



AN ATLAS OF THE WATER'S PATH

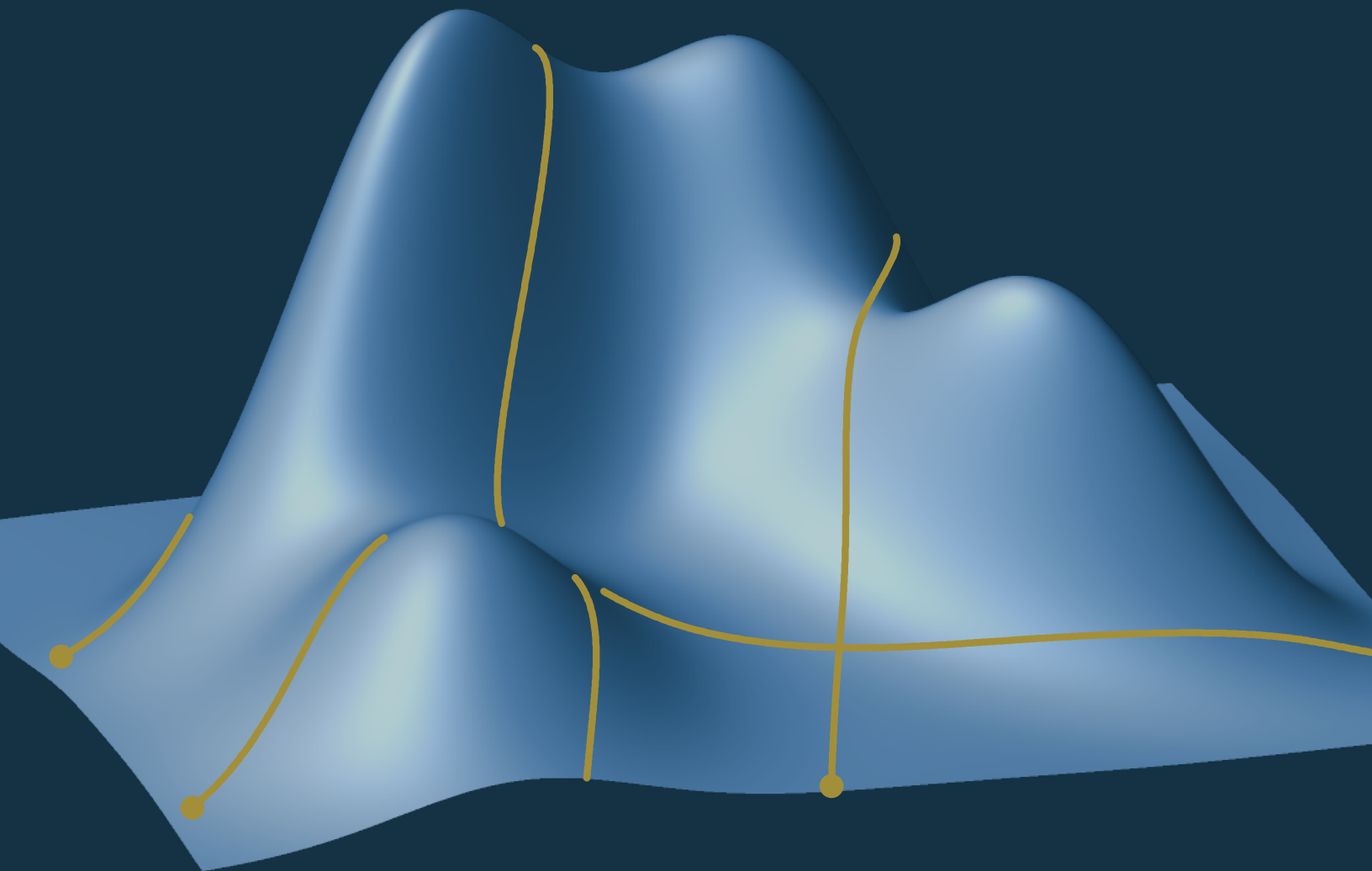
Millburn Flood Scenarios

An open-data flood model for Millburn Township, South Mountain and Essex County, with Hurricane Ida, historical storms and extreme what-if scenarios

Prepared for flood resilience planning in Millburn Township and Essex County, New Jersey

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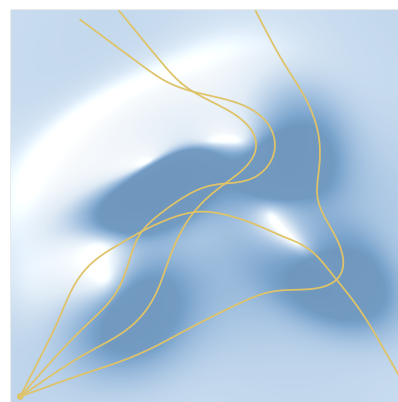


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IDA IN THE MODEL

Rain over Millburn	7.3 in
Wettest hour	3.1 in
Flooded over 1 ft	8.1 km²
Built-up land over 1 ft	0.96 km²
Scenarios compared	9



Water, like a geodesic, takes the path the ground allows. This model traces that path across the Watchung ridges into Millburn.



