Preparation of Input Information for SPRINT Model: Relationship between Discharge, Water Height and Catchment Area

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Introduction – Project Scope

A key challenge for hydrology is modeling and predicting flows in a massive continental-scale river network such as the Mississippi or the Amazon. To fully describe the water movement within a river channel the 3D Navier-Stokes and continuity equations are required (Liu and Hodges, 2012). However, in river networks a simpler model is commonly used in place of the Navier-Stokes equations: the Saint-Venant equations. To date, no one has successfully solved the Saint-Venant equations or simulate a Saint-Venant-based model for a 10th-order river network. (Hodges, 2013)

In this framework, a Simulation Program for River Network (SPRINT) was developed by Dr. Liu and Dr. Hodges (2012). SPRINT is a new model, written to address the grand challenge for river modeling: represent the physical dynamics of river flow in a continental-size basin (Hodges, 2012).

As stated in SPRINT User Manual (Liu, 2012), SPRINT will generally need the following input information:

- Node delimitation,
- Bottom slope,
- Manning's "n",
- Cross Section, and
- Discharge

Bottom slope and the node delimitation can be extracted and/or predicted by Digital Elevation Models (DEM) for the study area. The scope of this project will attempt to find a relationship between discharge (Q) and water height (h)[1]. Manning's "n" usually has a wide range of uncertainty and thus, it can serve as a calibration parameter.

[1] Water height is a function of cross-sectional area (A).

Study Area

This study will focus on the Guadalupe and San Antonio basins. The Guadalupe and San Antonio River watersheds are located in south-central Texas. The Guadalupe River basin has a drainage area of 6 700 square miles and the San Antonio River basin has a drainage area of 4 180 square miles.

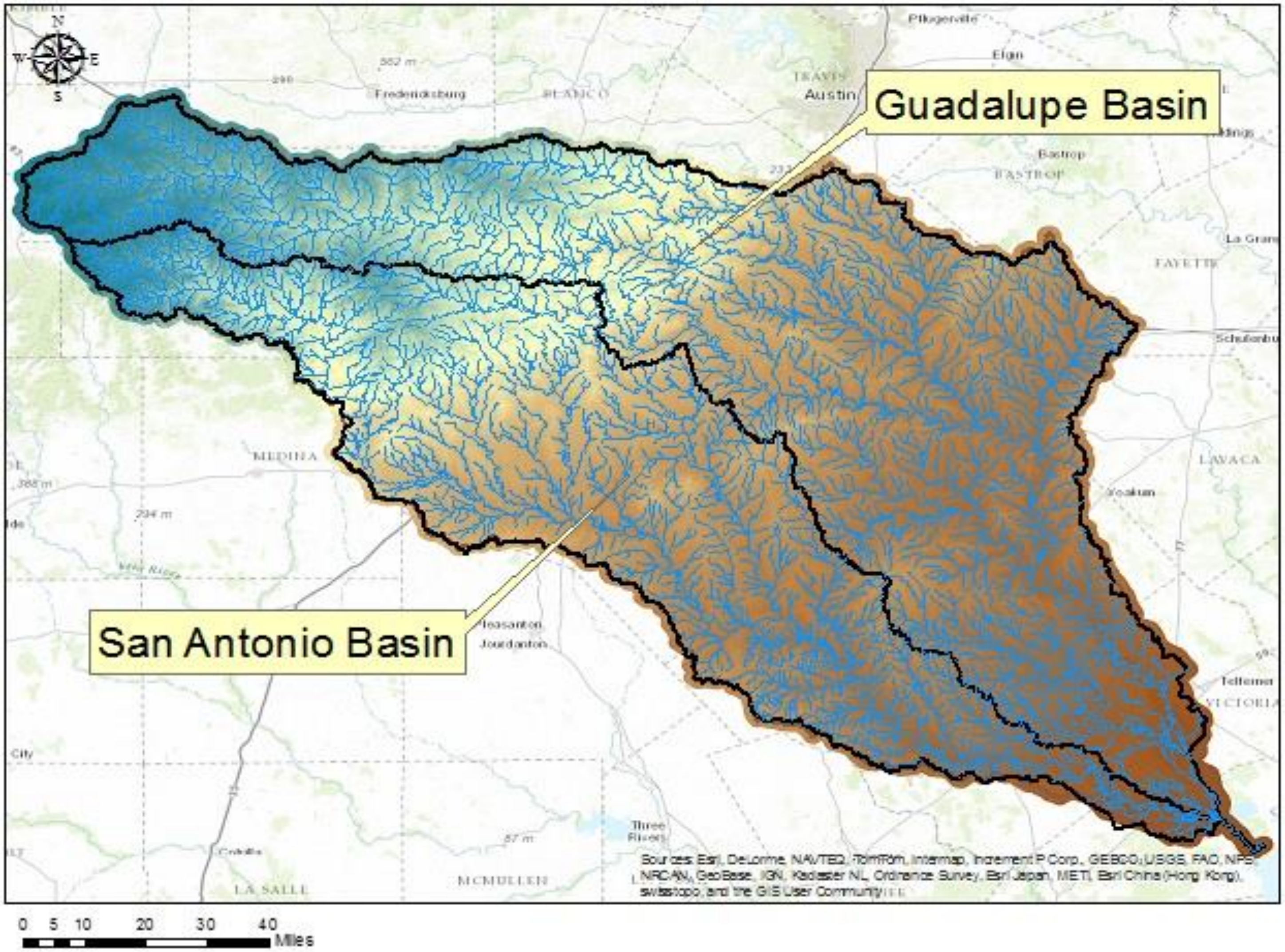
The San Antonio River basin is a dynamic ecosystem with rivers, creeks and streams that can quickly be impacted by rain events and other weather conditions. This basin is bordered on the west by the Nueces River Basin and on the east by the Guadalupe River Basin. Most of the San Antonio River Basin is rural. Average elevation of the basin is 229 meters; the lowest and the highest elevation are 2 and 710 meters. Average slope is 1.38 degrees and average aspect of the basin is 133.6 degrees southeast (Durmus Cesur, 2005).

The Guadalupe River basin is the fourth largest river basin whose watershed area is entirely within Texas. The flow is controlled by Canyon Dam, and by the amount of rainfall the area has received. However, the Guadalupe River is prone to severe flooding. During the rainy seasons the water can reach well above the banks of the river and exceed "normal" levels (Guadalupe-Blanco River Authority, 2008).

Figures 1 presents the overall location of the study area, while Figure 2 presents in detail the Guadalupe and San Antonio River basins.

