"Water You Waiting For," Santa Fe?

Modeling the Santa Fe Watershed

Super Computing Challenge Team
#94
New Mexico School For The Arts

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I. Executive Summary

Our project is focused on understanding and modeling how water moves through the Santa Fe Watershed, which includes many arroyos along with the all-important Santa Fe River. The model includes real-world aspects such elevation, rainfall, and stream-flow records that make it as precise as possible. This data was acquired from many different sources especially the federal USGS website and our friend Claudia Borchert, who is a hydrologist for the Santa Fe Water Division. Our model was entirely programmed in Netlogo with heavy use of its GIS feature, which allowed us to import and employ much of the aforementioned data. The program also includes water stations that correspond to the actual measuring gauges where the Santa Fe River intersects with Ricardo Road and St. Francis Drive. Also, since we are using accurate rainfall and snowmelt measurements along with correctly geo-positioned spots for these locations, we can use stream-flow outputs from the computer programmed gauges and compare them to actual measurements for those sites to test the accuracy of our model. If the yearly graphs that our model produces match up with those of the actual St. Francis and Ricardo sites for different years, then our team will be the first group of people to correctly model the Santa Fe Watershed. After many hours of obtaining data and programming we finally ended up with a working model that followed real-world rainfall patterns. When we compared the graphs of our simulation to those of definite stream-flow measurements we found them to match up quite nicely, with a small margin of error. Therefore, we concluded that we had created a mostly precise model that could be used by the local community to understand the watershed and how much water is actually flowing through it each year.

II. Project Introduction

II – A: Our Goal

The goal of this project has changed a great deal throughout the Supercomputing Challenge this year. Our initial goal back at the kickoff in 2011 was to model the entire Rio Grande River and how its water levels varied throughout the state. However, lack of cooperation from farmers and plausible data made that plan fall to pieces. So we decided to narrow our scope to our own local watershed in Santa Fe. Our new goal was to model the entire watershed along with optimizing water consumption and adding an aspect that accounts for the Buckman Direct Diversion Pipeline, which is a newly built pipeline that brings water from the Rio Grande to the Santa Fe River. This new goal proved much simpler and achievable than our first because of far more readily available data and easier programmability. Due to time restraints, we had to cut out the Buckman Pipeline and local usage optimization aspects but we still achieved our most important goal: to create an accurate model of the Santa Fe Watershed. Now that our model is complete, we hope to perhaps re-incorporate the two aspects we left out as well as make our model available to the public to help teach them about our city's naturally abundant water source.

