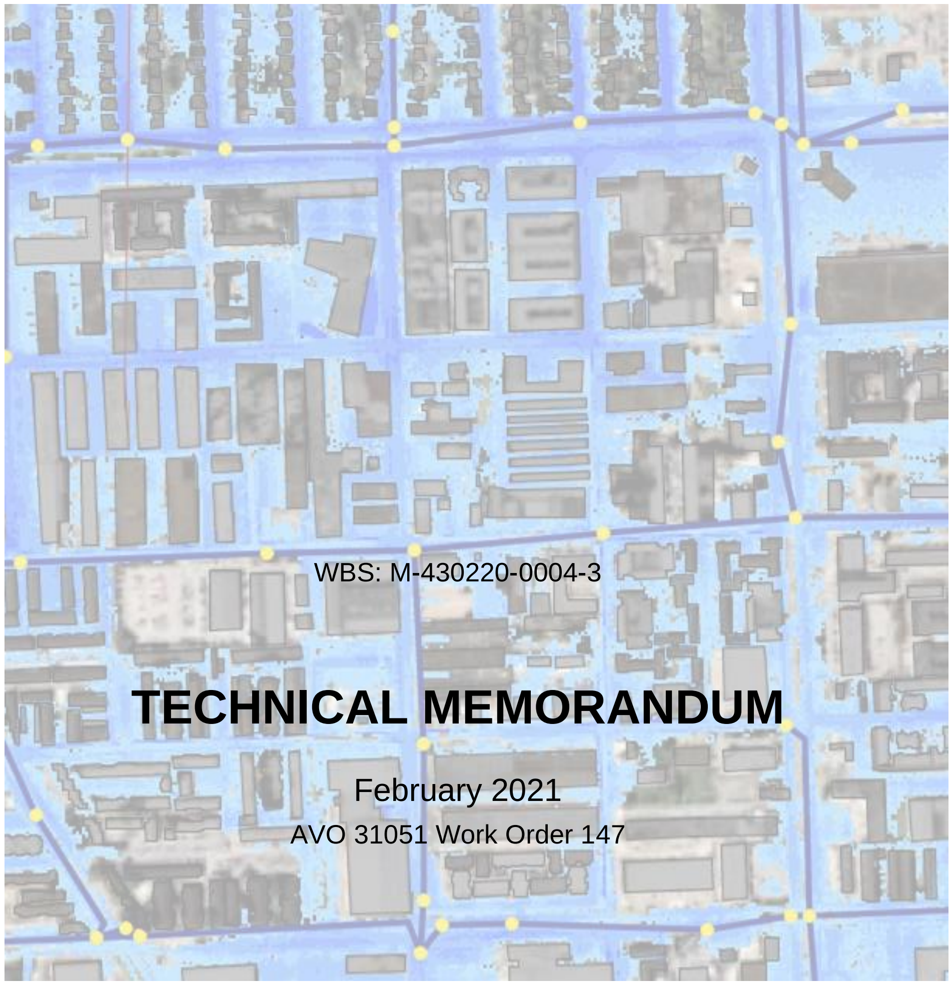
SOFTWARE EVALUATION AND ANALYSIS FOR STORMWATER INFRASTRUCTURE MODELING



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TECHNICAL MEMORANDUM

February 2021

AVO 31051 Work Order 147

Prepared for:

City of Houston

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HALFF

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by

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AVO 31051 Work Order 147
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Executive Summary

The City of Houston is planning to develop a citywide drainage model to facilitate evaluations of infrastructure capacity deficiencies and develop planning-level infrastructure improvements. The city-wide model will include both the subsurface (storm sewer) and surface infrastructure, including streets, overland conveyance, ditches, and bayous. The model will allow for watershed-wide analyses of the drainage infrastructure capacity with consideration of overflows and sheet flow.

Prior to embarking on the drainage model, a software elevation and analysis were conducted to to provide guidance to the City for developing criteria for a city-wide model. The purpose of the evaluation was to identify which stormwater modeling software will be used for the master drainage modeling effort. The software modeling evaluation included 1) the screening and comparison of various stormwater modeling platforms based on several metrics for the analysis and 2) an assessment of the level of model detail required to represent the drainage components in a cost-effective manner.

The initial software screening identified the top three software (FLO-2D, InfoWorks ICM, and XPSWMM) that have the capability perform a city-wide analyses for larger areas of the city's stormwater infrastructure. These were further evaluated by comparing both model development and results. The evaluation concluded that InfoWorks ICM had significant advantages in data management, 2D surface, and simulation runtimes over the other two softwares evaluated. Therefore, it is recommended that InfoWorks ICM should be used for hydrologic and hydraulic modeling for the Citywide stormwater infrastructure model.

The trunkline analysis evaluated the infrastructure detail needed to accurately model the City's drainage patters while managing the detail needed in the model results. The analysis showed that storm sewers equal to or greater than 36 inches in diameter should be included in the model to reduce the amount of trunkline pipe needed while providing similar ponding and flow results. Storm sewers less than 36 inches in diameter should be used only when they provide the singular drainage conveyance from an area of interest.

The next steps in the process include conducting a pilot study for a defined area of the City and using InfoWorks ICM to develop a process and modeling guidelines for conducting development of the city-wide model.

Table of Contents

List of Appendices

1.0 Introduction

The City of Houston (City) is planning to develop a citywide master drainage model to evaluate City drainage infrastructure capacity deficiencies and identify planning level infrastructure improvements. The intent of the master drainage model is to include both the subsurface (storm sewer) and surface drainage infrastructure, such as streets, overland conveyance, ditches, and bayous. This comprehensive model will allow for watershed-wide analyses of the drainage infrastructure capacity with consideration for overflows and sheet flow. The goals of the Citywide Stormwater Infrastructure Modeling effort include:

- Evaluate the existing level of service (capacity) of the drainage infrastructure network to understand potential deficiencies in the existing system
- Identify locations of significant ponding
- Identify overland sheet flow across watersheds and sub-watersheds that may contribute to flooding
- Identify planning level infrastructure improvements that will reduce flood risk based on discovered deficiencies in the system.
- Identify watershed mitigation needs for coordination with the HCFCD based on discovered deficiencies in the system.
- Provide additional information to other drainage models developed for the City such as overflows or downstream boundary conditions since the Citywide models will be validated with historical results and include entire watersheds