Figure 1
General Location of the Study Area

Figure 2
Location of the San Antonio and Guadalupe Basins



Methodology

Saint-Venant Equations

The Saint-Venant equations are based on certain approximations. These approximations are:

- Flow is one-dimensional
- Hydrostatic pressure prevails and vertical accelerations are negligible
- Streamline curvature is small.
- Bottom slope of the channel is small.
- Manning's equation is used to describe resistance effects
- The fluid is incompressible

Saint-Venant equations can be presented as follows:

- Continuity equation:

$$w\frac{\partial h}{\partial t}+\frac{\partial Q}{\partial x}=q_l$$

- Momentum equation:

$$\frac{\partial Q}{\partial t}+\frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right)+gA\frac{\partial h}{\partial x}=gA(S_o-S_f)$$

where "h" is the water height, "Q" is the flow rate, A is the cross-sectional area, S_o is the bottom slope of the river segment, and S_f is usually called "friction slope", which is usually determined by the classic Chézy-Manning formula:

$$S_f=n^2\frac{Q^2}{A^2}\frac{1}{R^{\frac{4}{3}}}$$

As seen from the continuity, momentum and friction equation, there are two independent variables in Saint-Venant equations: flow rate "Q" and cross-sectional area "A", which can be a function of water height "h". Once "Q" and "h" are known, the other quantities are dependent functions of "Q", "h" and river cross-section geometry (Hodges, 2012).

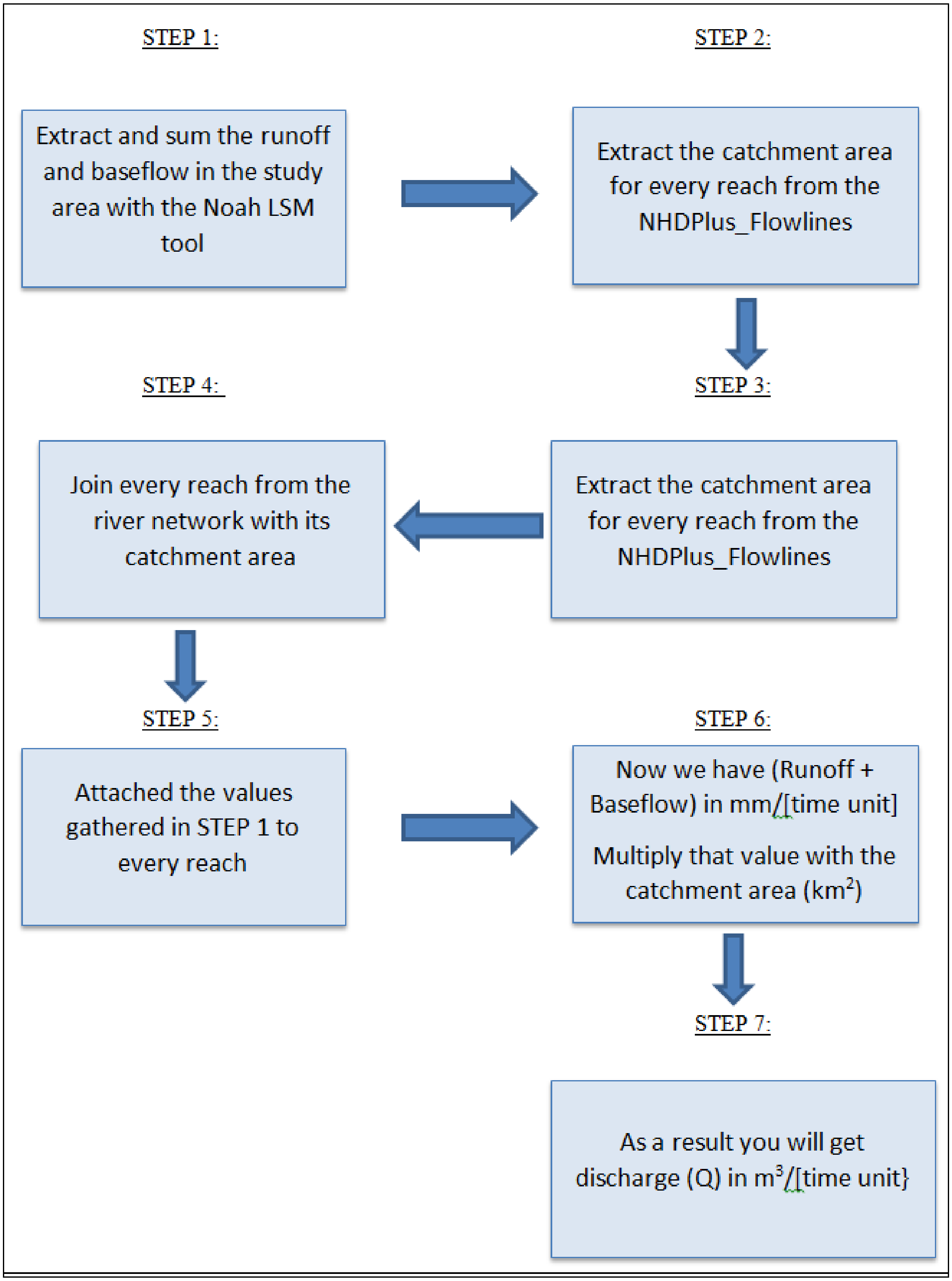
Discharge – Land Surface Models

As stated previously, the SPRINT model will need discharge information in every computational node (reach). Being the objective to model continental-scale river networks, Land Surface Models (LSM) arise as an accurate, computational and economic efficient alternative.

The Global Land Data Assimilation System (GLDAS) is generating a series of land surface state (e.g., soil moisture and surface temperature) and flux (e.g., evaporation and sensible heat flux) products simulated by four land surface models (CLM, Mosaic, Noah and VIC) (Fang et. al 2008).

