Mapping a Flood...Before It Happens

What's missing from flood forecasts?

Maps—The only maps generally available today are maps used for planning. They are maps of theoretical floods, not maps of flooding forecast for an approaching storm. The U.S. Geological Survey (USGS) and the National Weather Service (NWS) have developed a way to bring flood forecasting and flood mapping together, producing flood maps for tomorrow's flood today… and getting them on the Internet in time for those in harm's way to react.

Extending the National Weather Service Forecast Flood

Most flood maps today are not maps of real-life floods; they are maps of an imaginary flood used to help communities get an idea of where especially flood prone areas probably are. Sometimes these are called "100-year flood maps," although that phrase is a little misleading because it is based on statistical probabilities for some specific location, not for a region. There's a good chance that a "100-year flood" will occur somewhere in your state every year.

Flood forecasts (like the ones seen on TV newscasts) are made by the National Weather Service for storms days in advance of the actual flooding. These forecasts estimate the highest level the river will get, based mainly
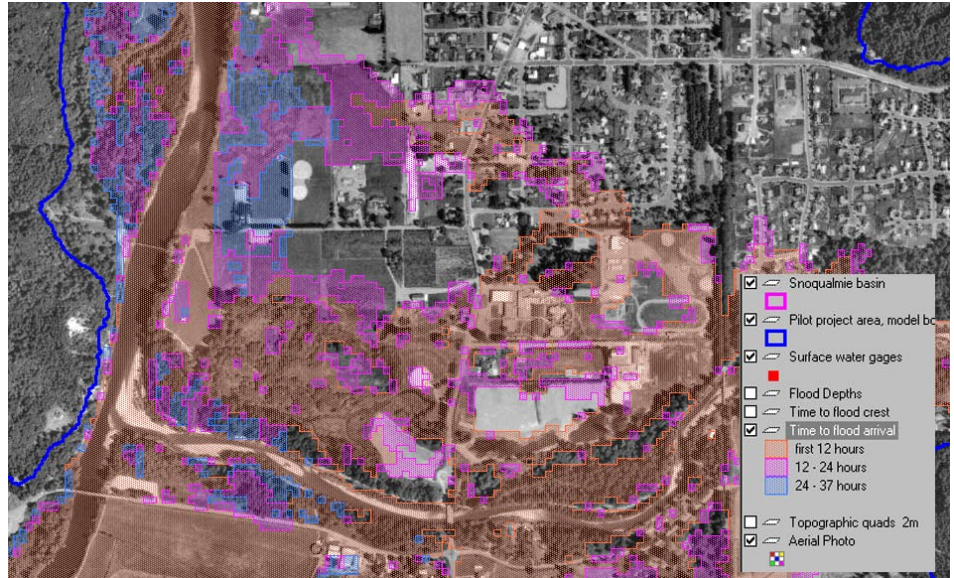

Figure 1. Time-to-arrival for flood, November 23, 1986, Snoqualmie River, Washington

on how much rain is expected. Unfortunately, the forecasts are made only for a few specific places; they don't predict flood levels for anywhere except those specific places. So, unless you live near one of these "forecast points," the predictions are good only as a rough measure of how large the flood is predicted to be. They don't tell you whether your house, or a school, or your local sewage treatment plant is in danger of being flooded. Even if you do live near a forecast point, the forecast is still only an elevation describing the highest expected river level. It doesn't mean a lot to you unless you know your elevation compared to the reference elevation, or "datum," of the forecast point. What you want if you live in a floodplain, whether you live near a forecast point or not, is a map that shows where flooding is expected.

When the NWS issues a forecast flood hydrograph (plot of flow vs. time) for a particular location, the USGS uses the hydrograph to create a flood-inundation map. The USGS has developed methods to make maps of these forecast floods for long stretches of a river near forecast points. These maps fill a critical information gap in flood forecasting: information on when and where floodwater from an approaching storm will arrive. The maps also show how deep the water is expected to be all across the floodplain. In essence, these methods combine to make a somewhat obscure "peak forecast elevation" into a map with flooded areas, times-of-arrival, and flood depths.