1.1 Scope of Work

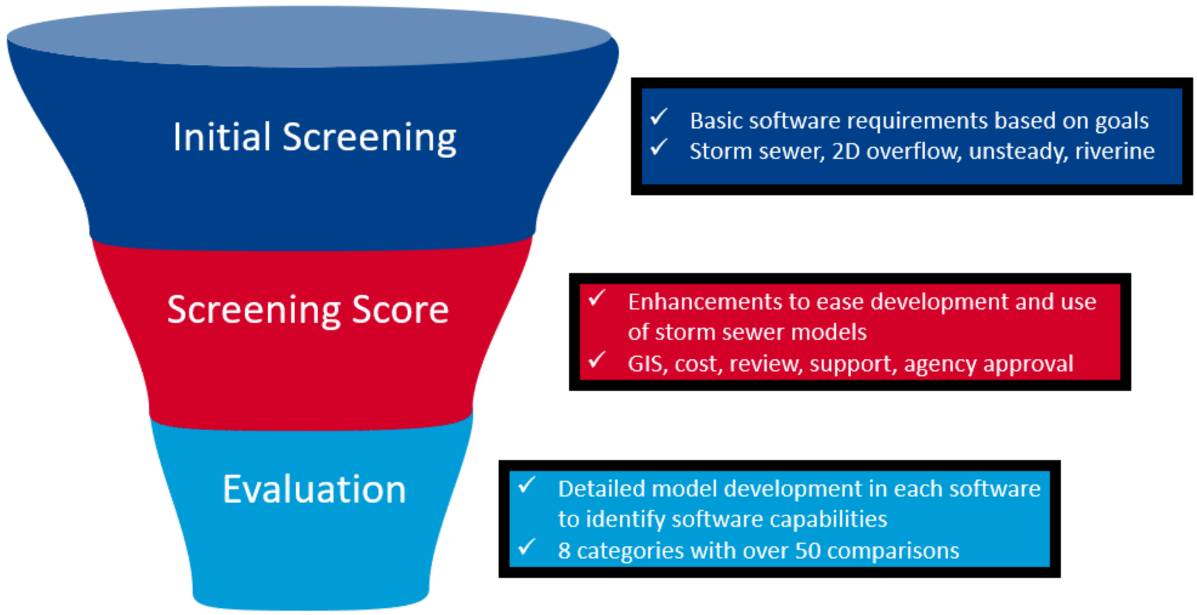
Undertaking a citywide stormwater master drainage planning effort requires planning to evaluate and determine the most effective process for model development and management to achieve the overall goals. In preparation of the plan, an evaluation of stormwater modeling software was performed. The purpose of the evaluation was to identify which stormwater modeling software will be used for the master drainage modeling effort. The software modeling evaluation included 1) the screening and comparison of various stormwater modeling platforms based on several metrics for the analysis and 2) an assessment of the level of model detail required to represent the drainage components in a cost-effective manner. This evaluation was divided among three tasks:

- Task 1: Desktop Review – Identify and screen stormwater modeling software packages and based on required and preferred modeling capabilities. Select up to three of the most suitable software packages for further evaluation.
- Task 2: Trunkline Analysis – Evaluate existing stormwater models at varying degrees of detail. Determine the level of detail that best balances accuracy with modeling time/cost.
- Task 3: Software Evaluation – Evaluate three most suitable software packages from Task 1 using a detailed set of metrics. Recommend modeling software based on the scoring matrix.

This report provides further details about each of these tasks, defines the metrics used in the evaluation, and provides recommendations on both the level of model detail for analysis and the modeling software to be used in the stormwater master drainage planning effort.

2.0 Desktop Review of Modeling Software

There currently are a multitude of available stormwater drainage model software packages that have the capability of modeling storm sewers, channels, and overland drainage. The purpose of the Desktop Review and Software Evaluation (Section 4.0) was to identify these software packages, screen the software based on required and preferred modeling capabilities, and perform a detailed evaluation to recommend a software for the master drainage plan modeling effort. The overall process is summarized in **Figure 1**.



The desktop review covered the first two pieces of the process and was divided into three tasks:

- **Identify** stormwater modeling software packages
- **Develop** high level metrics for screening the urban storm sewer software
- **Screen** software based on metrics and identify the top three packages for detailed evaluation

Screening metrics were developed to determine the suitability of each program for performing stormwater modeling. The metrics and screened software packages are discussed in more detail in the following sections.

2.1 Available Software

Fifteen stormwater modeling software packages were identified that were 1) well known stormwater modeling software packages used in the Houston area or 2) programs that were designed for evaluating storm sewer, for 2D urban drainage. The software packages included in the initial screening process are listed in **Table 1**.

Table 1: Software Packages Included in Initial Screening

Software Packages Considered	
Aquaveo Watershed Modeling System	InfoWorks ICM
Autodesk Storm and Sanitary Analysis	ICPR 4
Bentley OpenFlows	InfoSWMM
Bentley StormCAD	MIKE Flood/Urban
EPA-SWMM	PC-SWMM
FLO-2D	Stormwater Studio
HEC-RAS	XPSWMM
Houstorm	

Information including modeling capabilities, software cost, and typical applications were gathered for each software package from either vendor websites and/or from correspondence with vendor representatives. The available software packages were included in a two-part screening to identify the top software packages. The initial screening consisted of identifying programs that had basic capabilities needed for the infrastructure modeling effort. The more detailed screening identified additional capabilities that would enhance the model development process. These are discussed further in the subsequent sections.

2.2 Initial Screening

Stormwater drainage modeling in locations with relatively flat terrain such as the Houston region requires specific modeling capabilities to accurately estimate water surface elevations, flows, and ponding depths. Stormwater conveyance includes surface flow, underground stormwater systems, detention/retention basins, and open channels. The modeling software selected must include the capability to model these different components as well as the interaction between them. These four capabilities were identified as "required metrics" for the initial software screening. Programs that did not have these capabilities were removed from the screening process. The required software metrics included:

- Storm Sewer Capability – Approximately 75% of the stormwater drainage infrastructure in the City is comprised of underground storm sewer systems, with the remaining being roadside ditches or channels. The selected program must be capable of modeling inlets and sub-surface pipe networks to evaluate the capacity of the underground storm sewer system and resultant ponding above the surface.
- Unsteady Flow – Rainfall runoff volume can affect the detention storage within the drainage system, capacity of the main trunk lines, and tailwater of the downstream channels and bayous. The program must be capable of routing hydrographs, rather than peak flows, through the drainage and surface networks to simulate the impacts of volume.
- 1D/2D Capability – 2D flow capability is essential for flat urban areas like Houston where above ground drainage patterns can be complex. The selected program must be capable of modeling integrated 1D pipe and channel flow with 2D overland flow.

- Riverine Modeling – Much of the City drains into channel systems maintained by either the City or the Harris County Flood Control District (HCFCD). Channel capacity can affect the tailwater and capacity of the City infrastructure. The selected program must be capable of modeling these channels in detail to incorporate any downstream boundary affects. Modeling these downstream channels will also provide a comprehensive representation of urban and riverine drainage within the City.

The fifteen modeling software packages were initially screened using these four required metrics. Any program that did not meet any of these metrics, was removed from further screenings. Of the fifteen identified, seven programs had all the required modeling capabilities. The results of the initial screening tasks are summarized in **Table 2**.