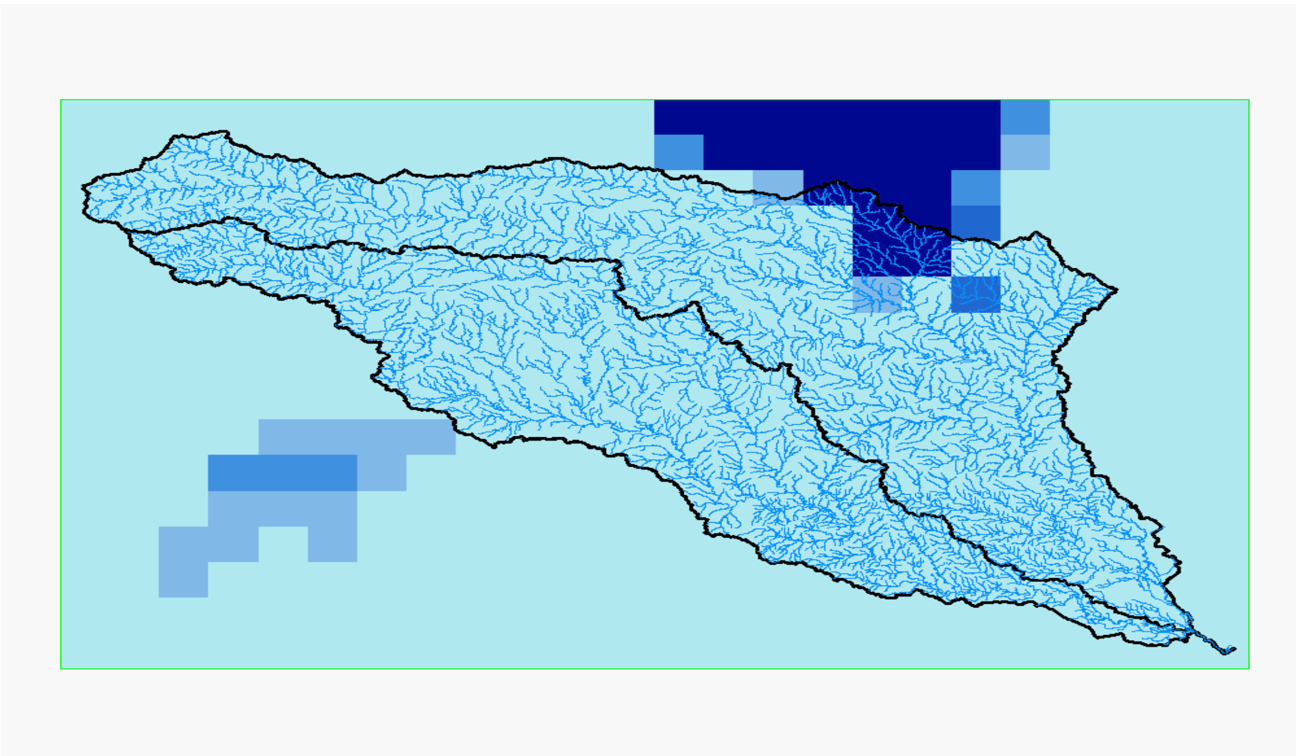
Due to its capabilities and more available information, Noah Land Surface Model was selected to generate the discharge information needed for the SPRINT model. In Diagram 1, I present the steps to calculate the discharge (Q) for every reach in the Guadalupe and San Antonio River Network.

Diagram 1
Step by step presentation to estimate discharge for every reach in a river network in ArcGIS



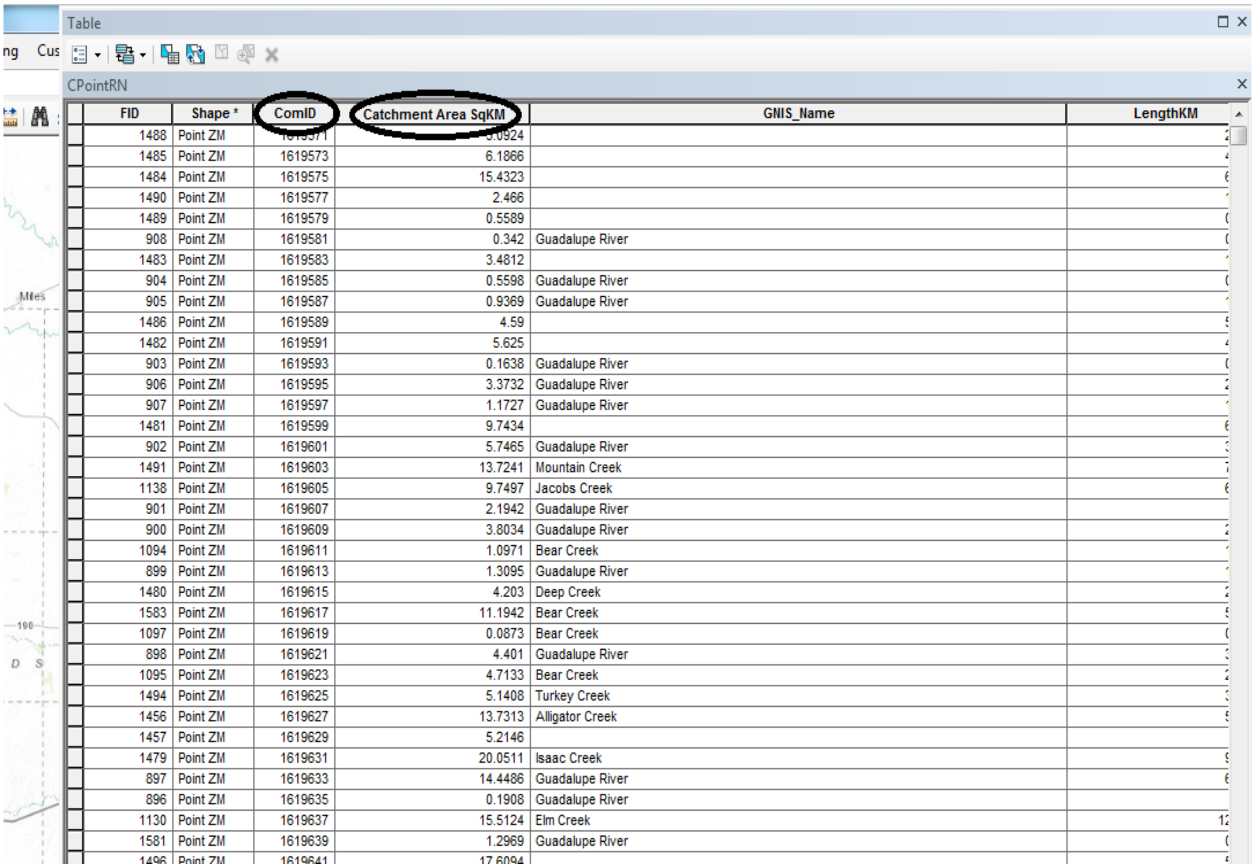
STEP 1 will use the LDAStools created by Gonzalo Espinoza to get some data from the NASA Land Data Assimilation System for the San Antonio and Guadalupe Basin. In Figure 3, we can see the overland runoff of the study area for a 1-hour time step.