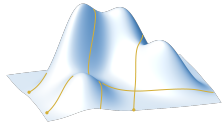


PLATE 1 Executive Summary

On the night of September 1, 2021, the remnants of Hurricane Ida dropped about seven and a half inches of rain on the upper Rahway River, nearly three of them in a single hour. The West and East Branches of the Rahway rose within a few hours and flooded downtown Millburn, Taylor Park and the low ground toward Springfield. This report describes an open-data flood model we built to replay that night, compare it with other historical and design storms, and ask what a worse storm would do.

The model is a two-dimensional rain-on-grid simulation of the whole watershed that drains through Millburn, from South Mountain Reservation and West Orange down to the USGS gauge at Springfield. It uses only public data: USGS lidar terrain, ESA land cover, NOAA's hourly gridded rainfall for real storms and NOAA Atlas 14 for design storms. The code is open and runs on a laptop in minutes.

Ida's intensity, not its total, made it Millburn's worst modeled historical storm. It flooded about 8 km² of the study area deeper than one foot, more than Floyd or Irene, which each dropped more rain. Moving Ida's wettest core 16 km over the Rahway headwaters would have made it roughly a 500-year event for Millburn.

Main findings.

- **Intensity governs flooding here.** Floyd (1999) and Irene (2011) delivered more rain than Ida but at one to one and a half inches per hour. Ida's three inches in an hour overwhelmed storm drains and sent water to the river all at once. Peak flows at downtown Millburn were two to three times those of Floyd or Irene.
- **The flood path is consistent.** In every scenario the deepest flooding follows the same corridor: the West Branch through downtown Millburn and Taylor Park, the confluence with the East Branch at the Springfield line, and the Canoe Brook lowlands in the northwest of the township.
- **Realistic worst cases are much worse.** Ida's wettest core passed northeast of the watershed. Shifted over the headwaters, the same storm floods 9.6 km² and puts 1.3 km² of built-up land under more than a foot of water, about the same as the 500-year design storm.
- **Absolute flows need calibration.** The model's peak flows, especially for Ida, are likely well above what USGS measured. Use the results to compare scenarios and locate flooding. Calibrate against the Springfield gauge before quoting flows or depths as predictions (Section 6).



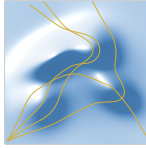


PLATE 2

Study Area and Open Data

Millburn sits where the Rahway River leaves the First and Second Watchung ridges. South Mountain Reservation, West Orange, South Orange and Maplewood drain through the township in two branches that join at the Springfield line. The model domain is the full watershed of USGS gauge 01394500 (Rahway River near Springfield), so every drop that reaches Millburn falls inside the model. Summary statistics are reported for a 7.9 by 7.6 km area of interest around the township. The model can clip them to the Census boundary of Millburn when that layer is available.

Layer	Source	Resolution
Terrain	USGS 3D Elevation Program, 1/3 arc-second DEM, lidar-derived in New Jersey	10 m, run at 30 m
Land cover	ESA WorldCover 2021, used for runoff (curve number), roughness and built-up area	10 m
Historical rain	NOAA Analysis of Record for Calibration (AORC) v1.1, hourly gridded rainfall, 1979 to present	800 m, hourly
Design rain	NOAA Atlas 14 Vol. 2, 24-hour depths for Millburn, NRCS Type III timing	point
Validation	USGS NWIS peaks and 15-minute flows at 01394500	gauge

As a check on the terrain processing, the model's drainage area at the Springfield gauge is 24.6 mi². USGS publishes 25.5 mi², so the two agree within four percent.