A number of new technologies and methods make the creation of flood forecast

maps possible. First is the ability to get very accurate elevations throughout the floodplain quickly and affordably. This is done with "LIDAR" technology (see more below). Second is a computer program (TRIMR2D) that can simulate flood flows all across the floodplain and many, many miles downstream from the forecast point. Third is spatial analysis software (GIS) that turns the model results into maps and overlays them on other maps, like a map of a neighborhood, or even onto an aerial photograph. Last is software (IMS) that makes the maps available on the Internet in a flexible and user-friendly way. (You can see a demonstration of the system on the Web at http://wa.water.usgs.gov/projects/pugethazards/urbanhaz/MappingNWS.htm.)

LIDAR-Based System Collects Data Quickly, Accurately

Light Detection And Ranging (LIDAR) technology collects high-accuracy elevation data (better than 1-foot accuracy) for very large areas very quickly and at lower cost than traditional methods. The concept is quite simple: it's essentially a laser rangefinder in an airplane, but it's no ordinary laser rangefinder.

LIDAR systems use lasers that pulse tens of thousands of times a second. To turn a laser-determined distance into the elevation of a point on the ground requires sophisticated hardware and software. First, you need to know the location of the airplane to within less than an inch at all times. This is done with a high-precision Global Positioning
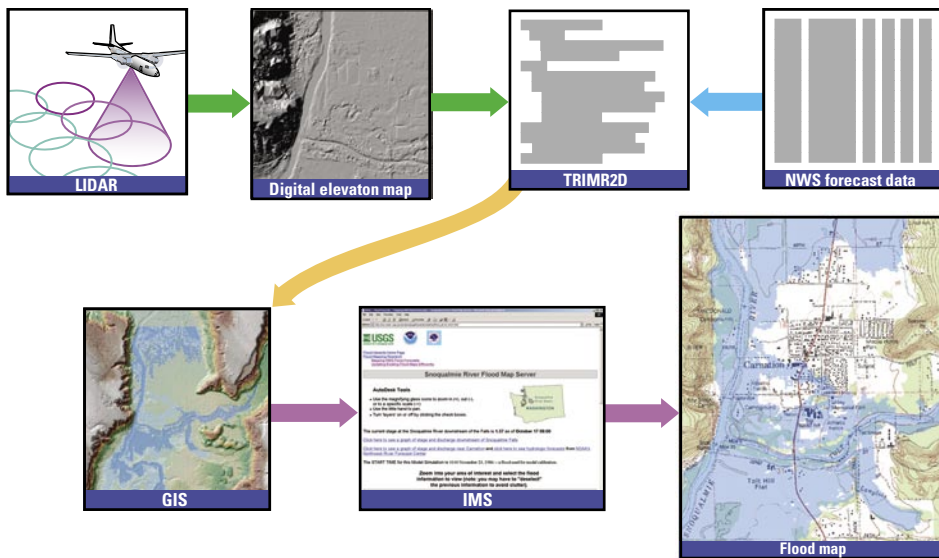

Figure 2. Flood waters washing out bridge.

Figure 3. A geographic information system (GIS) takes LIDAR elevations data and information from the TRIMR2D model to build maps of areas that likely will be inundated, based on the National Weather Service forecast flood.

System (GPS). Next, you must know the orientation of the airplane (nose up or down, wings level or not) with similar precision. This is done with Inertial Navigation Units (INUs) so advanced and accurate they are considered military secrets and must be licensed by the government.