Figure 3
Overland Runoff Information for the Guadalupe and San Antonio basin



In Figure 4 we can see the ID (ComID) and the catchment area for every reach in km^2.

Figure 4
ComID and Catchment area for every reach in the San Antonio and Guadalupe Basin



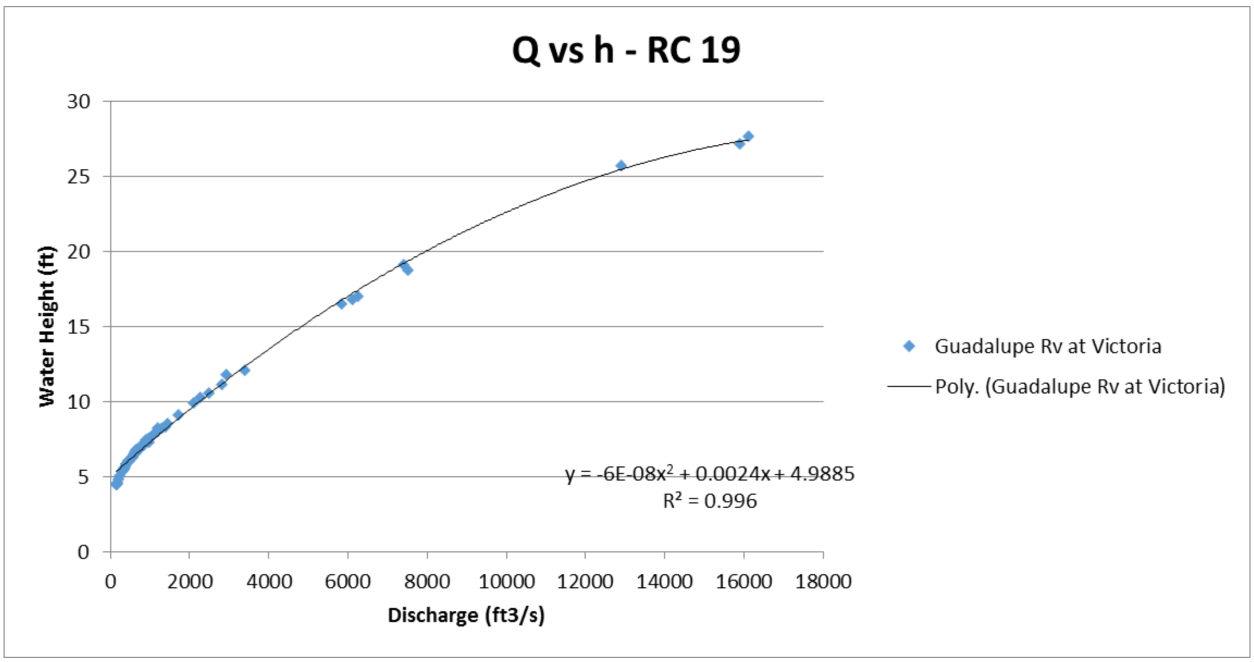
FID	Shape *	ComID	Catchment Area SqKM	GNIS_Name	LengthKM
1488	Point ZM	[illegible]	[illegible]		
1485	Point ZM	1619573	6.1866		
1484	Point ZM	1619575	15.4323		
1490	Point ZM	1619577	2.466		
1489	Point ZM	1619579	0.5589		
908	Point ZM	1619581	0.342	Guadalupe River	
1483	Point ZM	1619583	3.4812		
904	Point ZM	1619585	0.5598	Guadalupe River	
905	Point ZM	1619587	0.9369	Guadalupe River	
1486	Point ZM	1619589	4.59		
1482	Point ZM	1619591	5.625		
903	Point ZM	1619593	0.1638	Guadalupe River	
906	Point ZM	1619595	3.3732	Guadalupe River	
907	Point ZM	1619597	1.1727	Guadalupe River	
1481	Point ZM	1619599	9.7434		
902	Point ZM	1619601	5.7465	Guadalupe River	
1491	Point ZM	1619603	13.7241	Mountain Creek	
1138	Point ZM	1619605	9.7497	Jacobs Creek	
901	Point ZM	1619607	2.1942	Guadalupe River	
900	Point ZM	1619609	3.8034	Guadalupe River	
1094	Point ZM	1619611	1.0971	Bear Creek	
899	Point ZM	1619613	1.3095	Guadalupe River	
1480	Point ZM	1619615	4.203	Deep Creek	
1583	Point ZM	1619617	11.1942	Bear Creek	
1097	Point ZM	1619619	0.0873	Bear Creek	
898	Point ZM	1619621	4.401	Guadalupe River	
1095	Point ZM	1619623	4.7133	Bear Creek	
1494	Point ZM	1619625	5.1408	Turkey Creek	
1456	Point ZM	1619627	13.7313	Alligator Creek	
1457	Point ZM	1619629	5.2146		
1479	Point ZM	1619631	20.0511	Isaac Creek	
897	Point ZM	1619633	14.4486	Guadalupe River	
896	Point ZM	1619635	0.1908	Guadalupe River	
1130	Point ZM	1619637	15.5124	Elm Creek	
1581	Point ZM	1619639	1.2969	Guadalupe River	
1496	Point ZM	1619641	17.6094		

Relationship between Discharge and Water Height

As seen in the previous section, we now have the discharge (Q) for every computational reach that will be used in the SPRINT model. This section will attempt to describe a trend between “Q”, “h” and the catchment area (CA).