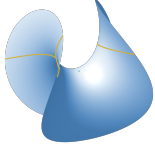


PLATE 3 Modeling Approach

Terrain conditioning

A DEM sees road and railway embankments but not the culverts and bridges beneath them, so it would otherwise dam every stream at Route 24, I-78 and the NJ Transit line. The model traces flow paths with the Priority-Flood algorithm and carves every path that drains more than 0.05 km² so it never runs uphill. Streams are then lowered to a bankfull depth from a Piedmont regional curve, and ponds and reservoirs start full. In the first test, before this step, two thirds of the runoff was trapped behind embankments. After it, the water reaches the river as it should.

Runoff and storm drains

Rainfall becomes runoff through the SCS curve-number method, evaluated cell by cell and minute by minute. With $S = 25400/\text{CN} - 254$ mm and initial abstraction $I_a = 0.2S$, the cumulative runoff from cumulative rain P is

$$Q = \frac{(P - I_a)^2}{P - I_a + S}, \quad P > I_a. \quad (1)$$

Built-up cells send water to the storm sewer at up to 25 mm/h, about one inch per hour, which is typical of municipal systems. The sewer delivers it to the nearest downstream river cell. Historical tropical storms run with wet antecedent soils, because Henri soaked the ground ten days before Ida.

Two-dimensional flow

Surface water moves under the local-inertial shallow-water equations used by LISFLOOD-FP (Bates et al., 2010). On each cell face the unit discharge q is updated as

$$q^{t+\Delta t} = \frac{q^t - g h_f \Delta t \partial \eta / \partial x}{1 + g \Delta t n^2 |q^t| / h_f^{7/3}}, \quad (2)$$

where η is the water surface, h_f the flow depth at the face and n Manning's roughness from land cover. The time step adapts to the deepest water, depths never go negative, and the mass balance closes to round-off in every run. Each scenario takes two to four minutes on a laptop at 30 m resolution.



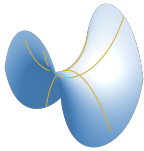


PLATE 4 Rainfall Scenarios

Scenario	What it represents	Rain, peak rate
2, 10, 100, 500-year	NOAA Atlas 14 24-hour design storms with NRCS Type III timing	3.4 to 11.7 in
Floyd 1999	AORC observed rainfall, September 15 to 17	8.4 in, 1.0 in/h
Irene 2011	AORC observed rainfall, August 27 to 29	8.5 in, 1.5 in/h
Ida 2021	AORC observed rainfall, September 1 to 2	7.3 in, 3.1 in/h
Ida, core over watershed	Ida's wettest six hours within 60 km, moved 16 km to sit over the Rahway headwaters	9.7 in, 3.6 in/h
Ida $\times$ 1.5	Ida's rainfall scaled by one half as a stress test	11.0 in, 4.7 in/h

Design storms report the peak five-minute rate, historical storms the wettest hour. The model also accepts a climate factor (for example the NJDEP county factors for future precipitation), any custom depth and duration, and any shift of a historical storm.



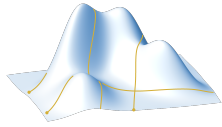
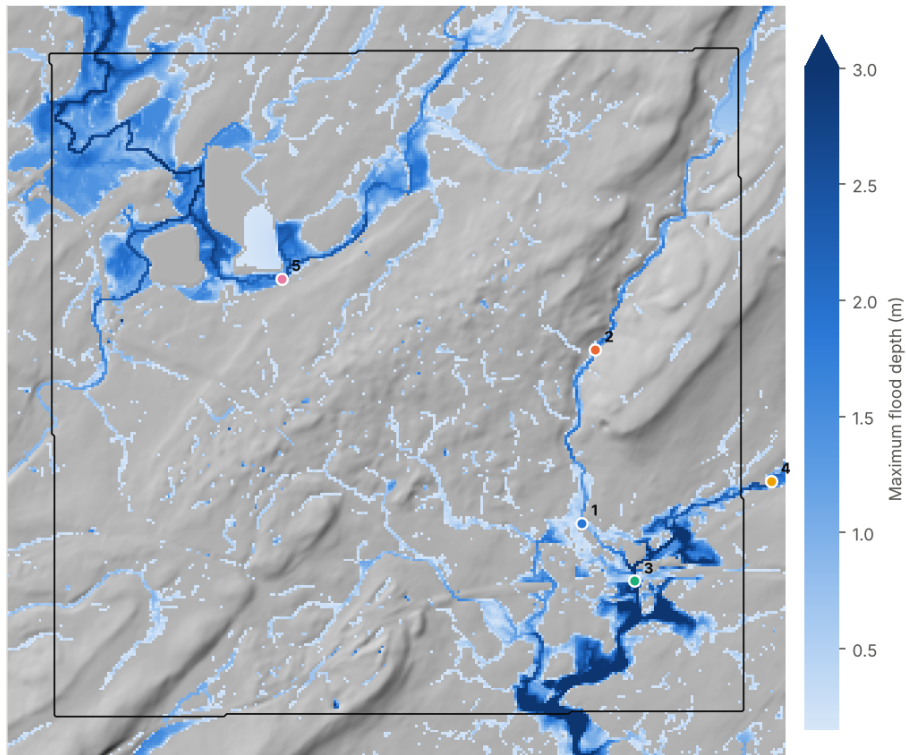