Table 2: Initial Screening Results

Modeling Software	Storm Sewer Capability	Unsteady Flow	1D/2D Capability	Riverine Modeling
Aquaveo Watershed Modeling System	✔	✔	✔	✔
Autodesk Storm and Sanitary Analysis	✔	✔		
Bentley OpenFlows	✔	✔	✔	✔
Bentley StormCAD	✔	✔		
EPA-SWMM	✔	✔		
FLO-2D	✔	✔	✔	✔
HEC-RAS		✔	✔	✔
Houstorm	✔			
ICPR 4	✔	✔	✔	✔
InfoSWMM	✔	✔	✔	
MIKE Flood/Urban	✔	✔	✔	✔
PC-SWMM	✔	✔	✔	✔
Stormwater Studio	✔			
XPSWMM	✔	✔	✔	✔
InfoWorks ICM	✔	✔	✔	✔

2.3 Secondary Software Screening

After the initial screening task was completed, the remaining seven software packages were further screened through additional metrics to identify potential capabilities that may limit the program's effectiveness for citywide modeling. These metrics were based on priorities such as streamlining the model development process, presentation of results, model limitations, and agency approval. The prioritized software metrics include:

- Hydrology Methods – Traditional hydrology may be required for the citywide analysis to allow the simplification of the drainage networks. Hydrologic analysis methods within the software package will prevent the need to develop hydrographs using other programs such as HEC-HMS. While importing data may be possible, the transfer of information from one program to another can be inefficient and a source of error.
- GIS Integration – The City storm sewer data is currently stored in GIS shapefiles that include essential information such as location, size, material, invert elevations, and age. Software packages that include GIS capabilities will ease the import and export of the storm sewer data within the drainage model during model development and maintenance for City staff.
- 2D Cell Limitation – The models developed need to be able to simulate surface flows across regional watersheds. Software packages that limit the number of 2D cells/grids/mesh may limit either the detail of the terrain or the watershed size that can be used in the model.
- Results Review – Reviewing results within the program allows for ease of reviewing any model output errors and rapid identification of system capacity. Results may include flow, water surface elevation, and ponding depths in both the 1D and 2D flow regimes. Results also include detailed tabular information provided by the model.
- Node Limitation – The models need to be able to evaluate existing system capacity regionally. Software packages that limit the number of hydraulic nodes may limit either the detail of the regional models or limit the watershed size the model can evaluate.
- Software Support – Complex software can have known bugs and issues unrelated to the model development process. Vendors that offer program support as well as active upgrades will enhance the ability to develop and continually maintain the storm sewer models.
- Cost – Cost is a major factor for both the City budget as well as use by the engineering community that may be developing or using these models in the future.
- Agency Approval – Software packages that are currently being used by other agencies and government entities show that the software may be appropriate for use by the City.

Each of the seven software packages were reviewed at the desktop level by reading available online literature and communicating with the respective vendor to identify the capabilities relating to each of these prioritized metrics. A summary of each software package with respect to the prioritized metrics is included below.

2.3.1 Innovyze XPSWMM

XPSWMM 2019.1 is a 1D/2D unsteady stormwater modeling software currently used by entities around the world to analyze localized urban flooding. XPSWMM is widely used in the Houston region but has issues with stability and long run times. A summary of the product is shown below.

- Hydrology Methods: Multiple methods available including Clark Hydrograph and Green & Ampt
- GIS Integration: High
- 2D Cells: Rigid Grid
- Results Review: Tables, Graphs, Animations
- Node Limitation: Based on License
- 2D Cell Limitation: Based on License
- Software Support: Yes
- Initial Cost: $44,000 (varies based on license type)
- Yearly Cost: $9,000
- Agency Approval: FEMA, Houston, Richardson, San Antonio, HCFCD, Dallas

2.3.2 InfoWorks ICM

InfoWorks ICM is a 1D/2D unsteady urban drainage modeling software, similar to XPSWMM. Some capabilities that distinguish ICM from XPSWMM are a flexible 2D mesh instead of a 2D grid, the ability to use multiple GPUs to speed up model run time, and the ability for multiple users to work on the model simultaneously.

- Hydrology Methods: Multiple Methods
- GIS Integration: High
- 2D Cells: Flexible Mesh
- Results Review: Tables, Graphs, Reports, Animations
- Node Limitation: Based on License
- 2D Cell Limitation: Based on License
- Software Support: Yes
- Initial Cost: $50,000 (varies based on license type)
- Yearly Cost: $10,000
- Agency Approval: Houston, Fort Worth, San Marcos, Sugar Land, Austin

2.3.3 CHI PCSWMM

PCSWMM is a 1D/2D unsteady stormwater modeling software based on EPA-SWMM. It provides a better graphical user-interface and additional capabilities such as 2D modeling compared to EPA-SWMM. The 2D capabilities, however, are not as robust as compared to ICM or XPSWMM.

- Hydrology Methods: Multiple Methods
- GIS Integration: Mid-High
- 2D Cells: Flexible Grid
- Results Review: Tables, Graphs, Animations
- Node Limitation: None
- 2D Cell Limitation: None
- Software Support: Yes
- Initial Cost: $0 (cost is a per year subscription)
- Yearly Cost: $2,160
- Agency Approval: Austin, Irving

2.3.4 DHI MIKE FLOOD

MIKE FLOOD is a stormwater modeling software capable of 1D and 2D modeling and is used throughout the world. The program is not as well used within the Houston region. The 2D modeling uses a flexible 2D mesh similar to ICM. Coupling the 1D, 2D, and riverine modeling components is not as straight-forward as other modeling packages.

- Hydrology Methods: Multiple Methods
- GIS Integration: Mid-High
- 2D Cells: Flexible Mesh
- Results Review: Tables, Graphs, Animations
- Node Limitation: None
- 2D Cell Limitation: None
- Software Support: Yes
- Initial Cost: $0 (cost is a per year subscription)
- Yearly Cost: $12,000
- Agency Approval: FEMA

2.3.5 Bentley OpenFlows/Civil Storm

OpenFlows is a new open channel and 2D modeling software. The 1D stormwater system is modeled in a different software, Civil Storm, and then coupled with the 2D in OpenFlows.

- Hydrology Methods: Multiple Methods
- GIS Integration: Mid
- 2D Cells: Rigid Grid
- Results Review: Tables, Graphs, Animations
- Node Limitation: Link Limits
- 2D Cell Limitation: None
- Software Support: Yes
- Initial Cost: $0 (cost is a per year subscription)
- Yearly Cost: $11,400
- Agency Approval: None

2.3.6 Streamline Technologies ICPR-4

ICPR4 is a stormwater modeling software, widely used in Florida, with 1D/2D and groundwater modeling capabilities. The model uses a flexible mesh and shapefiles for hydrologic parameters. The model is not well integrated with GIS and typically has long run times.