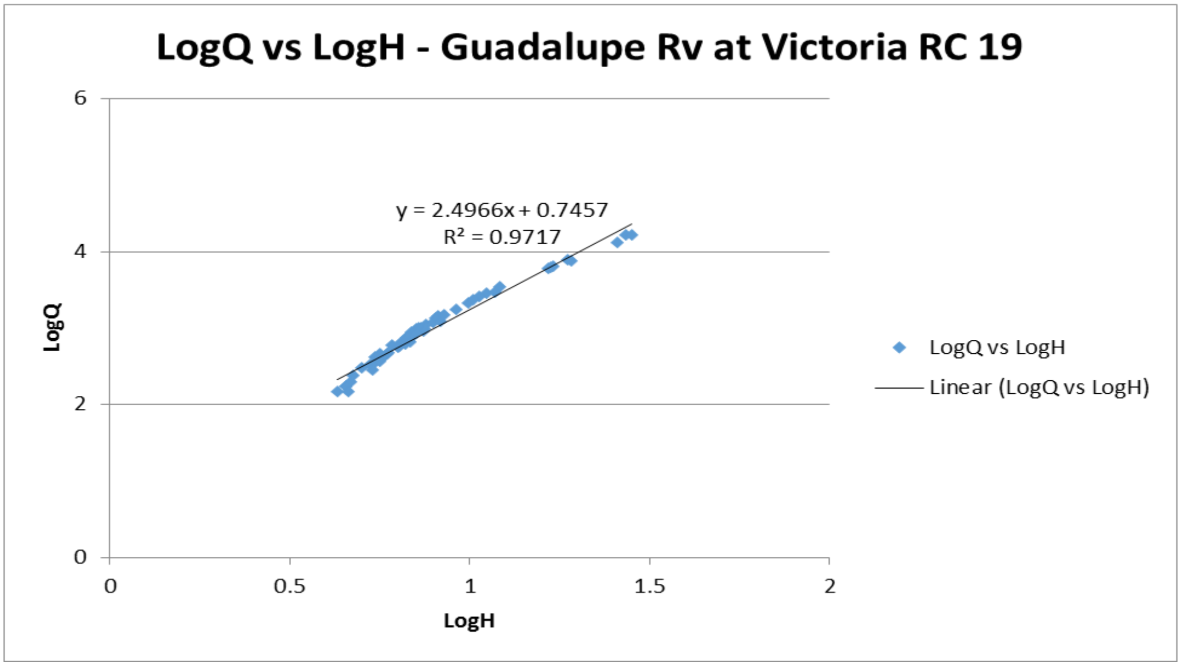
First, we need to understand the relationship between the discharge and water height in a stream. In hydrology, a rating curve (RC) is a relationship between discharge and water height for a given point on a stream, usually at gauging stations, where the stream discharge is measured across the stream channel with a flow meter. Figure 5 presents a RC for the Guadalupe River at Victoria.

Figure 5
Rating Curve from the Guadalupe River at Victoria



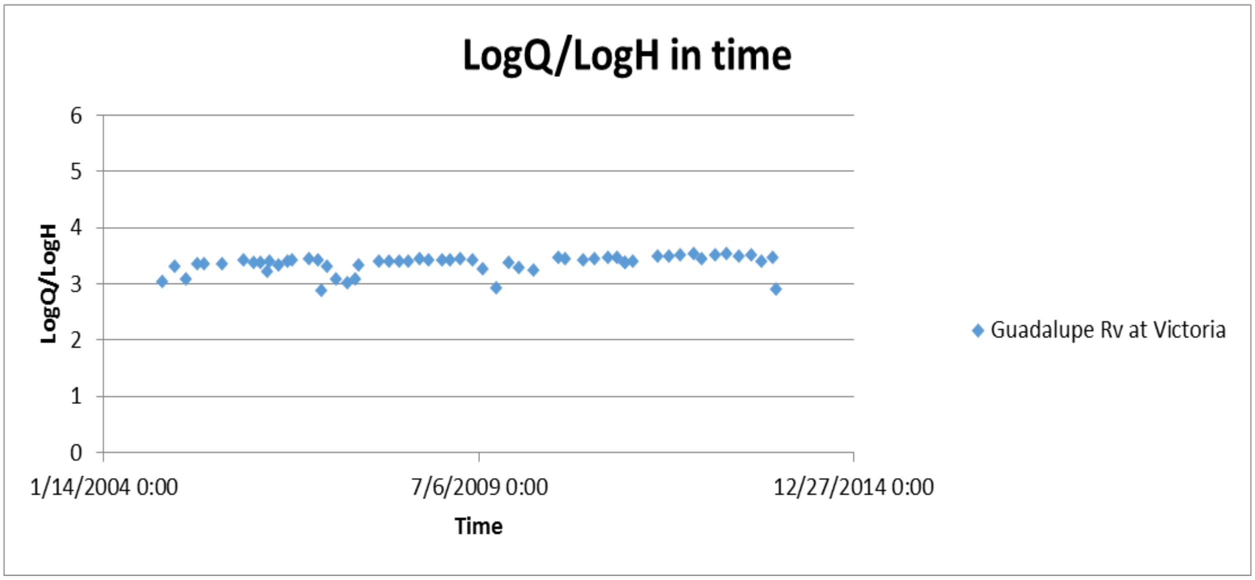
Logarithmic scales can be very useful when displaying data with a large range. That is the case for the discharge (Q) and water height (h). Thus, in Figure 6, we will see the relationship between Log (Q) and Log (h).

Figure 6
Log (Q) vs. Log (H) - Guadalupe River at Victoria



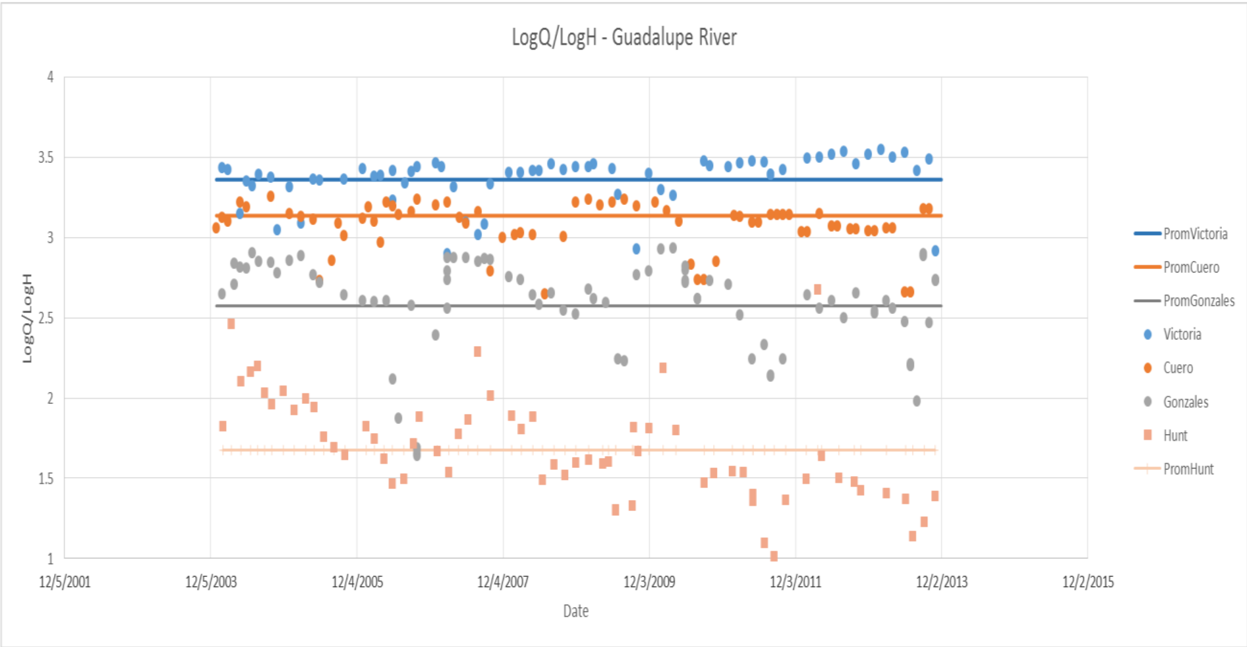
From Figure 6, we see that there can be a linear relationship between Log (Q) and Log (h) in the Guadalupe River at Victoria. Now we will plot Log (Q) / Log (h) over item (See Figure 7).

