A Additional Materials

This component of the proposal is to illustrate the level of background work relevant to this project. This component should be read after the required components of the proposal - it does not make sense without the main body.

A.1 Physics-based County Scale Prototype

Figure 1 is a screen capture of an exploratory county scale hydraulics model built using EPA SWMM 5.0. The figure displays red labels at locations where the county operates

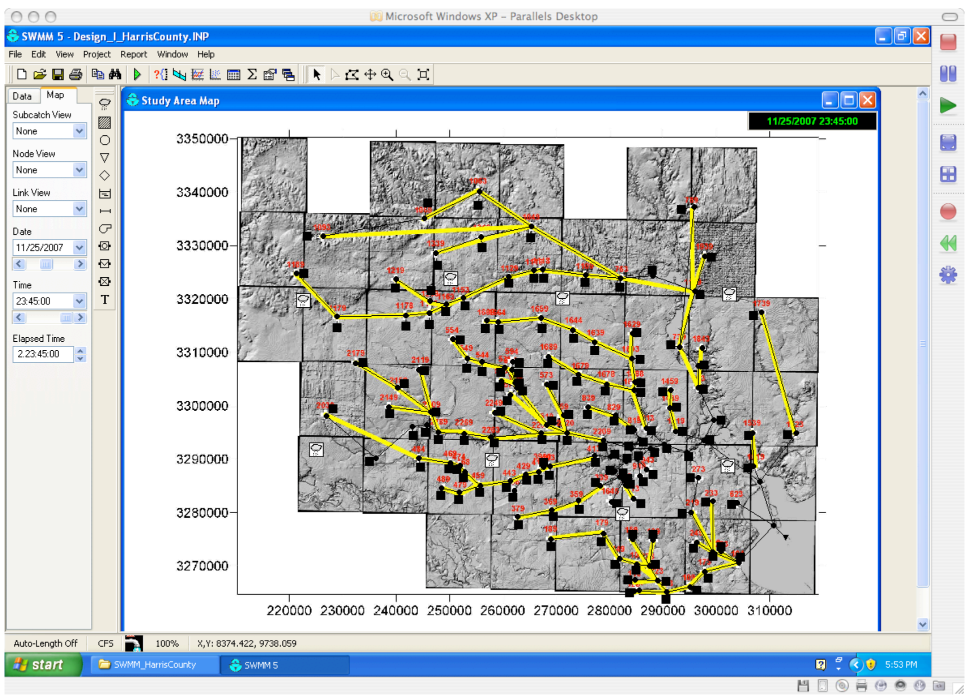

Figure 1: Harris County Network Model. Labeled nodes identify co-located rainfall and stage gages. Branches are hydraulically independent under most flow conditions.

paired raingages and stage (depth) gages. The f igure also displays black nodes and links;

these are the hydraulic elements in the SWMM model. Of relevance for this proposal are the yellow "branches." The proposal body states that the transfer function network can be decomposed into independent elements and these computed in parallel. The unconnected yellow branches are such independent elements. In the figure there are 11 independent branches depicted, although the PI believes additional disconnections can be justified. The branches eventually connect east of downtown Houston, but this location can be handled with a forced boundary value.

This type of network model represents the physics-based side of the hybrid approach. The author is aware that SWMM is a link-node model, and the overland component is not well modeled using this tool. The proposed effort will estimate depths at the red labels and use these depths as inputs to the mapping routine.

The model in Figure 1 was built by a team of undergraduate students under direct supervision of the PI. The rainfall for November 24, 2007 was supplied to this hydraulics model and the peak predicted discharge (all branches) was about 75,000 cfs. Observed discharges for the same time period (collated from USGS real-time data) was about 90,000 cfs. These values are reasonably close considering the model was never calibrated, but built using strictly hydraulic elements and average literature values for friction terms.

A.2 Comparison of Physics-based and Transfer function-based computations

To illustrate the applicability of using a physics-based model to parameterize a transfer function model an experiment using a small watershed with paired rainfall-runoff data is presented. The transfer function used both the methods reported in Cleveland and others, 2008. The physics-based model used the EPA SWMM model with a relatively fine spatial resolution[1].

