Submittal Letter

To: Dan Evans, P.E. – Stormwater Master Planning Manager

From: Gerald Blackler, Ph.D, P.E., D.WRE

Date: October 17th, 2019

Cc: Beck Anderson, Colin Barry, Jeff Sickles

Re: Corrected Effective and Existing EPA SWMM Model for the Foothills Basin

Dear Mr. Evans,

This letter accompanies a digital submittal of the corrected effective and Existing EPA SWMM5 model for the Foothills Basin and portions of Spring Creek. Our previous submittal included the duplicate effective model, which documented the changes from MODSWMM software to EPA SWMM 5.1.013. This submittal modified the duplicate effective with the following steps to create an Existing model:

1.) Model CE1-A: Updated the impervious values with the most recent National Land Cover Database (NLCD).
2.) Model CE1-B: Updated 1-A to include topographic changes in drainage areas and slopes.
3.) Model CE1-C: (Existing): The final existing model added channel cross section geometry, pipes and manholes from City's most recent GIS data, and adjusted any routing lengths based on the most recent data.
4.) Model CE1-D (Existing Dynamic): This is the existing model (CE1-C) updated to run using dynamic flow routing equations.

The steps taken to convert the MODSWMM hydrologic model to an Existing Kinematic and Dynamic Wave model, which are bulleted above, are also presented in the graphic below.

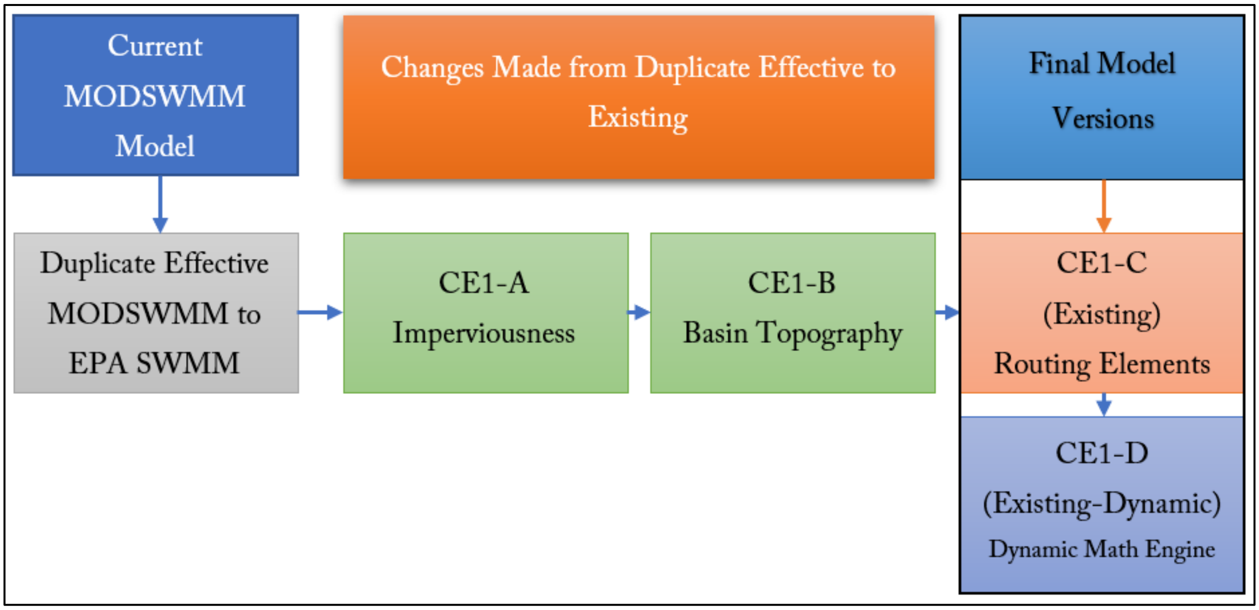

Figure 1 - Graphic of the Model Conversion Process

Conversion to the Dynamic model initially had large flow routing continuity errors that were in excess of 19%. A comparison with SWMM version 5.1.012 did not show the same flow routing continuity error. Upon further investing the error, we found that the model was having difficult time converging after most of the stormwater had drained and the flow rates were very low. To correct this, the model simulation time was reduced to 12 hours. This corrected the flow routing continuity error and reduced it to -1.55%, which is within standards of practice for hydrologic routing.