Figure 7
Trend of Log (Q) / Log (h) through time at Guadalupe River at Victoria



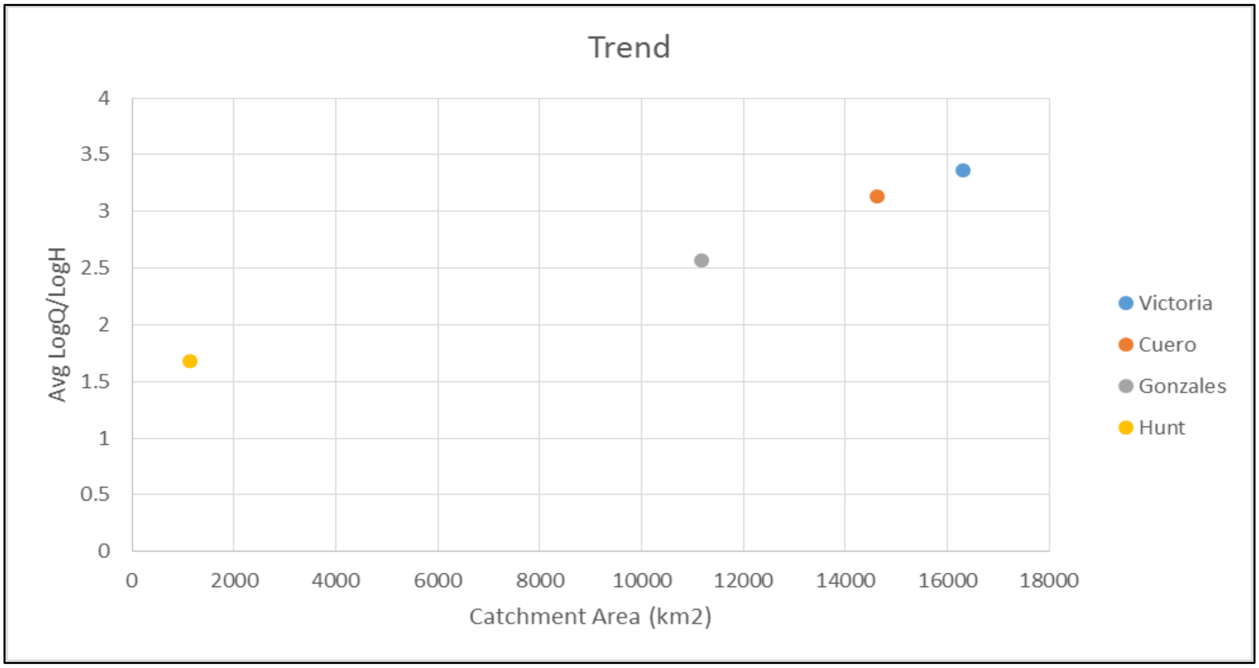
From Figure 7 we can see that we can have a good average from Log(Q)/Log(h) in time. If we analyze other sections of the Guadalupe river and averaged the Log(Q)/Log(h) in time, we have (See Figure 8):

Figure 8
Trends in different sections of the Guadalupe River



From Figure 8, and knowing that the catchment area of the Guadalupe River at Victoria > Cuero > Gonzales > Hunt, we can induce a trend for Log(Q)/Log(h) and the catchment areas, like in Figure 9.

Figure 9
Relationship between Log(Q)/Log(h) and catchments area in the Guadalupe River



Results

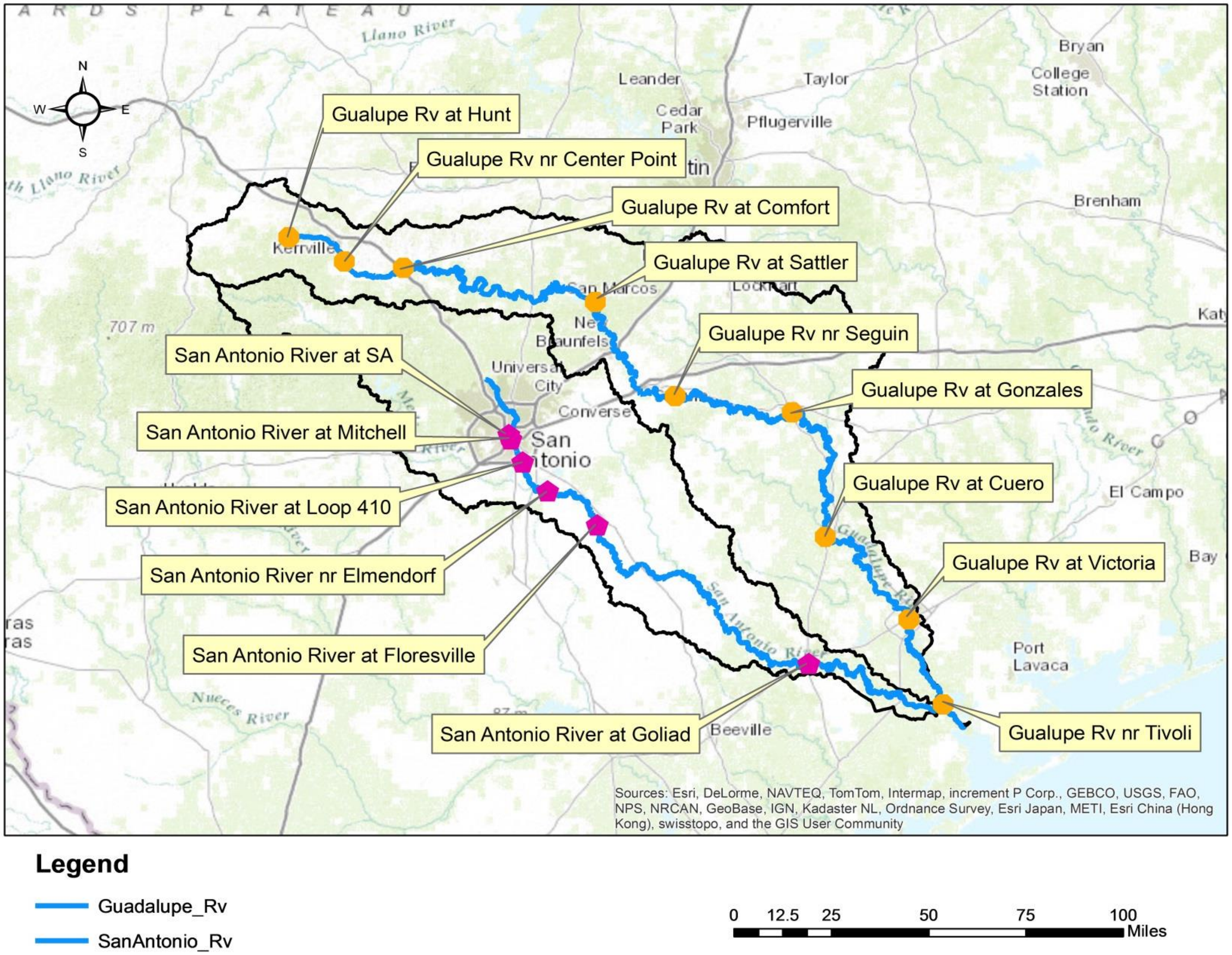
The San Antonio River and the Guadalupe River basins have approximately, 25 stream-flow measurement stations. In this study we have investigated 15 of them, 6 in the San Antonio River basin and 9 in the Guadalupe River basin. Figure 10 and Table 1 present the different stations. The timeframe for the studied measurements are usually between 3-5 years (as seen in Figure 7 and 8).