- Hydrology Methods: Multiple Methods
- GIS Integration: Low
- 2D Cells: Flexible Grid
- Results Review: Tables, Graphs, Reports
- Node Limitation: None
- 2D Cell Limitation: None
- Software Support: Yes
- Initial Cost: $0 (cost is a per year subscription)
- Yearly Cost: $1,200
- Agency Approval: Florida

2.3.7 FLO-2D

FLO-2D is a stormwater modeling software with 2D flood routing capability. FLO-2D has a low software cost, however it does not appear to have as robust pipe network capabilities as other software packages.

- Hydrology Methods: Multiple Methods
- GIS Integration: Low
- 2D Cells: Flexible Grid
- Results Review: Tables, Graphs, Reports
- Node Limitation: None
- 2D Cell Limitation: None
- Software Support: Yes
- Initial Cost: $0
- Yearly Cost: $995.00
- Agency Approval: FEMA, USACE

2.4 Screening Recommendation

Based on the desktop review and prioritized metrics, a ranking system was developed to score each software based on the potential ability of the software screening. Since the review was based on available internet information, a simple ranking system was used. Each product received a score of 1, 2, or 3 for each of the prioritized categories. A score of (1) indicated no performance or poor performance, a score of (2) indicated mid performance and a score of (3) indicated a high performance.

The categories were also weighted since some categories are prioritized higher over others. Storm sewer capabilities, 2D capabilities, and GIS integration are keys to effective and efficient modeling, and were weighted higher (ranging from 15-20%). Riverine modeling and results review improve the analytical capacity but are not as necessary if other rankings were high and were given a weight of 10%. The remaining categories provide benefit to the modeling process but are not essential and assigned a weight of 5%. The weighing and scoring of the described metrics are presented in **Table 3**.

Table 3. Weighing and Scoring of Modeling Categories

	Weight	ICM	XPSWMM	PC-SWMM	MIKE Flood	OpenFlow	ICPR4	Flo-2d
Storm Sewer Capability	15%	3	3	2	3	2	3	3
2D Capability	20%	3	2	1	3	2	2	2
Riverine Modeling	10%	2	2	1	2	1	2	3
Hydrology Methods	5%	3	3	3	3	3	3	3
GIS Integration	20%	3	3	2	2	1	2	2
Results Review	10%	3	2	1	2	1	1	2
Cost (10-year)	5%	1	1	3	1	1	3	3
Software Support	5%	3	3	3	3	3	1	3
Agency Approval	5%	2	3	2	3	1	1	2
Local Engineering Knowledge	5%	2	3	1	1	1	2	1
	100%	**2.7**	**2.5**	**1.7**	**2.45**	**1.55**	**2.05**	**2.35**

Of the software packages, InfoWorks ICM ranked highest with a score of 2.7. This score is due to flexible 2D mesh which will allow detail to vary throughout the model, results reviewing capabilities for understanding flooding patterns, and extensive GIS Integration. XPSWMM ranked second with a score of 2.5, based on GIS Integration and the benefits of widespread local knowledge. MIKE Flood ranked third with a score of 2.4, due to flexible mesh and agency approval. FLO-2D ranked fourth just behind MIKE Flood, with a score of 2.35, due to the cost, storm sewer capabilities, and riverine modeling. **Table 4** shows the top seven available software and their respective scoring.

Table 4. Final Software Scoring

Software	Score
ICM	2.7
XPSWMM	2.5
MIKE Flood	2.4
Flo-2D	2.35
ICPR-4	2.05
PCSWMM	1.7
OpenFlows	1.5

ICM, XPSWMM, and MIKE Flood software packages appear to be similar in capabilities and cost. Since InfoWorks ICM and XPSWMM are both used locally, these are recommended for the detailed evaluation. While MIKE Flood ranked third, FLO-2D had a similar score in the desktop screening, but cost significantly less than all three packages above. Since cost could be a limiting factor for some of the engineering community, the City recommended further evaluating FLO-2D to understand if similar results can be achieved for less software cost.

InfoWorks ICM, XPSWMM, and FLO-2D were recommended and selected for a further software evaluation.

3.0 Trunkline Sensitivity Analysis

The trunkline sensitivity analysis assessed the level of detail in the 2D model necessary to achieve informative simulation results while managing effort required to construct the model. The end goal of the trunkline sensitivity analysis was to determine the minimum pipe size needed to adequately identify areas at risk of structural flooding or excessive ponding throughout the city.

3.1 Background

The City's stormwater infrastructure network is extensive and includes storm sewer and roadside ditches that outfall to bayous and channels throughout the City. According to the data on the City's Geographic Information Management System (GIMS) website, the City has over 2,500 miles of storm sewer lines that are 24 inches or greater in diameter. To model all of these pipes would require significant effort and is likely not needed for the City's planning purposes.

Figure 1 shows the City's storm sewer network color-coded by pipe size. Within City limits, there are 2,500 miles of pipes between 24 and 36 inches in diameter; 1,500 miles of pipes between 36 and 48 inches in diameter; and 900 miles of pipes that are 48 inches in diameter or greater.