II – B: The Santa Fe Watershed

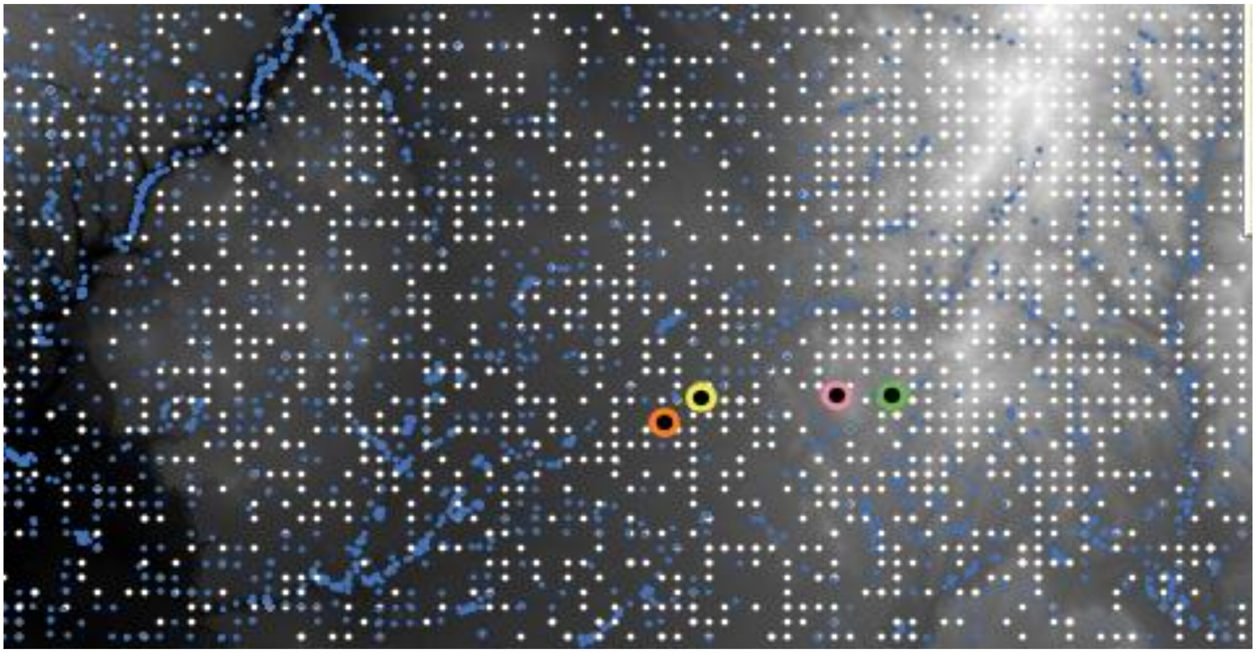
The Santa Fe Watershed is the region of New Mexico that contains the Santa Fe River and its accompanying tributaries. It starts high up in the Sangre De Cristo Mountains where springs and snowmelt feed the river as it descends, passes through the city of Santa Fe, and extends all the way out to meet the Rio Grande at Cochiti Lake (however there is a dam separating the river from the lake by two miles), spanning a distance of about 285 square miles. On its descent, the river fills up two very important reservoirs: the Nichols and McClure, both of which lie above the city of Santa Fe and supply it with about half of the city's water. As seen in both our model and the real world, the water levels in the river and the reservoirs usually peak between late-April and mid-July, however, because of damming, the Santa Fe River is mostly dry throughout the year. In a watershed, water can be lost in four major ways (only two of which we accounted for in our model): infiltration, evapo-transpiration, runoff, and animal consumption. Infiltration is the absorption of water by the soil, which accounts for a very small percentage of loss. Runoff, the surface flow that occurs when the soil is infiltrated to full capacity, and evapo-transpiration, the combined loss of water due to evaporation and plant transpiration, are the two that we accounted for because they make up about fifty percent of water loss in a watershed. Lastly, human consumption is the use of water by humans, but because it is taken from reservoirs above the city of Santa Fe, it does not affect the data produced by our model.

A map of the Santa Fe Watershed that we created. It displays the source of the river, the course of the river, where the Buckman Direct Diversion Pipeline is, and also where water consumers are (the city of Santa Fe as well as farms and residences around La Cienega).

III. Model And Programming

There were many steps in the process of programming our model of the Santa Fe Watershed in NetLogo. First off, we had to collect and import a realistic GIS model of the elevation and terrain of the watershed boundary. This was done by gathering many different .asc/.shp/.xml files of each aspect of the watershed to have the most in-depth visualization of the area itself. Once this was successfully achieved, we had to develop a program that accounted for gravity. That way, the water would follow the elevation GIS and run downhill until it disappears off the edges of the map. Next, after making sure that everything was working properly, we were able to incorporate precipitation levels (rainfall along with snow in the winter months) based on the local averages for the last 50 years and per month, so that there would be accurate amounts of water filling up the river. We also created a slider, which allows for variance in precipitation by about half an inch in either direction to account for wet and dry years. From there we put in the four color-coded transfer stations (only two of which we actually use) with realistic latitude/longitude points so that the water levels could be measured like they are in the real Santa Fe River. After that, we wrote code to tell the transfer stations to measure the amount of water, treated as a breed of turtles, passing through them each tick and send those numbers to a graph. The two graphs produced by the model correspond to the two real-life measurement sites at Ricardo Road and St. Francis Drive. Lastly, we included a timer that converted the amount of ticks that have passed into months, so the program knows when to end the yearly data collection. We could then compare the NetLogo produced graphs to the ones based on real-world levels at the river gauges. Once all of that was complete, we fixed all the bugs and ended up with an accurate model of the Santa Fe Watershed that can project stream-flow values for the Santa Fe River during various wet and dry years. These graphs only differed in the fact that the total water was affected only by average evaporation and not by any other water loss/usage variables.

IV. Screenshots And Code



A screenshot of the model running.