Figure 2 is an aerial image of the watershed used in the experiment, along with the the structure of the SWMM model used in the experiment.

There were 23 paired rainfall-runoff events for which data were available to test the performance of either model. Like the county level model, no calibration was performed, instead the models are constructed using topography, link geometry, and realistic friction parameters or characteristic velocities. These 23 events were simulated and compared to observations and each other.

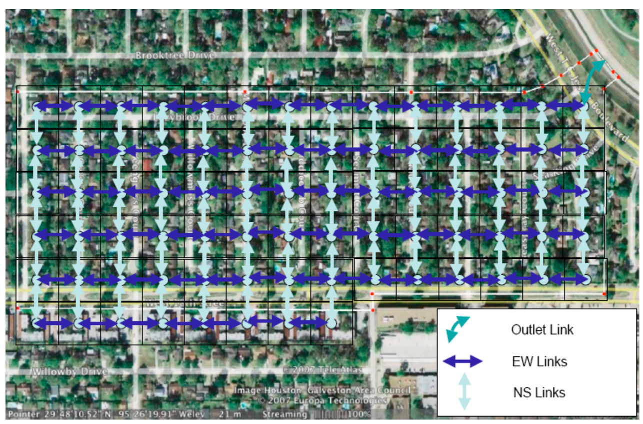

Figure 2: Lazybrook SWMM model

Figures 3 and 4 compare observed and simulated hydrographs by both methods for a selected storm. This particular plot pair is an example of a better performing simulation. The

[1]In fact the spatial dimensions used in the experiment is well beyond what EPA SWMM was ever designed to handle. It is a testament to the original developers of SWMM and the many programmers involved that the program produced stable results. The courant condition required time steps in fractions of a second (consider that default time step in the program is 20 minutes).

relative percent-error at the peak discharge value is about the same for either simulation method.

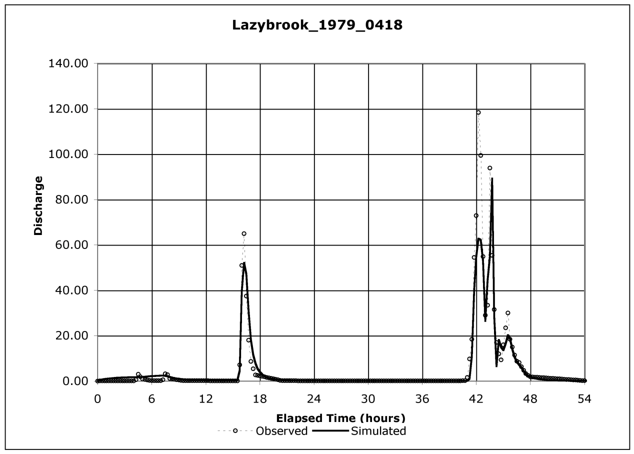

Figure 3: SWMM results for 1979_0418 storm.

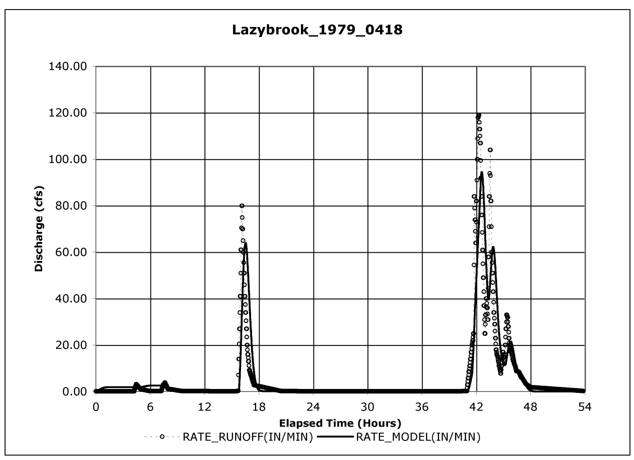

Figure 4: GIUH results for 1979_0418 storm.