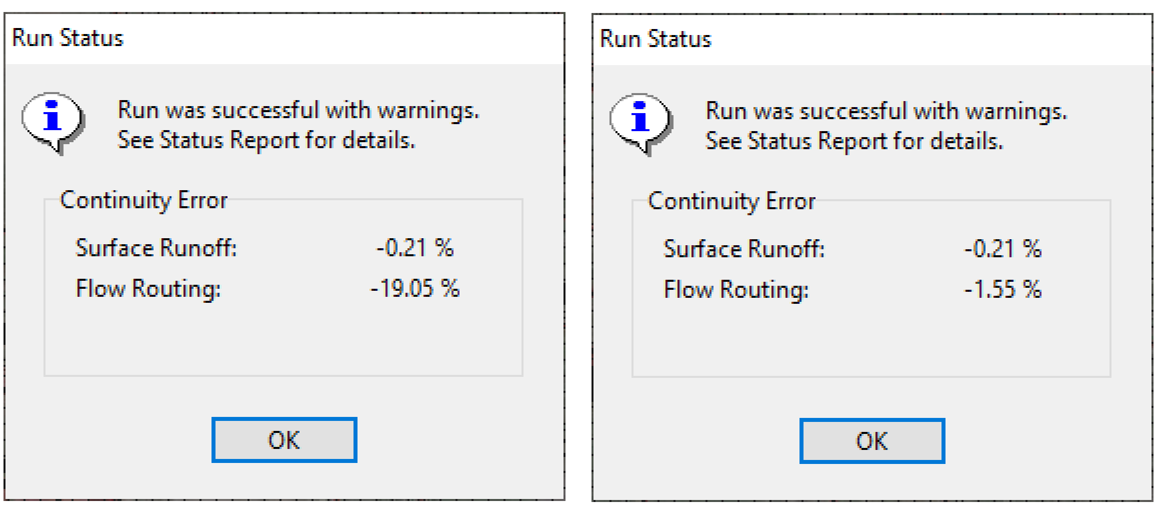

Figure 2 - (Left) Continuity error for 48-hour simulation, (Right) Continuity error for a 12-hour simulation in Dynamic Wave Routing with EPA SWMM 5.1.0.13

Attached to this submittal letter, we have a more detailed documentation of our findings. The next phase of this project consists of the preliminary design for the Drake and Lemay Intersection. We will convene as a group at 10:00am on September 19th and afterwards start on the next phase.

Please let me know if you have any questions.

Sincerely,

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Enginuity
Engineering Solutions

Enclosures:

- Summary of Model Development
- Digital Files (attached separately).

Summary of Model Development

Project Background and Purpose

On June 20th, 2019 Enginuity Engineering Solutions (Enginuity) and the City of Ft. Collins (City) entered into an agreement to provide a master plan update for the Foothills Basin and services for preliminary stormwater design at the Drake and Lemay intersection. As part of the Master Plan Update, Enginuity has been scoped to convert the original Stormwater Management Model (MODSWMM) to the most recent version of EPA SWMM (EPA SWMM5). Enginuity has proposed the following steps for this model update:

1.) Develop a duplicate effective model: A duplicate effective model has the exact same inputs as the original model and the only change is the updated software. (Submitted 7/30/19)
2.) Develop a corrected effective model: A corrected effective model takes the duplicate effective model and updates for changes in land use, topography, and other changes that have occurred since the original model was developed.
3.) Develop a proposed conditions model: This model builds on the corrected effective model to input proposed changes to the stormwater system.

The purpose of steps 1 through 3 are to document the change in flow rates from each iteration so the City will know what changes are from software alone, are from physical changes in the watershed, and what changes will occur from any proposed conditions. The purpose of this summary is to submit step 2 above, the corrected effective model. Like the overall approach of documenting change over each iteration, a series of corrected effective models were created to isolate the impact of different changes made to the model.

Development of Corrected Effective Model – 1A (CE-1A)

Model Development Notes

Percent impervious is one of the most sensitive inputs within EPA SWMM5. The parameter effects infiltration, runoff, and depression storage within each of the subcatchment meaning that any changes will have a significant effect of the modeling results. As such, Enginuity create an initial model to isolate the changes associated with an update to the percent impervious within each subcatchment.