Table 1
Information of the stream-flow stations

River Basin	Station Name	Station Number	Catchment Area (km^2)*	Average LogQ/LogH	Rating Curve
San Antonio	San Antonio Rv at San Antonio, TX	8178000	112	2	22, 21 & 20
	San Antonio Rv at Mitchell St, San Antonio, TX	8178050	122	1.86	6.1
	San Antonio Rv at Loop 410, San Antonio, TX	8178565	296	2.18	9 & 8.1
	San Antonio Rv nr Elmendorf, TX	8181800	4528	2.23	16
	San Antonio Rv nr Floresville, TX	8183200	5050	3	5 & 4
	San Antonio Rv at Goliad, TX	8188500	10081	4.01	18
Guadalupe	Guadalupe Rv at Hunt	8165500	744	1.5	6.1
	Guadalupe nr Center Point	8166250	1432	2.8	2
	Guadalupe Rv at Comfort	8167000	2181	3.1	27.1, 27 & 26
	Guadalupe Rv at Sattler	8167800	3721	3.06	5
	Guadalupe Rv at FM 1117 nr Seguin	8169792	4883	2.3	3
	Guadalupe at Gonzales	8173900	8891	2.6	7 & 6
	Guadalupe at Cuero	8175800	12789	3.1	8.1
	Guadalupe at Victoria	8176500	13500	3.36	19
	Guadalupe Rv nr Tivoli	8188800	26203	4.8	3 & 2

* Note: Information extracted from NHDPlus_Flowlines

Figure 10
Location of measurement stations



The following figures (Figure 11 to Figure 13) introduced the relationship between Log(Q)/Log(h) and the catchment area for the San Antonio and Guadalupe basin.