To quantify the behavior for each storm a set of metrics was computed to compare the two methods to the observations and to each other; these metrics are

1. $\%V_{error}$, A measure of volumetric error – a mass balance requirement. The metric is

computed using Equation 1.

$$\%V_{error} = 100 \times \frac{V_{obs} - V_{sim}}{V_{obs}} \tag{1}$$

Ideally, this value should be close to zero.

2. $RMSE_{Qp}$, The root-mean-square error of the discharge. The metric is computed using Equation 2.

$$RMSE_{Qp} = \sqrt{\frac{(Q_{obs} - Q_{sim})^2}{n}} \tag{2}$$

Ideally, this value should also be close to zero.

3. $\%Qp_{error}$, The relative error of the peak discharge values. The metric is computed using Equation 3.

$$\%V_{error} = 100 \times \frac{Qp_{obs} - Qp_{sim}}{Qp_{obs}} \tag{3}$$

Ideally, this value should also be close to zero.

4. $\%Tp_{error}$, The relative error of the time of peak discharge. The metric is computed using Equation 4.

$$\%V_{error} = 100 \times \frac{Tp_{obs} - Tp_{sim}}{Tp_{obs}} \tag{4}$$

Ideally, this value should also be close to zero.

Table 1 lists the metrics for 23 storms examined in the study using the GIUH methodology and convolving the observed[2] 1-minute rainfalls to produce the outflow hydrograph. Of note in this table is that the $\%V_{error}$ is quite small for all the storms. This result is

[2] Albeit interpolated.

anticipated because the excess rainfall is computed for each storm from the observations. A similar approach was used in the SWMM model effort so as to be supplying nearly identical input. The values in the table are truncated for computed values with greater reported digits than shown. The trailing zeros for such entries are not significant and these zeros were added to improve the readability of the table.

Table 1: GIUH Summary Results

STORM_ID	Qp_{obs}	Qp_{mod}	Tp_{obs}	Tp_{mod}	$\%V_{error}$	$RMSE_{Qp}$	$\%Qp_{error}$	$\%Tp_{error}$
79_0418	118.9	94.4	42.3	42.6	-0.69	8.8	20.59	-0.83
79_0819	118.9	51.6	14.3	14.8	0.06	12.53	56.58	-3.86
79_1030	118.9	59.3	16.8	17.3	0.06	10.6	50.08	-2.88
80_0327	98.9	45.2	15.6	16.0	0.06	4.88	54.27	-2.35
80_0425	49.9	30.4	10.9	11.4	0.06	5.17	39.21	-3.81
81_0423	118.9	54.8	9.6	10.0	0.06	8.55	53.89	-3.65
81_0504	118.9	59.6	17.9	18.3	0.06	11.06	49.88	-2.23
81_0625	88.9	52.5	11.4	11.6	0.06	5.29	40.93	-1.91
81_0710	49.9	4.9	18.1	18.5	0.06	5.29	90.26	-2.59
81_1005	43.0	16.3	15.1	15.5	0.06	3.56	61.96	-2.65
82_0513	115.9	30.5	13.3	16.6	0.06	13.02	73.7	-24.44
82_0613	88.9	52.7	18.8	18.7	0.06	6.54	40.72	0.53
82_1102	14.0	6.0	17.4	17.5	1.1	1.17	56.88	-0.67
83_0209	33.0	16.7	13.5	14.0	-0.05	2.17	49.41	-3.69
83_0220	62.9	38.9	21.5	21.9	0.06	3.87	38.26	-1.7
83_0811	88.9	52.4	13.3	13.7	0.06	7.77	41.01	-3.01
83_0910	110.9	69.4	18.0	18.4	0.06	9.4	37.42	-1.94
84_0323	78.9	54.4	20.0	20.4	0.06	7.57	31.07	-2.08
84_0705	93.9	49.9	16.6	16.9	0.06	8.16	46.85	-2.01
84_0805	104.9	42.1	14.4	15.3	0.06	13.58	59.87	-6.12
85_1124	97.9	69.7	14.1	13.1	0.06	15.84	28.8	7.2
86_0615	108.9	73.4	13.4	13.7	0.06	6.64	32.61	-2.25
87_0523	55.9	40.8	14.1	14.5	0.06	5.09	27.08	-2.6