PLATE 5 Results

Hurricane Ida

Maximum flood depth - ida (30 m grid)

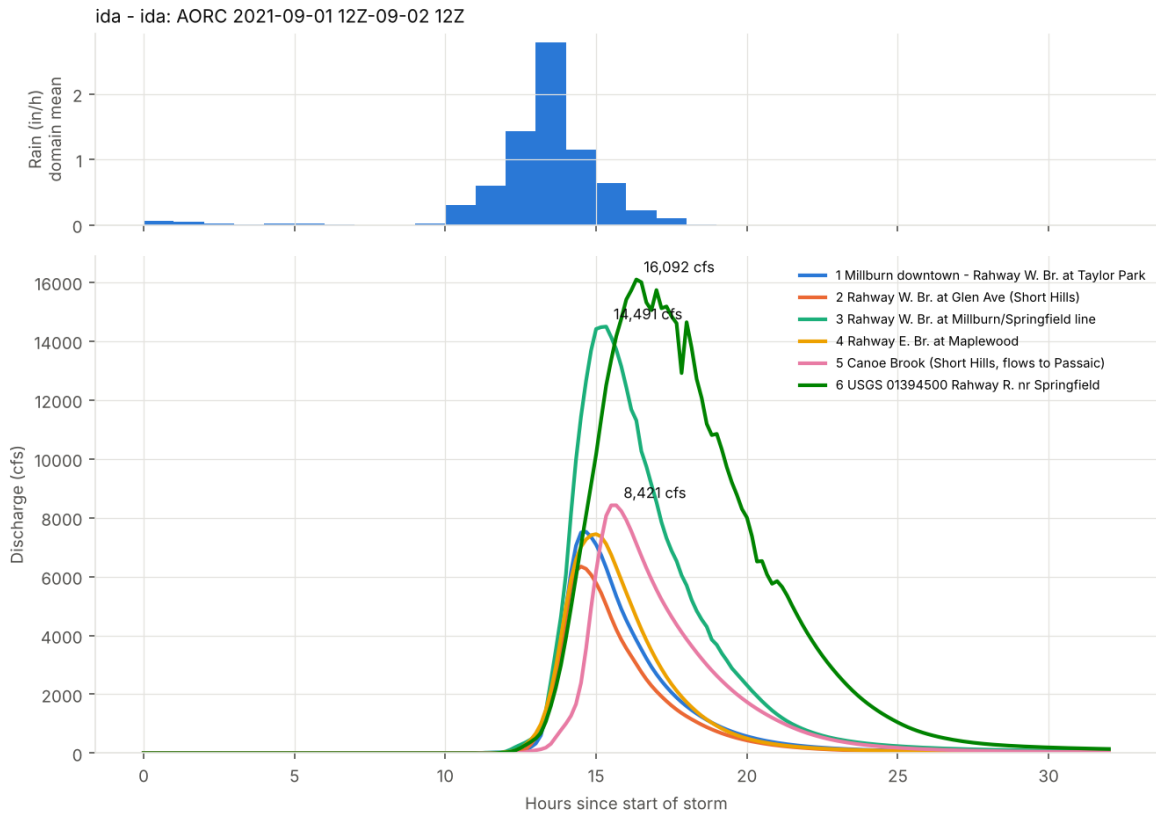


Gauges: 1 Millburn downtown - Rahway W. Br. at Taylor Park 2 Rahway W. Br. at Glen Ave (Short Hills) 3 Rahway W. Br. at Millburn/Springfield line 4 Rahway E. Br. at Maplewood 5 Canoe Brook (Short Hills, flows to Passaic) 6 USGS 01394500 Rahway R. nr Springfield

Maximum flood depth for Ida over the Millburn area of interest (outlined). Numbered points are the gauges in Table 1. Grey areas are reservoirs and ponds.