The National Land Cover Database (NLCD 2016) raster file of land use types developed by the Multi-Resolution Land Characteristics Consortium in 2016 was used to approximate the composite percent impervious for each subcatchment. Corresponding percent impervious values for each land use type from the Fort Collins Stormwater Criteria Manual table 4.1 and 4.2 were used to calculate a composite percent impervious value from existing imagery captured in 2016 (Figure 1).

The total change throughout all the sub-basins was an increase in percent imperviousness from 48.75% in the effective model to 49.87% in CE-1A, an increase of 1.12%. Despite the minor overall change, there are areas of changes in percent impervious values from the effective MODSWMM file to CE-1A when comparing individual sub-basins (Impervious_Difference.pdf). Reasons for these slight changes are explained below and assumptions made during modeling are described below:

1) **Open Water.** A value of 100% impervious was used for open water. This is consistent with City of Fort Collins practices.
2) **Existing vs. Future.** An existing model is all that is required to effectively mitigate flood hazard areas within the Foothill Basin. Areas of recently land use change (Supporting_Shapefiles\ Development_Change_Areas.shp), some of which was not captured in the NLCD 2016 area highlighted in Impervious_Difference.pdf.
3) **Developed, Open Space.** A value of 20% was used as the impervious value for developed open space based of City of Fort Collins Criteria Manual (FCCM). The potential overlap with Urban Estate areas (30% imperviousness) was deemed to be a minor issue.

Comparison of Peak Flow Rates

The overall change to the percent impervious values throughout the model was a slight increase of 1.12%.. Table 4 below presents a comparison of peak flow rates at selected locations with a percent difference between the duplicate effective model and the corrective effective model 1A.

Table 1 - Comparison of Peak Flow Rates at Select Locations (CE-1A)

Location Description	Node ID	MODSWM Model (2010 Update)	Duplicate EPA SWMM5 (Ver 5.1013)	Corrected Effective – 1A (Land Cover)	Percent Difference (Dup to 1A)
Drake and Lemay Intersection	740	1,586	879	815	-8%
Inflow into Warren Lake	49	770	320	290	-10%
North Outfall	97	126	96	94	-2%
South Outfall	96	1,151	756	768	2%
Nelson Farm Pond	56	546	444	464	4%
Drake and Ridgen Pkwy	184	161	104	92	-12%
College South of Swallow Rd.	129	260	140	129	-9%
				Average	**-5%**

Summary from CE-1A Effort

In summary, the following are conclusions from this phase of the project:

- A corrected effective model with changes only to percent impervious values was successfully developed.
- Three main contributors to changes were identified and a map (Impervious_Difference.pdf) showing areas of change and development was created.
- Peak flows are reduced on average by 5 percent.

Development of Corrected Effective Model – 1B (CE-1B)

Model Development Notes

Following the updates to the percent imperviousness values for each subcatchment, a model (CE-1B) was created to quantify the impacts of changes made to the model based on more accurate spatial and topographic information including pipe lengths, pipe sizes, subcatchment areas, open channel lengths, overflow channel length, rim elevations, and invert elevations. In addition to these factors, it was decided to use a method developed by Guo and Urbonas (2007) (Guo Method), described in detail in the SWMM Reference Manual Vol. 1. The following includes all the changes made within this iteration of the model.

- Recalculated subcatchment areas with geographic information software (G.I.S.) software. The average changes in subcatchment area was a decrease of 0.064 acres.
- Changed the pipe sizes within the model to match the infrastructure database.
- **GIS Match.** Adjusted the position and length to better represent the G.I.S. infrastructure database provided by Fort Collins, including links 90, 91, 446, 133, 76, 77, 307, 64, 244, 11, 133, 134, 14, 142, 150, 152, 153, 154, 156, 163, 173, 178, 188, 257, 35, 36, 361, 40, 401, 43, 441, 446, 5, 53, 54, 543, 548, 55, 6, 61, 67, 7, 77, 78, 81, 85, 86, 88, 94, 97, 554, and 453. (A detailed list of length changes is available in the Detailed_Model_Changes.xlsx) The average percent difference in the pipe lengths that were altered was a decrease of 10%.
- **Overland Flow Paths.** Overflow link lengths were changed to match the pipe length if the water flows along a pipe alignment, or the overland flow path length. The overland flow paths were delineated using G.I.S. software (Supporting_Shapefiles\Flow_Paths.shp).
- **Subcatchment Width Calculation.** The Guo Methods was used to update the subcatchment width to a more physically based measure based on methods within the SWMM Manual. A basin skew factor, *Z*, was estimated visually while the main channel was measured using Flow Path delineations with a minimum drainage area of 5 ac. An upper watershed factor, *K*, of 4 was used based on the UDFCD criteria. Using the area of each subcatchment in feet squared along with the other parameters described, the Width can be calculated (SWMM Models\CE-