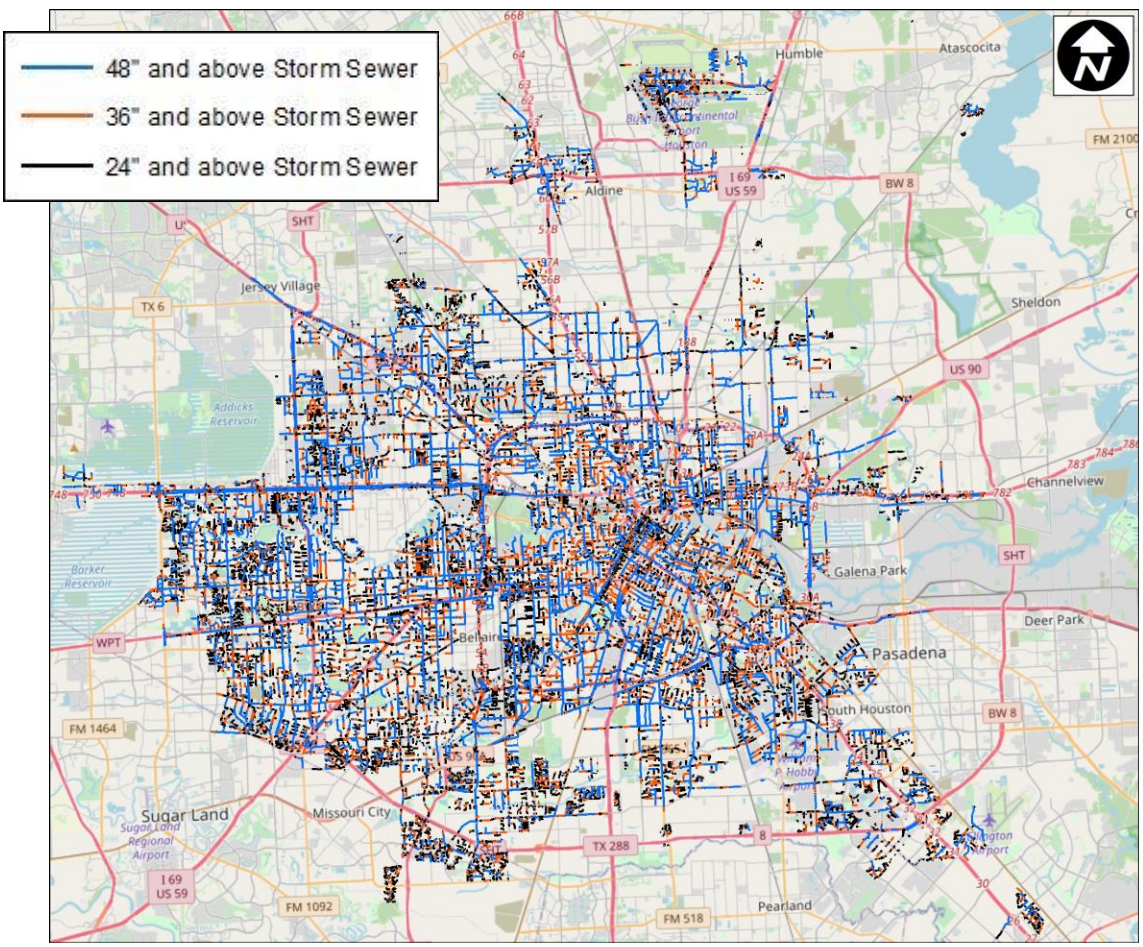


Figure 1: COH Storm Sewer Network (Source: GIMS)

A sensitivity analysis was conducted to determine the targeted minimum pipe size for future modeling efforts. For the analysis, three scenarios that included different diameters of storm sewer were simulated for two project areas. The first scenario included all pipes that were equal to or greater than 24 inches in diameter; the second scenario modeled only pipes that were equal to or greater than 36 inches in diameter; and the third scenario modeled only pipes that were equal to or greater than 48 inches in diameter. The frequency events for the 2-year and 100-year storms were modeled. The results from each scenario were compared against the others to determine the level of detail required for a city-wide model. In addition, the trunkline models were compared to HEC-RAS rain-on-grid models similar to those prepared as part of the HCFCD Modeling, Assessment & Awareness Project (MAAPnext) program.

Two project areas, Chimney Rock and Kashmere Gardens, were chosen for the sensitivity analysis. These areas were specifically selected as detailed existing conditions XPSWMM models had been developed during previous drainage analyses. The existing models consisted of storm sewer, roadside ditches, and HCFCD channels. The existing Chimney Rock model, developed by Halff, included storm sewer and an outfall channel modeled in 1D and overland flow modeled in 2D. The Chimney Rock project area is located in the Brays Bayou watershed in southwest Houston. The existing Kashmere Gardens model, developed by Huitt-Zollars, Inc., included storm sewer modeled in 1D and overland flow modeled in 2D. The Kashmere Gardens project area is located in the Hunting Bayou watershed in northeast Houston.

Each scenario was simulated for both the 2-year and 100-year storm events to evaluate the following differences between the scenarios which could affect the analytical capabilities of a city-wide model.

- Area of Ponding – One purpose of the city-wide stormwater master plan is to identify areas of significant ponding that should be further evaluated through future drainage improvement analyses and projects. These locations can be identified by the resultant 2D ponding of the model. If trunkline scenarios have significant differences between the amount or location of ponding on the 2D surface, potentially-flooded areas could be omitted from future improvement projects. These areas may be omitted if the level of detail in the model construction is insufficient.
- Outflow Volume – Another purpose of the analysis is to identify potential mitigation volumes for regional projects and coordination with the HCFCD. Outflows from drainage improvement projects will need to be mitigated as to not cause adverse impacts in the downstream bayous and channels. In these cases, the outflow volumes from the drainage networks are important for quantifying the potential mitigation.
- Water Surface Elevations – Ponding areas and flows in the drainage system are influenced by the water surface elevations in the network. If a scenario results in simulated water surface elevations lower than actually seen during a given event, ponding areas may not be as extensive as in reality. In this case, resulting drainage improvement projects modeled in those areas may be undersized.

3.2 Chimney Rock Results

3.2.1 Model Setup

The existing XPSWMM model of the Chimney Rock project area (1,079 acres) was modified for use in the trunkline sensitivity analysis. For the respective scenarios (24-inch, 36-inch, 48-inch), pipes were removed from the model if they were below the scenario's given threshold for pipe size. In a few instances, pipes below the threshold were retained if they were the only pipes servicing a neighborhood. The removal of modeled pipes required revisions to the hydrologic calculations. This involved combining drainage basins and recalculating Rational Method peak discharges. **Table 5** shows the resulting modeled pipe lengths and number of drainage basins for each scenario.

Table 5. Chimney Rock Model Statistics

	24-inch Scenario	36-inch Scenario	48-inch Scenario
Storm Sewer Length	70,000 ft	38,000 ft	25,000 ft
Drainage Basins	250	146	98

Approximately 45% of the existing storm sewer network in Chimney Rock consisted of 24-inch storm sewer and only 35% of the systems were greater than 48 inches in diameter.

3.2.2 2-Year Model Results

Table 6 summarizes the results of the 2-year storm event for the modeled scenarios and the ponding comparison is shown in **Figure 2**. The area of ponding is reduced for both the 36-inch and 48-inch scenario by 47% and 67% respectively. These differences correlate to the reduction in modeled storm sewer for each scenario. Since the 2-year is typically contained at or near the ground elevation, areas that were removed from the model were also removed from showing ponding.

The outflow volume remained consistent between the 24-inch and 36-inch scenarios, only varying by 1%. However, there was a 44% reduction in outflow volume for the 48-inch scenario. The difference is due to the volume that remained in the model. Low-lying areas are usually drained by smaller storm sewers which were not included in the 48-inch scenario. Subsequently, ponding remained in the model due to lack of connectivity. The reduction in volume could potentially be an issue in determining mitigation volumes for future drainage improvement projects.

Water surface elevations in the 36-inch and 48-inch scenarios were slightly lower than the 24-inch scenario, though not significantly. By reducing the amount of storm sewer modeled, the drainage areas for the scenarios were slightly larger than the 24-inch model, resulting in slightly lower discharge rates from the drainage basins. The lower flows resulted in slightly lower water surface elevations. The 36-inch scenario was, on average, 0.2 feet lower than the 24-inch model and the 48-inch model was 0.4 feet lower, on average.