The blue particles represent rain, the white represent snow, the transfer stations are represented by the colored circles, and the elevation of the area is represented by the background shading (the higher elevations are lighter).

```
to datado
  set-current-plot "plot 1"
  set-current-plot-pen "water2"
   plot sum [count waters-here with [snow? = false]] of water2-patches

   set-current-plot "plot 2"
   set-current-plot-pen "water3"
   plot sum [count waters-here with [snow? = false]] of water3-patches
end
```

The section of code that creates the stream-flow graphs.

```
gis:load-coordinate-system (word "data/Arroyos.prj")
set rivers-dataset gis:load-dataset "data/Arroyos.shp"
set countries-dataset gis:load-dataset "data/SantaFeWatershedwithVegetation.shp"
gis:set-world-envelope (gis:envelope-union-of (gis:envelope-of rivers-dataset)
                                              (gis:envelope-of countries-dataset))

set elevation gis:load-dataset "data/SantaFeElevation_30meter.asc"
gis:set-world-envelope gis:envelope-of elevation
let horizontal-gradient gis:convolve elevation 3 3 [ 1 1 1 0 0 0 -1 -1 -1 ] 1 1
let vertical-gradient gis:convolve elevation 3 3 [ 1 0 -1 1 0 -1 1 0 -1 ] 1 1
set slope gis:create-raster gis:width-of elevation gis:height-of elevation gis:envelope-of elevation
set aspect gis:create-raster gis:width-of elevation gis:height-of elevation gis:envelope-of elevation
let x 0
repeat (gis:width-of slope)
[ let y 0
  repeat (gis:height-of slope)
  [ let gx gis:raster-value horizontal-gradient x y
    let gy gis:raster-value vertical-gradient x y
    if ((gx <= 0) or (gx >= 0)) and ((gy <= 0) or (gy >= 0))
    [ let s sqrt ((gx * gx) + (gy * gy))
      gis:set-raster-value slope x y s
      ifelse (gx != 0) or (gy != 0)
      [ gis:set-raster-value aspect x y atan gy gx ]
      [ gis:set-raster-value aspect x y 0 ] ]
    set y y + 1 ]
  set x x + 1 ]
gis:set-sampling-method aspect "bilinear"
```

The section of code that imports and sets up the multiple GIS layers.

```
ask waters
[ if snow? = true[ if seasons < 9 and seasons > 3 [ if timetodie <= ( 100 + random 500)[
      set snow? false
      set color blue]]
]
  set timetodie timetodie - 1
  if snow? = false[
  forward random-normal 0.05 0.05
  let h gis:raster-sample aspect self
  ifelse h >= -360
  [ set heading subtract-headings h 180 ]
  [ ]
  if count waters in-radius 1 <= 20 [forward random-normal 0.05 0.05] ]
]
tick
```

The section of code that makes the water flow downhill according to elevation.