1B\Width_Calcs.xlsx). These values were used to update the subcatchment widths in this model iteration.

Comparison of Peak Flow Rates

The most sensitive parameter change within this iteration is the change to the subcatchment width. Because the Guo Methods resulted in a decrease of the subcatchment width (SWMM Models\CE-1B\Width_Calcs.xlsx). This reduction in width effectively creates a longer narrower subcatchment which results in a slightly larger time of concentrations and increased attenuation. Figure 2 shows the effect of the width reduction in SUB624 on the 100-year design hydrograph. The width of this basin was changed from 6200 ft. to 2871 ft. resulting in increased attenuation which reduced the overall peak outflow of the subcatchment.

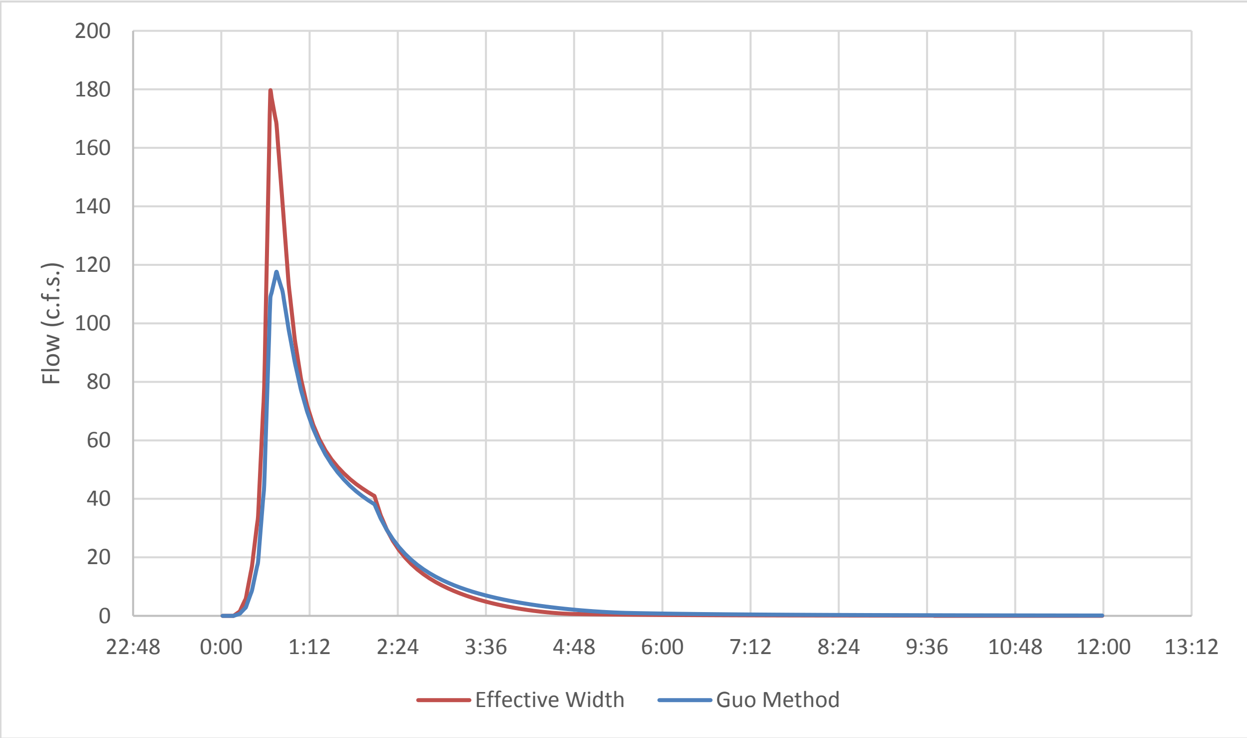

Figure 2: A graph of the flow from SUB624 and the resulting change of the update to Subcatchment Width. The Effective Width refers to the original width values within the MODSWMM model.