Table 6: Chimney Rock 2-Year Storm Event Results

	24-inch Scenario	36-inch Scenario	48-inch Scenario
Area of Ponding	150 acres	80 acres	50 acres
Outflow Volume	342 ac-ft	337 ac-ft	193 ac-ft
Elevation Difference	-	-0.2 ft	-0.4 ft

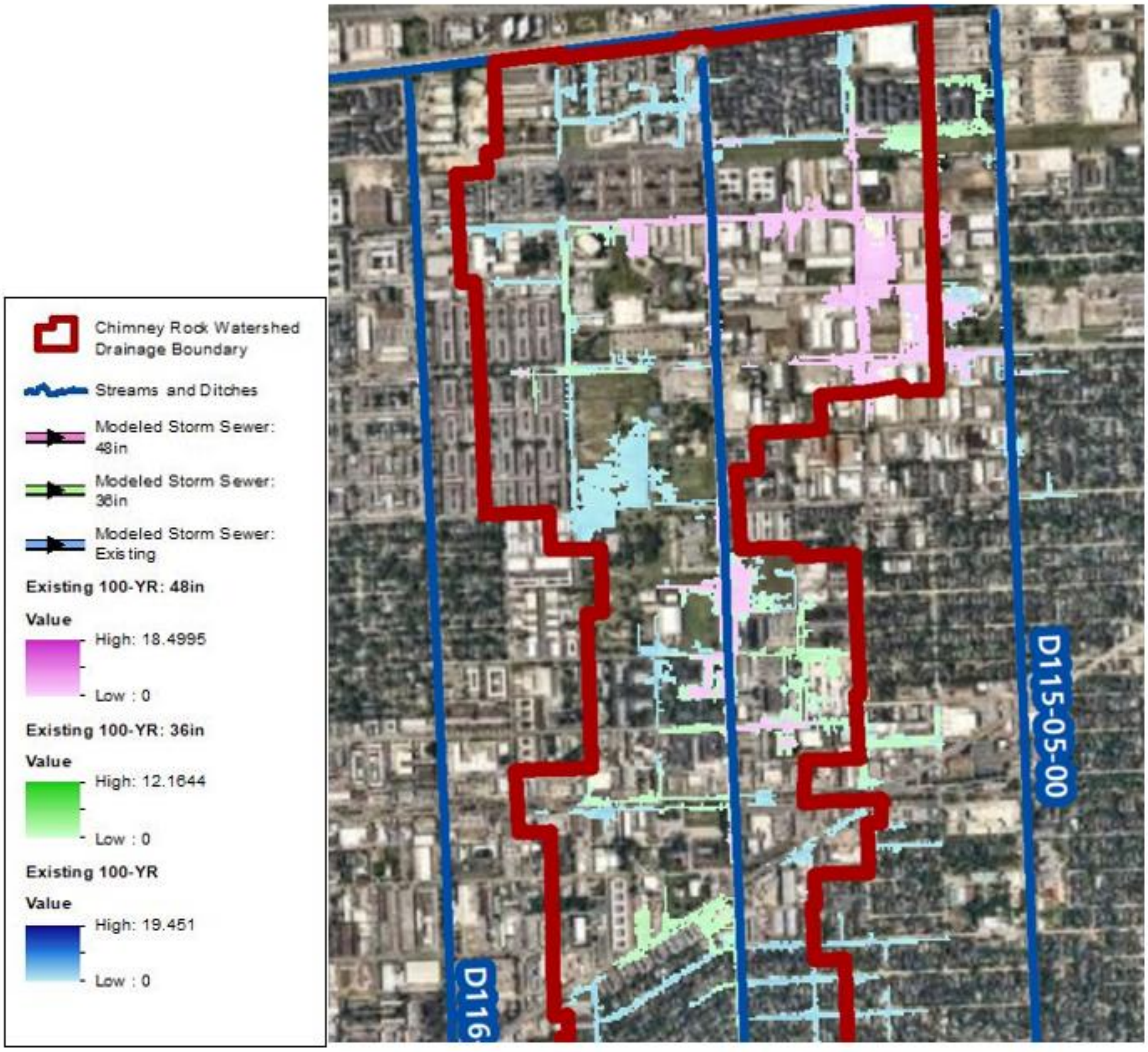


Figure 2: Chimney Rock 2-Year Scenario Comparison

3.2.3 100-Year Model Results

Table 7 summarizes the results of the 100-year storm event for the modeled scenarios and the ponding comparison is shown in **Figure 3**. The area of ponding is reduced for both the 36-inch and 48-inch scenario by 37% and 54%, respectively. These differences correlate to the reduction in storm sewer in the model for each scenario. The 100-year differences are smaller than the 2-year due to the overland conveyance through the streets.

The outflow volume varied between the scenarios. The 36-inch model produced 27% lower volume than the 24-inch model and the 48-inch produced 40% lower volume than the 24-inch model. The difference is due to low lying areas that are usually drained by smaller storm sewers where ponding remained in the model due to lack of connectivity. The higher the reduction in volume could potentially be an issue in determining mitigation volumes for future drainage improvement projects.

Water surface elevations in the 36-inch and 48-inch scenarios were slightly lower than the 24-inch scenario, though not significantly. By reducing the amount of storm sewer modeled, the drainage areas for the scenarios were slightly larger than the 24-inch model, resulting in slightly lower discharge rates from the drainage basins. The lower flows resulted in slightly lower elevations. The 36-inch scenario was on average 0.2 feet lower than the 24-inch model and the 48-inch was on average 0.5 feet lower than the 24-inch model, similar to the 2-year analysis.

Table 7: 100-Year Storm Event Results

	24-inch Scenario	36-inch Scenario	48-inch Scenario
Area of Ponding	544 ac	342 ac	250 ac
Outflow Volume	1129 ac-ft	820 ac-ft	674 ac-ft
Elevation Difference	-	-0.2 feet	-0.5 feet