V. Mathematics And Logistics

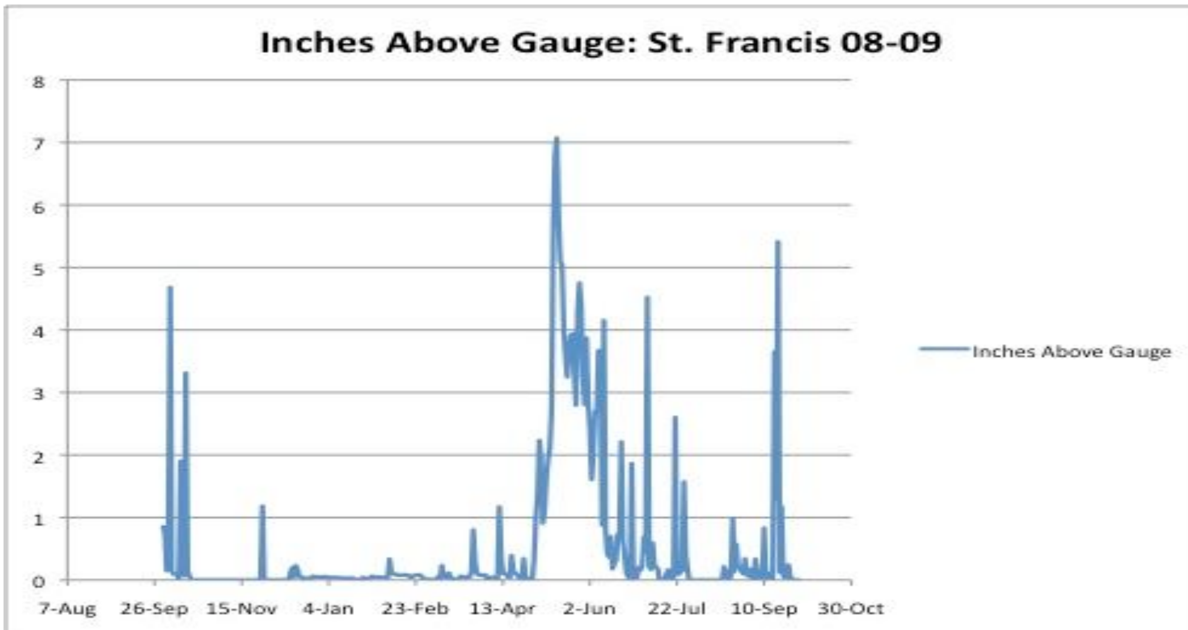
To truly understand the correlation between our model and the real world, mathematics can be used to calculate true values that our data resembles. Lets begin with the size of our Netlogo “world”, the area that our model covers. This can be thought of either in Netlogo patches or real-world units (square miles, acres, etc.); let’s begin with the latter. By using Netlogo to geo-coordinate the maximum and minimum x-y coordinates of our “world”, we calculated its dimensions to be 149,209’ x 111,907’, which is roughly 599 square miles. In our model, one thousand turtles represent one inch of rain, so we can use that as an example to calculate how much rain each turtle represents in real-world measurements (acre-feet, gallons, etc.). First, we converted the area of our map into acres, which ended up being about 383,251 total acres. Next we had to divide those acres by one inch of water to calculate the amount of acre-feet that one thousand turtles represent, which came out to 31,937.6 acre-feet being released every time it rained one inch. To put that into perspective the total annual precipitation in 2009 was 14.9 inches. The City of Santa Fe has recently agreed to release 1,000 acre-feet of water into the Santa Fe River annually from the upriver dams at Nichols and McClure during normal to wet years.

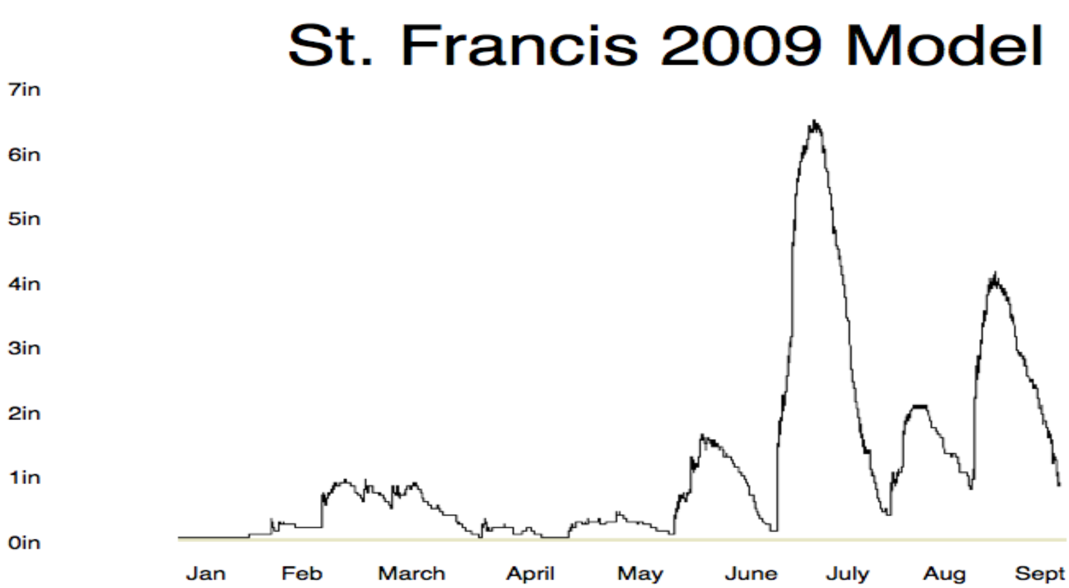
Now that we know what we’re dealing with, let’s calculate how much water is coming down in a common unit: gallons. Since one inch, we know, represents 31,937.6 acre-feet and each acre-foot is approximately 325,361 gallons, we get that 1.04 x 10^11 gallons of water are flowing through our model for each inch of precipitation. Therefore, each turtle represents 1.04 x 10^8 gallons of water. That’s enough to supply a single person with water for about 2,315 years!