The flood concentrates where the West Branch leaves the ridge at Glen Avenue and runs through downtown, around Taylor Park, and at the confluence near the Springfield line. There, depths exceed two to three meters on the model's 30 m grid. The rivers peaked one and a half to three hours after the wettest hour, which ended at 9 pm EDT. This short lag is typical of small, steep, urban streams.





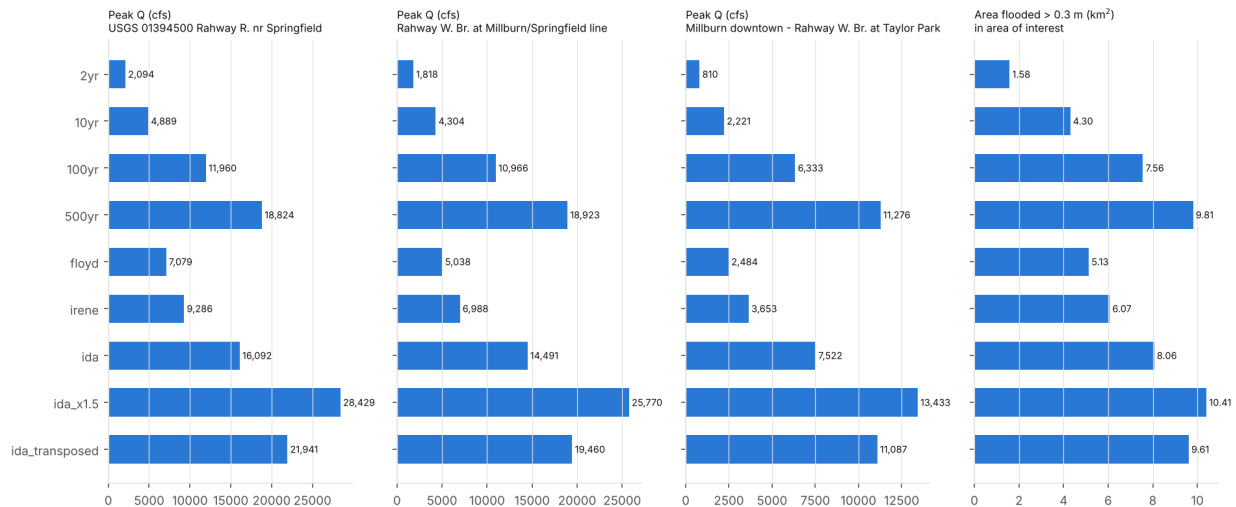
Ida rainfall (top) and modeled discharge at each gauge (bottom). Discharge values are uncalibrated.

All scenarios

Scenario	Rain (in)	Millburn Q (cfs)	Springfield Q (cfs)	Flooded >1 ft (km ²)	Built-up >1 ft (km ²)
2-year	3.4	810	2,094	1.6	0.07
10-year	5.1	2,221	4,889	4.3	0.25
100-year	8.5	6,333	11,960	7.6	0.75
500-year	11.7	11,276	18,824	9.8	1.27
Floyd 1999	8.4	2,484	7,079	5.1	0.28
Irene 2011	8.5	3,653	9,286	6.1	0.47
Ida 2021	7.3	7,522	16,092	8.1	0.96
Ida, core over watershed	9.7	11,087	21,941	9.6	1.27
Ida × 1.5	11.0	13,433	28,429	10.4	1.49

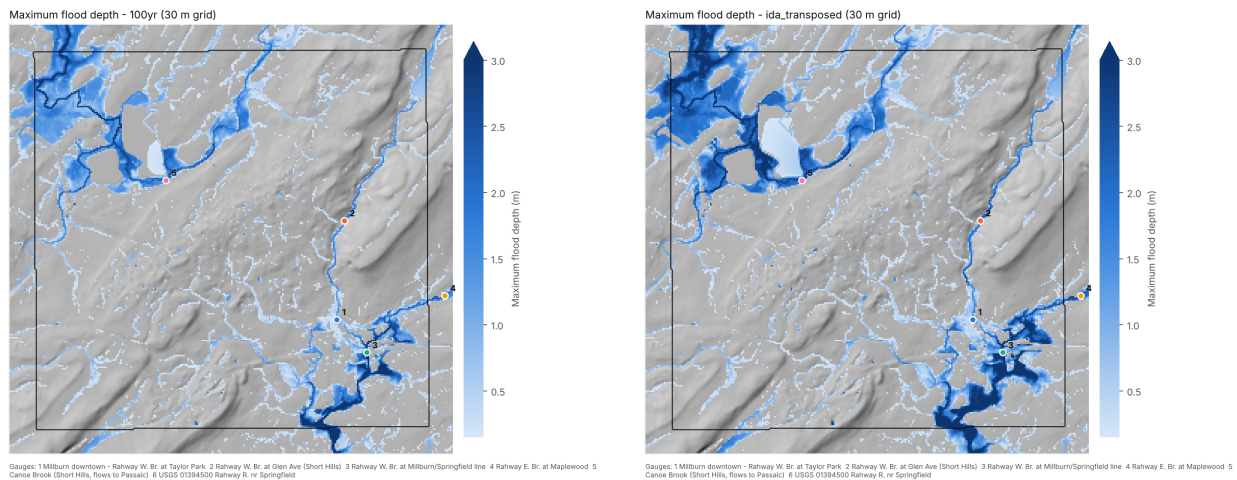
Table 1: Scenario results. Millburn Q is the peak at downtown Millburn (Taylor Park, 6.8 mi²); Springfield Q is the peak at USGS 01394500 (24.6 mi²). Flooded areas exclude river channels and reservoirs. Flows are uncalibrated.