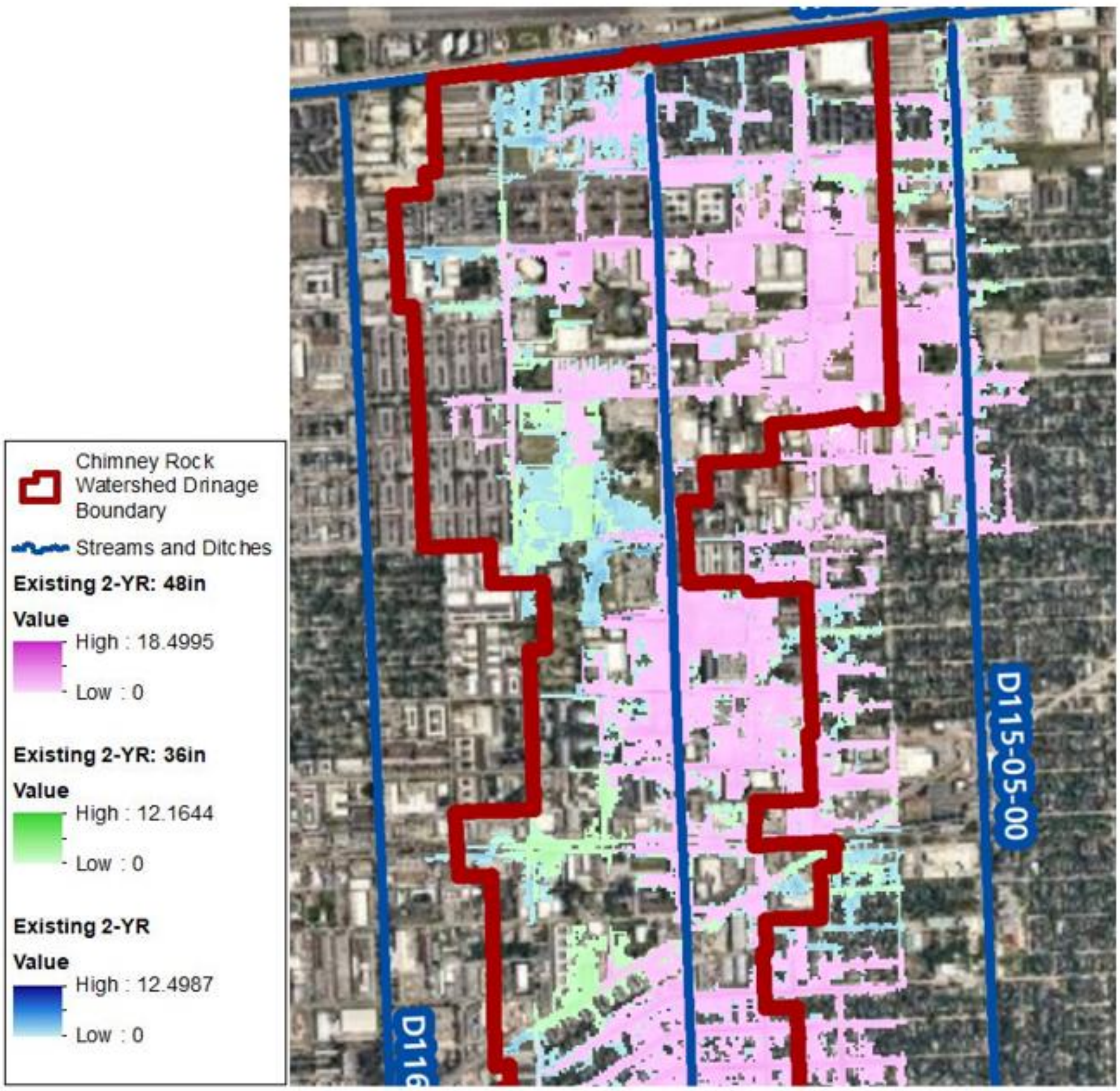


Figure 3: Chimney Rock 100-year Scenario Comparison

3.3 Kashmere Gardens Results

3.3.1 Model Setup

The existing XPSWMM model of the Kashmere Gardens project area (1,300 acres) was modified for use in the trunkline sensitivity analysis. For the respective scenarios (24-inch, 36-inch, 48-inch), pipes were removed from the model if they were below the scenario's given threshold for pipe size. In a few instances, pipes below the threshold were retained if they were the only pipes servicing a neighborhood. The removal of modeled pipes required revisions to the hydrologic calculations. This involved combining drainage basins and recalculating Rational Method peak discharges. **Table 8** shows the resulting modeled pipe lengths and number of drainage basins for each scenario.

Table 8: Kashmere Gardens Model Statistics

	24-inch Scenario	36-inch Scenario	48-inch Scenario
Storm Sewer Length	55,000 ft	52,000 ft	47,000 ft
Drainage Basins	85	81	76

The Kashmere Gardens model was majority 48-inch storm sewer and greater, providing a contrast to the Chimney Rock model which included more 24-inch pipe. Approximately 5% of the existing storm sewer network in Kashmere Gardens consisted of 24-inch storm sewer and 85% of the systems were greater than 48-inch in diameter. The model scenarios were simulated for the 2-year and 100-year storm events to identify the differences in ponded area, outflows into the downstream systems, and water surface elevations within the 1D nodes.

3.3.2 2-Year Model Results

Table 9 summarizes the results of the 2-year storm event for the modeled scenarios and the ponding comparison is shown in **Figure 4**. The area of ponding, outflow volume, and water surface elevations were virtually the same between the three scenarios. The similarity is contributed to the lesser amounts of 2-year ponding within the system and the ponding occurring as a cause of the larger storm sewer.

Table 9: 2-Year Storm Event Results

	24-inch Scenario	36-inch Scenario	48-inch Scenario
Area of Ponding	66 acres	67 acres	66 acres
Outflow Volume	156 ac-ft	155 ac-ft	153 ac-ft
Elevation Difference	-	-0.07 ft	-0.04 ft