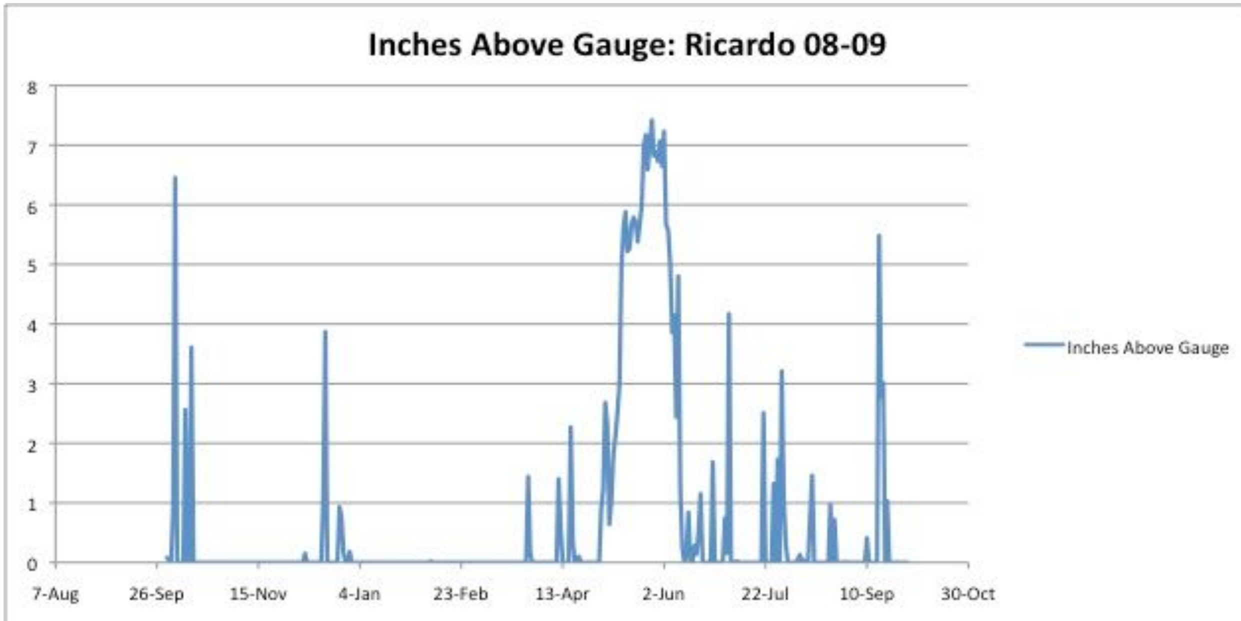
Lastly, we can calculate the size of each patch in our world in acres; to show how much land we are actually modeling. The dimensions of our world in patches are 120 x 90, or about 10,800 total patches. If we divide our earlier calculation of 383,251 acres by the number of patches, we get that each patch represents about 35.5 acres (approximately .055 square miles).

VI. Results And Analysis

The upper graph represents real world data for a stream gauge and the lower graph was produced by our model. *Note that the real world graphs begin and end three months earlier than our graphs.







As you can see, the graphs match up quite nicely with peaks in graphs matching up with a small margin on error. This error is due to the fact that we can't control the exact date that rain falls, and therefore causes the graphs to rise. There is also a discrepancy in the steepness of the peaks, probably because our evaporation and infiltration rates were off, causing the water to remain near the gauge and continue being measured.

VII. Conclusion Statement

In conclusion, we achieved our goal of creating an accurate model of the Santa Fe Watershed. Through this experience we have learned very much about the watershed and the many aspects that go into it, such as where water goes in a rainstorm and how water is lost through infiltration and evapo-transpiration. By checking our model with real-world data we not only proved its accuracy but also found room for improvement. For example, in the future we will have more exactly calculated evaporation and precipitation amounts to make our model even more precise. We also hope to re-add the Buckman Direct Diversion Pipeline and human consumption optimization aspects into our model now that we know its capacity; this way our program can become more than just a model. Our significant original achievement was that of being the first team of people to successfully model the Santa Fe Watershed in its entirety, in which we take great pride. We hope to be able to improve and perfect our model from here so that we may soon release it to the public to better educate them about where their water is coming from and how much is actually available to the community.

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