Figure 11

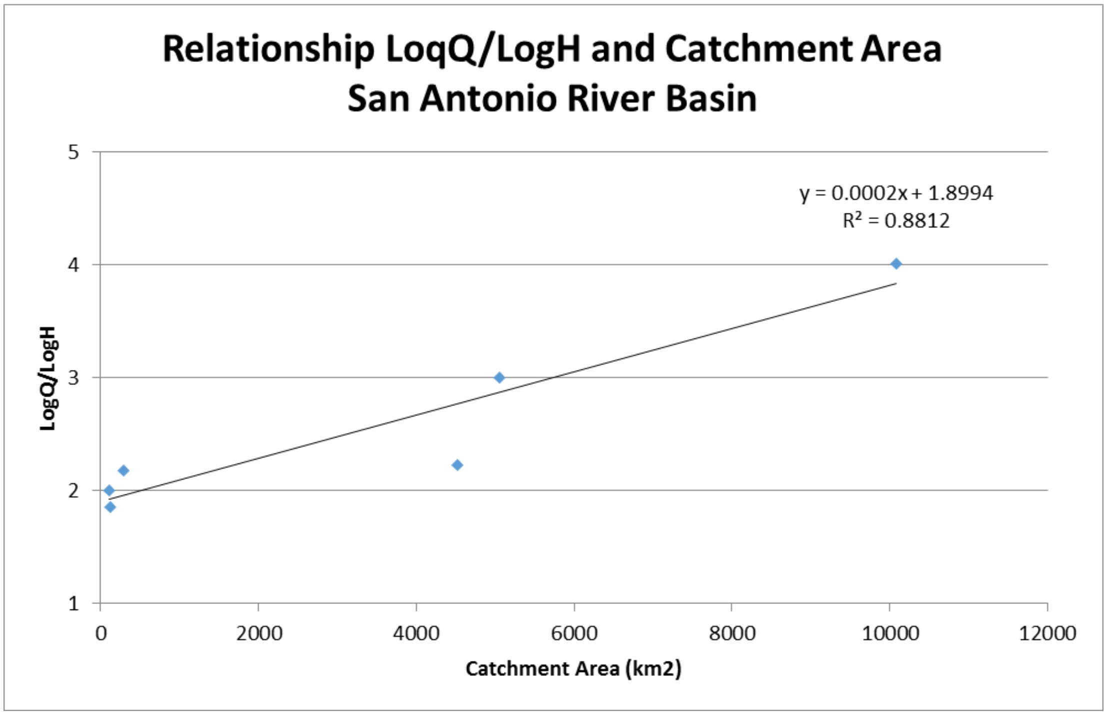


Figure 12

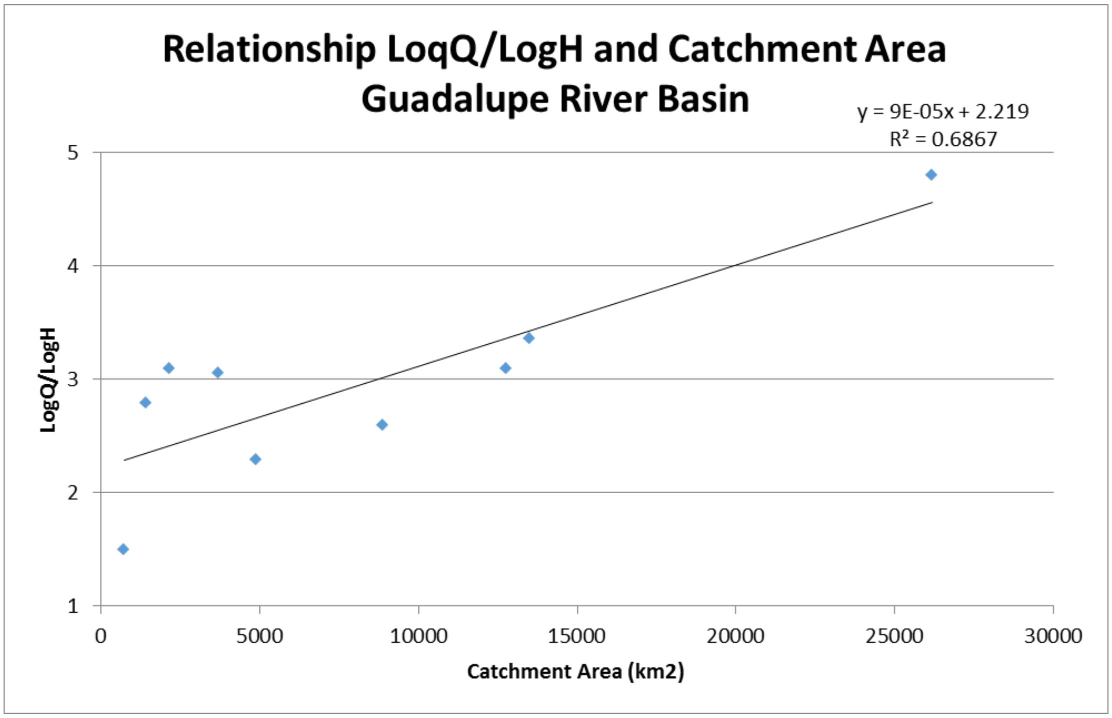
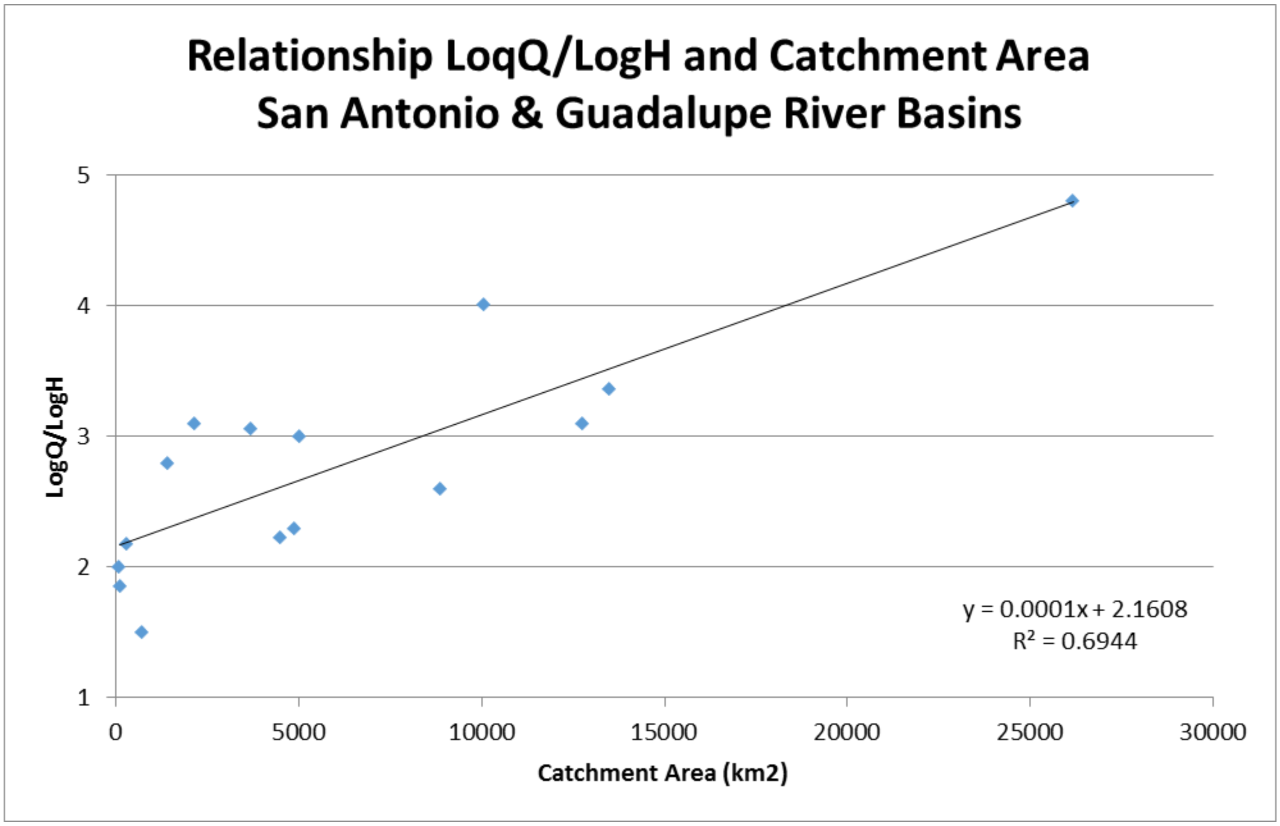


Figure 13



Conclusions

As part of this project, a relationship between discharge (Q) and water height (h) has been developed for the Guadalupe and San Antonio River basins, if the catchment area is known. The following equation presents the relationship:

$$\frac{Log(Q)}{Log(h)} = 10^{-4}CA + \alpha$$

Where "Q" is the discharge, "h" is the water height, "CA" is the catchment area, and "α" is the relationship coefficient. This relationship will serve as input information for the SPRINT model, as it can calculate "h" for any given "Q" and "CA". And as seen before, discharge can be obtained from Land Surface Models (LSM). Finally, this study should/could be replicated for other basins and see if the trend continues.