These reductions to subcatchment peak outflow are reflected in the peak flows at selected locations. Table 2 below presents a comparison of peak flow rates at selected locations with a percent difference between the duplicate effective model and the corrective effective model 1A.

Table 2 - Comparison of Peak Flow Rates at Select Locations (CE-1B)

Location Description	Node ID	MODSWM Model (2010 Update)	Duplicate Eff. Model	Corr. Eff. – 1A (Land Cover)	Corr. Eff. – 1B (Spatial & Width)	Percent Difference (1A to 1B)
Drake and Lemay Intersection	740	1,586	879	815	542	-40%
Inflow into Warren Lake	49	770	320	290	233	-22%
North Outfall	97	126	96	94	75	-23%
South Outfall	96	1,151	756	768	555	-32%
Nelson Farm Pond	56	546	444	464	364	-24%
Drake and Ridgen Pkwy	184	161	104	92	75	-21%
College South of Swallow Rd.	129	260	140	129	150	15%
					Average	**-21%**

Summary from CE-1B Effort

In summary, the following are conclusions from this phase of the project:

- A corrected effective model with changes only to spatial and topographic parameters including subcatchment width, was successfully developed.
- The Gou Method was used to update the subcatchment width and resulted in an average reduction of -73.4% in the widths throughout the model.
- Overall the changes resulted in a reduction of peak flows by an average by 21%. The reduction is primarily driven by the reduction in width values throughout the model.

Development of Corrected Effective Model – 1C (CE-1C) (Existing)

Model Development Notes

The next iteration of the corrected effective model involved increasing resolution of the model using LiDAR and updating the routing. The following lists generally describes all the changes made during this modeling iteration.

- **LiDAR Sampling.** Transects (Supporting_Shapefiles\Transects.shp) were cut from the 2014 LiDAR and added as irregular cross-section geometries for all applicable open channels and street sections. Links with sampled cross-sections total 94 and are provided on a sheet within Detailed_Model_Changes.xlsx.

- **Entrance / Exit Losses.** Minor losses generally occur at each manhole and account for rapid changes in the magnitude and direction of velocity. Due to the lack of resolution and pipe invert data within the model, only the manholes that represent a change in pipe size, a crossing, or a pivotal flow constriction were added to the model, meaning that minor losses across all the manholes isn't possible. As such, general values of 0.3 and 0.15, for entrance and exit losses respectively, were used for all the pipe junctions. In areas of transition between open channel and pipe flow, like an outfall, culvert, or inlet, a value of 0.5 and 1 was used the entrance and exit coefficient respectively.
- **Added Crossings.** Within the MODSWMM model, there were many open channel links that crossed road without representing those culverts and pipe within the model. Crossings were added to the model to better understand and isolate these areas of potential flooding and overtopping within the open channel system. Some of these crossing did not have dimensions within the GIS database and were verified in the field, including Link 10A, 55A, 60A, 53, 184B, and 35A.
- **Routing Changes.** Using the GIS database provided by Fort Collins, many of the routing schematics and alignments were verified to altered to better reflect the data and flow patterns throughout the area of interest. These areas include the area around Node 49, Link 555, Node 6, Link 14, Link 18, Link 26, Link 45, Link 37, Link 142, Link 173, Link 55, Link 52, Link 53, Link 600, Link 58, Link 77, Link 257, Link 449-OF, Link 133, Link 361, Link 90-OF, Link 94, Link 188, Link 88, and Link 184. In addition to these areas of confirmed change, there are also several areas that will require further conversation and evaluation with the City and Enginuity, including the areas around Link 152, Link 47, Link 36, Link 51, Link 60, Link 552, and Link 553.

Comparison of Peak Flow Rates

Most of the changes described above are limited in their impact of the overall flow rates except for the changes in routing throughout the model. These changes, while adding resolution and accuracy of the model, can significantly change the quantity, timing, and location of stormwater throughout the study area. Different areas are affected in different ways depending on the changes to the upstream routing. The following peak flow comparisons show the different impacts within the model area.