Peak discharge at three gauges and area of interest flooded deeper than one foot, for each scenario.

What a worse Ida looks like



Left: the 100-year design storm. Right: Ida with its wettest core moved over the Rahway headwaters.

Ida's heaviest rain fell to the northeast of the watershed, and AORC shows totals near ten inches nearby. Moving that core about 16 km so it sits over South Mountain and West Orange raises the rain over Millburn from 7.3 to 9.7 inches. Peak flow at downtown Millburn rises by about half, and the built-up area under more than a foot of water grows by a third. The result matches the 500-year design storm, which shows that an event of that size needs no new kind of weather, only a different track for a storm the region has already seen.



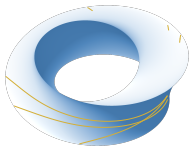


PLATE 6

Limitations and Calibration

This is an uncalibrated screening model. Its value lies in comparing scenarios and showing where water goes. The modeled Ida peak at Springfield, about 16,000 cfs or 650 cfs per square mile, is extreme for New Jersey and is probably several times what USGS recorded.

Likely reasons the flows run high, in order of expected effect:

- **Wet soils.** Historical storms use saturated (AMC III) soils, which convert most rain to runoff.
- **Instant storm drains.** Sewer water reaches the river with no travel time or pipe limits.
- **No bridges or culverts.** Carved channels pass water freely where real crossings constrict it and store it upstream. Debris blockage, a real factor in downtown Millburn, is not represented.
- **Coarse grid.** At 30 m, narrow channels and street-level detail are smeared. The model also runs at 10 to 20 m.
- **Representative rainfall tables.** Atlas 14 depths are built in for Millburn. The model can download the exact values, and NOAA Atlas 15 should replace them when it is published for New Jersey.

The model includes a `validate` command that downloads the USGS annual peaks and 15-minute flows at 01394500 and compares them with each run. Calibrating soil group, antecedent moisture, sewer capacity and roughness to Ida, Irene and Floyd together is the first recommended step.

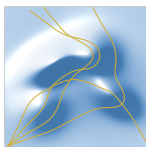


PLATE 7

Recommendations and Next Steps

1. **Calibrate** against USGS 01394500 for Floyd, Irene and Ida, then fix the parameters and rerun every scenario.
2. **Refine the downtown corridor** at 10 m with surveyed bridge and culvert openings on the West Branch between Glen Avenue and the Springfield line.
3. **Add future rainfall** with the NJDEP county factors for Essex County, to support the Inland Flood Protection Rule.
4. **Extend to Essex County** with the built-in county domain, adding the Passaic River inflow from upstream of the county line.
5. **Share the dashboard** with township engineering and emergency management so that scenarios can be compared side by side.



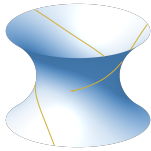


PLATE 8

Reproducing This Work

Everything in this report comes from open data and open code at https://github.com/steve98654/flood_modeling. The figures were produced with

```
python -m millburn_flood compare 2yr 10yr 100yr 500yr floyd irene ida ida_x1.5  
ida_transposed -res 30  
python -m millburn_flood dashboard results/millburn_30m
```

The first command downloads the data, runs the nine scenarios and writes maps, hydrographs, GeoTIFFs and summaries. The second builds the interactive dashboard. A run at 30 m takes two to four minutes per scenario.