Table 2 lists the metrics for 23 storms examined in the study using SWMM 5.0 and the observed[3] 15-minute rainfalls to produce the outflow hydrograph. Of note in this table is that the $\%Tp_{error}$ is small for several storms. This result is a direct consequence of sampling at 15-minute intervals from the 1-minute data constructed for the GIUH method. Likewise

[3]The observed values are samples from the 1-minute intervals, thus there will be disagreement in peak values, but the values should be reasonably close to one another.

this sampling is also the cause of different reported observed peak discharges.

Table 2: SWMM Summary Results

STORM_ID	Qp_{obs}	Qp_{mod}	Tp_{obs}	Tp_{mod}	$\%V_{error}$	$RMSE_{Qp}$	$\%Qp_{error}$	$\%Tp_{error}$
79_0418	118.4	89.2	42.3	43.8	10.48	5.63	24.63	-3.55
79_0819	101.9	41.3	14.3	14.5	9.17	6.89	59.5	-1.75
79_1030	89.9	41.9	16.8	17	13.67	7.79	53.41	-1.49
80_0327	54.4	43.5	15.8	15.8	3.92	10.61	20.16	0.00
80_0425	45.0	48.0	11.0	11.3	-105.17	9.03	-6.75	-2.27
81_0423	102.4	39.9	9.8	9.8	5.45	7.06	61.06	0.00
81_0504	110.4	47.3	18.0	18.0	0.92	7.79	57.14	0.00
81_0625	62.9	37.3	11.5	11.3	10.02	7.01	40.8	2.17
81_0710	47.0	3.4	18.0	18.8	9.98	1.28	92.84	-4.17
81_1005	23.5	14.4	15.3	15.3	2.72	2.66	38.55	0.00
82_0513	88.4	28.4	13.5	16.3	5.68	8.59	67.91	-20.37
82_0613	68.4	43.2	18.8	18.5	10.4	7.37	36.91	1.33
82_1102	13.5	5.2	17.3	17.3	7.19	1.26	61.71	0.00
83_0209	29.5	14.3	13.5	13.8	7.47	3.13	51.4	-1.85
83_0220	47.0	32.0	21.5	21.8	4.76	6.47	31.75	-1.16
83_0811	88.9	43.6	13.3	13.5	5.3	7.78	50.99	-1.89
83_0910	108.4	49.8	18.0	18.0	10.46	8.91	54.05	0.00
84_0323	69.4	44.8	20	20.3	10.36	7.96	35.49	-1.25
84_0705	84.4	36.4	16.8	16.8	9.56	6.48	56.92	0.00
84_0805	103.4	34.7	14.5	15.0	8.82	8.07	66.42	-3.45
85_1124	84.9	48.5	14.3	12.8	16.43	12.59	42.83	10.53
86_0615	77.9	47.3	13.5	13.5	12.26	8.93	39.25	0.00
87_0523	52.4	34.8	14.3	14.3	5.32	5.44	33.71	0.00

None of the storms are particularly rare; the rarest storm is estimated to be a 65-percentile storm (the median storm is a 50th-percentile storm and rare storms would be a 1-percentile storm).

What the PI's team concludes from these experiments is:

1. The hydraulic model (SWMM) and the geomorphic instantaneous unit hydrograph (GIUH) produce essentially the same performance (and results). This agreement is anticipated as the GIUH and SWMM approach use a common physics.

2. The GIUH once parameterized takes a fraction of the time to compute a response

hydrograph as compared to the SWMM model (less than 2 seconds versus over one minute on the same processor architecture). This result is also anticipated because of the far different nature of convolving on a kernel versus finite difference time stepping.

3. A hydraulics model can conceivably be used to parameterize a transfer function model, thus allowing direct and traceable incorporation of physical change in a system, while maintaining the high speed of transfer functions for operational applications.