The LIDAR system collects billions of elevation values, but commonly most of the laser reflections are off of tree tops, shrubs,
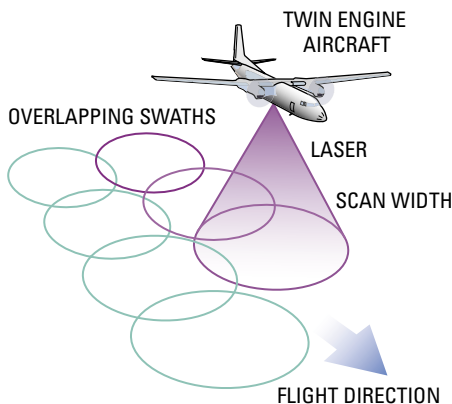

Figure 4. Typical Light Detection And Ranging (LIDAR) typical system used to collect high-accuracy elevation data needed to make flood maps.

bridge decks, vehicles, even telephone poles. Sorting through all these points to find the ones that are really "on the ground" requires complex and often tedious computer processing. But as difficult as all this sounds, it's still less expensive, faster, and more accurate than anything that was available before.

What does LIDAR mean for flood mapping? It means that the computer programs (flow models) can simulate floods over the entire floodplain, rather than for just a few dozen cross-sections. In the past, elevation data was collected manually in the field, and because that's very expensive, only cross-sec-

tions were measured. Flow models therefore could simulate flow in one dimension through these cross-sections. With elevation data available for the entire floodplain, flow can be simulated everywhere. This type of simulation, two-dimensional, gives us a much more detailed picture of where water will go during a flood.

TRIMR2D Computer Model is Exceptionally Stable

Flow models are computer programs that attempt to solve equations that describe the physics of fluid flow. Because the set of equations is very large, a critical feature of all models is the method they use to arrive at a solution. The larger the area being modeled, the larger the set of equations, and the more difficult it is to arrive at a solution. So the size of area that can be simulated is limited by the solution method. Two-dimensional models, which simulate flow throughout the entire floodplain, are much larger than one-dimensional models, so the solution method is especially important.

The ability of a model to successfully solve large problems is referred to as "stability." This is because of the iterative way the model attempts to solve the problem, closing in gradually on the solution. For very difficult problems, the model will perpetually overshoot the answer and never reach a solution—a condition called "numerical instability." TRIMR2D is a two-dimensional model that uses a unique and especially stable solution method, so it can solve much larger problems—for much larger areas—than other two-dimensional models. Stability limits not only the size of the area that can be simulated, but also the ability to solve flow predictions that involve very large or fast changes in flow. TRIMR2D has demonstrated that it can solve

equations not only for large areas, but also for problems that have large and fast flow changes.

The stability of TRIMR2D is due to a solution method that separates the more stable terms in the equations from the less stable terms, and then solves them in a manner that minimizes the effect of the less stable terms. In modeling terms, TRIMR2D is called a semi-explicit, semi-lagrangian, finite-difference, two-dimensional, depth-averaged hydraulic model.

GIS Draws the Map

A Geographic Information System, GIS, is a state-of-the-art database that includes a location with each piece of information. A GIS is used to manipulate, calculate, and process information that is inherently spatial in nature—all of the data is related to some point on the ground. Elevation data is a good example; all points on the ground have their own value of elevation. A GIS also can make maps of these data; they are so good at making maps that some people mistake them as merely mapping tools.

For making flood forecast maps, the GIS uses one of several common processing methods—cell-based, or raster, calculation. This method is well suited for processing the solution provided by TRIMR2D, which is in a raster format (raster means all data is for locations that are evenly spaced on the ground, like a checkerboard).

The GIS uses the model results to make maps of the entire floodplain showing areas that are likely to be flooded and how deep the water may get, when the floodwater is likely to first arrive, and when the flood will crest.

Internet Map Server Delivers the Information

To deliver these information layers in a useful manner to emergency responders and the public, an Internet Map Server (IMS) is employed. This system allows the IMS author to make a variety of data layers available to the end user so that they can customize the map to their needs by selecting or turning off various information or reference layers. The information available and the appearance of symbols are scale dependent, allowing a great amount of flexibility to both the author and the user.

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