Location Description	Node ID	MODSWM Model	Duplicate Eff. Model	Corr. Eff. – 1A	Corr. Eff. – 1B	Corr. Eff – 1C (Routing)	Percent Diff. (1B to 1C)
Drake and Lemay Intersection	740	1,586	879	815	542	484	-11%
Inflow into Warren Lake	49	770	320	290	233	183	-24%
North Outfall	97	126	96	94	75	77	3%
South Outfall	96	1,151	756	768	555	603	8%
Nelson Farm Pond	56	546	444	464	364	370	2%
Drake and Ridgen Pkwy	184	161	104	92	75	77	3%
College South of Swallow Rd.	129	260	140	129	150	150	0%
						Average	**-3%**

Summary from CE-1C Effort

In summary, the following are conclusions from this phase of the project:

- A corrected effective model with changes to routing, cross-section geometry, resolution and minor losses was successfully developed.
- Areas of GIS and MODSWMM model difference and changes include:
    - Horsetooth Rd. and College Ave.
    - Horsetooth Rd. and Northstar Course
    - Shields St. and Arbor Ave.
    - Northstar Course and Sailors Reef
    - Along Drake Rd. from Stover St. to Lemay Ave.
    - Along Parkwood Dr.
    - Along Del Clair Rd.
- These changes had a varied impact of peak flows throughout the model depending generally on the changes in routing and the system that gained water or lost water. Overall these changes resulted in a decrease at the selected locations of 3%.

Development of Corrected Effective Model – 1D (CE-1D) (Existing Dynamic)

Model Development Notes

The final iteration of the corrected effective models for this submittal involved changing the routing from Kinematic Wave to Dynamic Wave. The goal of this step was to create a more realistic model, accounting for momentum and inertial forces. The list below describes the changes made to the model.

- **Storage and Rating Curve Updates.** The largest task in switching the model routing from kinematic wave to dynamic wave is updating the volume-discharge curves within MODSWMM to more physically based storage and rating curves within EPA SWMM. The update was done to avoid unintentionally storing additional water in channels, overflow channels, and pipes that outfall into detention basins due to backwatering from the storage nodes.
- **Diversion Nodes.** Because dynamic wave routing allows for multiple outlet links without a divider, the model will route diversions more accurately that previous model iterations. It was decided to alter the diversion to allow for the model to calculate the split flow at these locations.
- **Comment Changes.** Aside from the Width Changes and Percent Impervious Updates, all the other model changes were limited to this final iteration because the modeling changes were minor and more for clarity or pipe routing that for large scale shift in modeling parameters.

Comparison of Peak Flow Rates

A change in the routing method can have a drastic effect of the modeling outputs because of the addition of momentum into the calculations, causing backwatering and additional storage. These effects will need to be evaluated in detail to ensure that the model is functioning conservatively and accurately.

Location Description	Node ID	MODSWM Model	Duplicate Eff. Model	Corr. Eff. – 1A	Corr. Eff. – 1B	Corr. Eff – 1C (Routing)	Corr. Eff. – 1D (Dynamic)	Percent Diff. (1C to 1D)
Drake and Lemay Intersection	740	1,586	879	815	542	484	283	-52%
Inflow into Warren Lake	49	770	320	290	233	183	183	-0%
North Outfall	97	126	96	94	75	77	71	-8%
South Outfall	96	1,151	756	768	555	603	492	-20%
Nelson Farm Pond	56	546	444	464	364	370	324	-13%
Drake and Ridgen Pkwy	184	161	104	92	75	77	107	33%
College South of Swallow Rd.	129	260	140	129	150	150	153	2%
							Average	**-8%**

Summary from CE-1D Effort

In summary, the following are conclusions from this phase of the project:

- A corrected effective model using dynamic wave routing was successfully created.
- Diversions were altered to allow the model to split the flows rather than relying on an input table.
- Corrections based on City of Fort Collins comments, additional information, and field verification were added to the model.
- Future Conceptual Pond were updated based on drainage reports provided.
- The changes resulted in an average decrease in peak flows of 8% across the model.