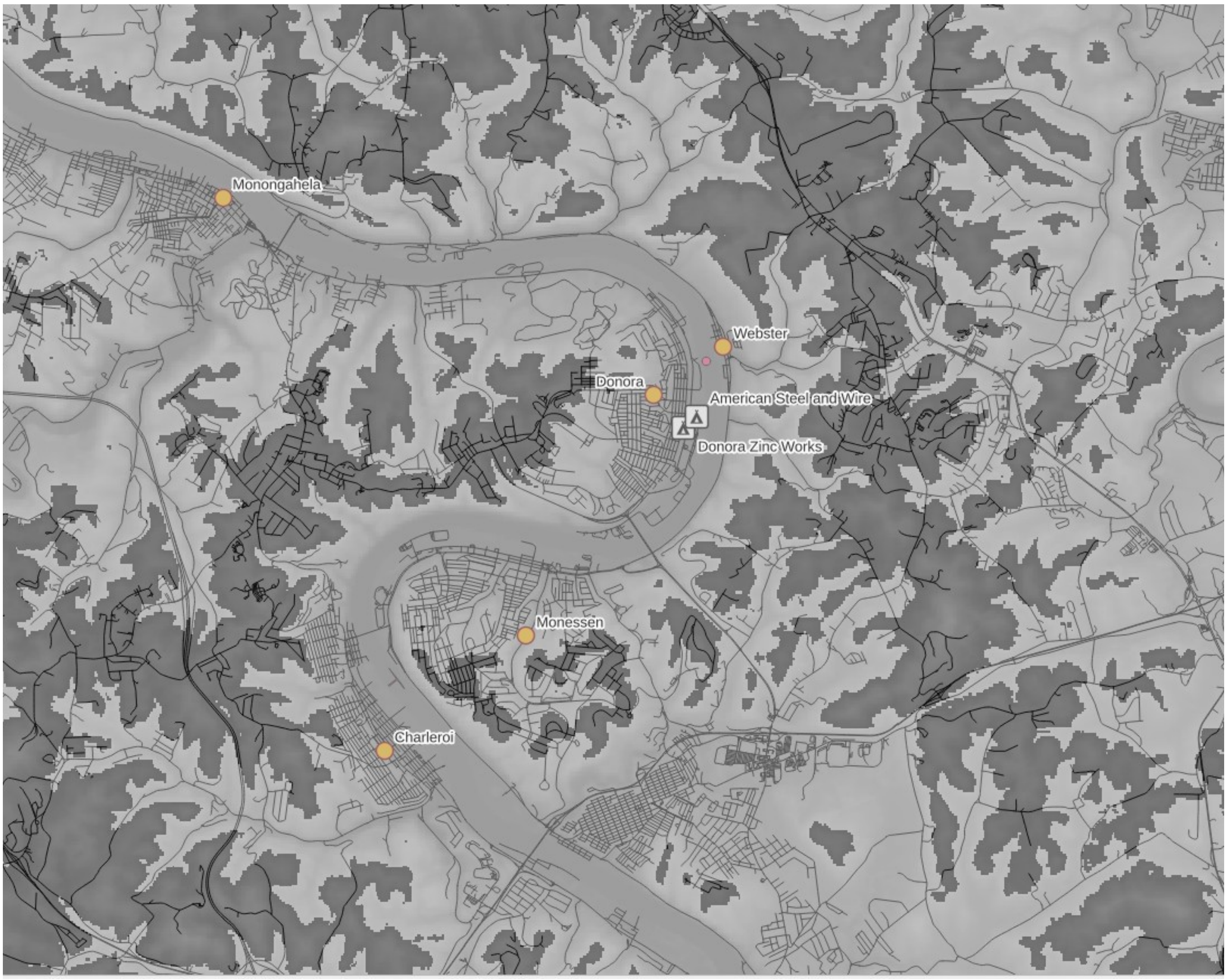


Figure 4: Zoomed elevation model of the valley floor and surrounding hills near Donora and the two plants.

Results

The elevation model confirms the physical basis of the disaster (Figures 3 and 4). In the grayscale terrain map the dark hillsides surrounding Donora rise roughly 120 to 130 meters above the pale valley floor, consistent with the commonly cited figure of over 400 feet. The map shows how tightly the five towns sit on the narrow white twisting floor of the Monongahela, hemmed in on both sides by darker steep hillsides rather than open or gently sloping ground. The towns and both plants sit entirely within the lightest lowest band of the valley, boxed in by higher ground on every side. This enclosure is reflected directly in the dispersion results. With the terrain constraint active, modeled concentration accumulates along the same pale valley floor where the towns and the two plants sit, matching the historical pattern of illness concentrated in Donora and Webster. In the flat ground control run, the identical source terms produce a plume that spreads over a much wider area with no location reaching the concentrations seen in the terrain constrained run. Since both runs begin from the same source strength and differ only in the terrain constraint, the comparison identifies valley geometry as the variable responsible for concentrating the plants' otherwise unremarkable emission rate into a hazardous exposure.

Fire department records and contemporary accounts show the practical impact of those valley concentrations. From Friday night October 29 through Sunday the Donora Fire Department answered continuous calls for residents unable to breathe. Crews exhausted their own oxygen supply of roughly 800 cubic feet and borrowed cylinders from neighboring towns while volunteers carried tanks door to door in near zero visibility. Responders refused oxygen themselves so the limited stock would reach more victims. The emergency continued until rain broke the inversion on October 31, 1948.

Conclusions

The dispersion results confirm the enclosure effect. With the terrain constraint active, modeled concentrations build up along the valley floor where the towns and plants sit, matching the historical concentration of illness in Donora and Webster. In the flat-ground control run the same sources produce a much wider, lower-intensity plume. Because the two runs share identical source strength and differ only in terrain, the comparison shows that valley geometry alone turned an otherwise ordinary emission rate into a hazardous exposure.

From a chemical engineering standpoint the disaster was not an unavoidable act of weather but the result of a missing unit operation. A properly designed off gas train for a roaster routes the SO_2 laden stream through absorption before release, historically a contact process producing sulfuric acid as a saleable byproduct or in simpler form a lime or limestone scrubber neutralizing SO_2 through the reaction $SO_2(g) + CaCO_3(s) + 0.5\ O_2(g) \rightarrow CaSO_4(s) + CO_2(g)$. Particulate emissions including zinc oxide dust and trace cadmium oxide would be captured with an electrostatic precipitator or baghouse rather than vented directly to the stack and hydrogen fluoride is readily removed by wet scrubbing into an alkaline solution before release. None of these controls were installed at Donora in 1948 so the atmosphere itself was the plant's only gas treatment step and the inversion disabled it. Modern process safety practice treats this failure mode explicitly. Emission control design must be evaluated against worst case atmospheric conditions not average ones because a rare stagnant weather event can convert an ordinarily survivable emission rate into a lethal one. The Donora incident reconstructed here through a terrain constrained dispersion model built in Python from QGIS derived geography stands as a direct illustration of why gas treatment not dilution by the open sky is the engineering control that should never be treated as optional.

References

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(5) U.S. Environmental Protection Agency. *Air Pollution Control Technology Fact Sheets: Wet Scrubbers, Electrostatic Precipitators, and Flue Gas Desulfurization.*