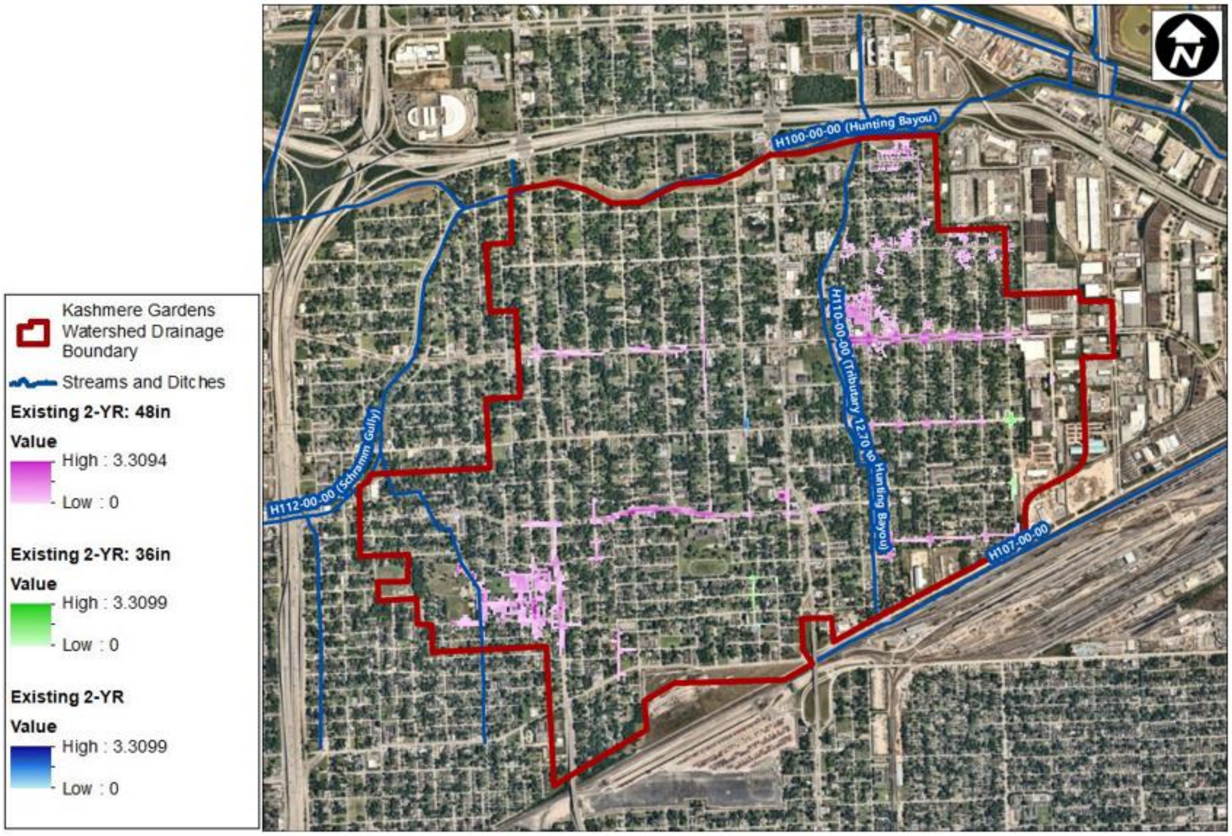


Figure 4: Kashmere Gardens 2-Year Ponding Results

3.3.3 100-Year Model Results

Table 10 summarizes the results of the 100-year storm event for the modeled scenarios and the ponding comparison is shown in **Figure 5**. The area of ponding and outflow volumes were similar between the three scenarios.

Water surface elevations in the 36-inch and 48-inch scenarios were slightly lower than the 24-inch scenario, though not significantly. By reducing the amount of storm sewer modeled, the drainage areas for the scenarios were slightly larger than the 24-inch base model, resulting in slightly lower discharge rates from the drainage basins. The lower flows resulted in slightly lower water surface elevations. The 36-inch scenario was on average 0.12 feet lower than the 24-inch model and the 48-inch scenario was on average 0.28 feet lower than the 24-inch model.

Table 10: 100-Year Storm Event Results

	24-inch Scenario	36-inch Scenario	48-inch Scenario
Area of Ponding	389 ac	393 ac	396 ac
Outflow Volume	562 ac-ft	559 ac-ft	562 ac-ft
Elevation Difference	-	-0.12 ft	-0.28 ft

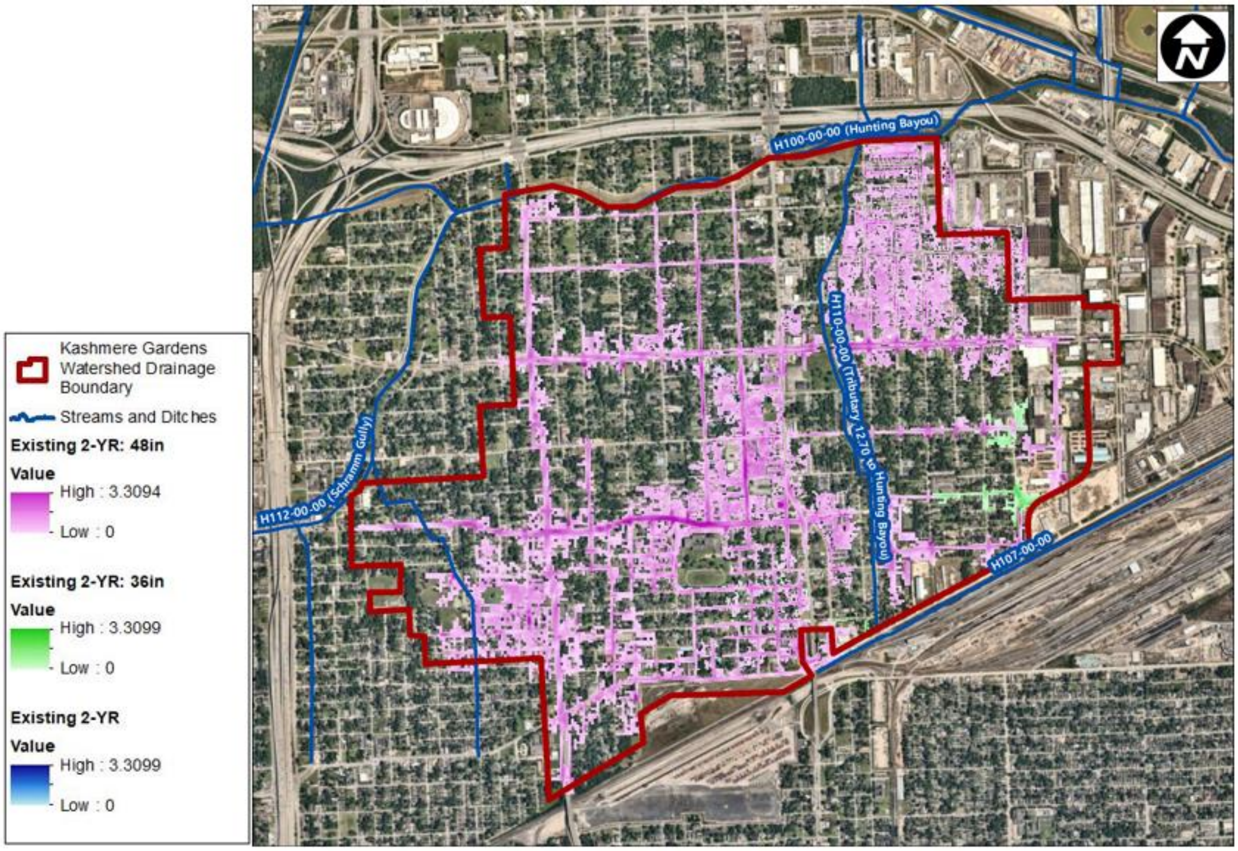


Figure 5: Kashmere Gardens 100-Year Ponding Results

3.4 Rain on Grid HEC-RAS Model Comparison

The HCFCD is currently re-mapping Harris County under the MAAPnext program. The program includes developing dynamic 2D HEC-RAS models for all watersheds throughout the county. A by-product of the 2D mapping is a rain-on-grid analysis of the overland sheet flow for each watershed. This information could be used to identify potential flooding "hotspots" throughout the City with minimal additional effort. The MAAPnext effort does not, however, include any storm sewer modeling, and is therefore of little use for satisfying the requirements of this study.

A rain-on-grid analysis was conducted for the Chimney Rock area and compared against the detailed XPSWMM model. A model was developed of the watershed using HEC-RAS, the terrain information from the XPSWMM model, and the 100-year rainfall. The rainfall was applied directly to the 2D model and allowed to flow in natural overland patterns.

Since the underlying terrain is identical between the two scenarios, the ponding patterns are generally the same. Areas that are ponded in the detailed XPSWMM model correlate well to the rain-on-grid. However, the magnitude of the ponding is higher for the rain-on-grid model since the model does not account for underground conveyance which assists in draining the area. This limitation could show excessive ponding where the underground system may be effective at draining, but can be used at a high level to understand potential ponding. The other limitation to using a rain-on-grid analysis is that the system capacity remains unknown and improvement solutions cannot be easily investigated. **Figure 6** compares the rain-on-grid results to the detailed XPSWMM model.

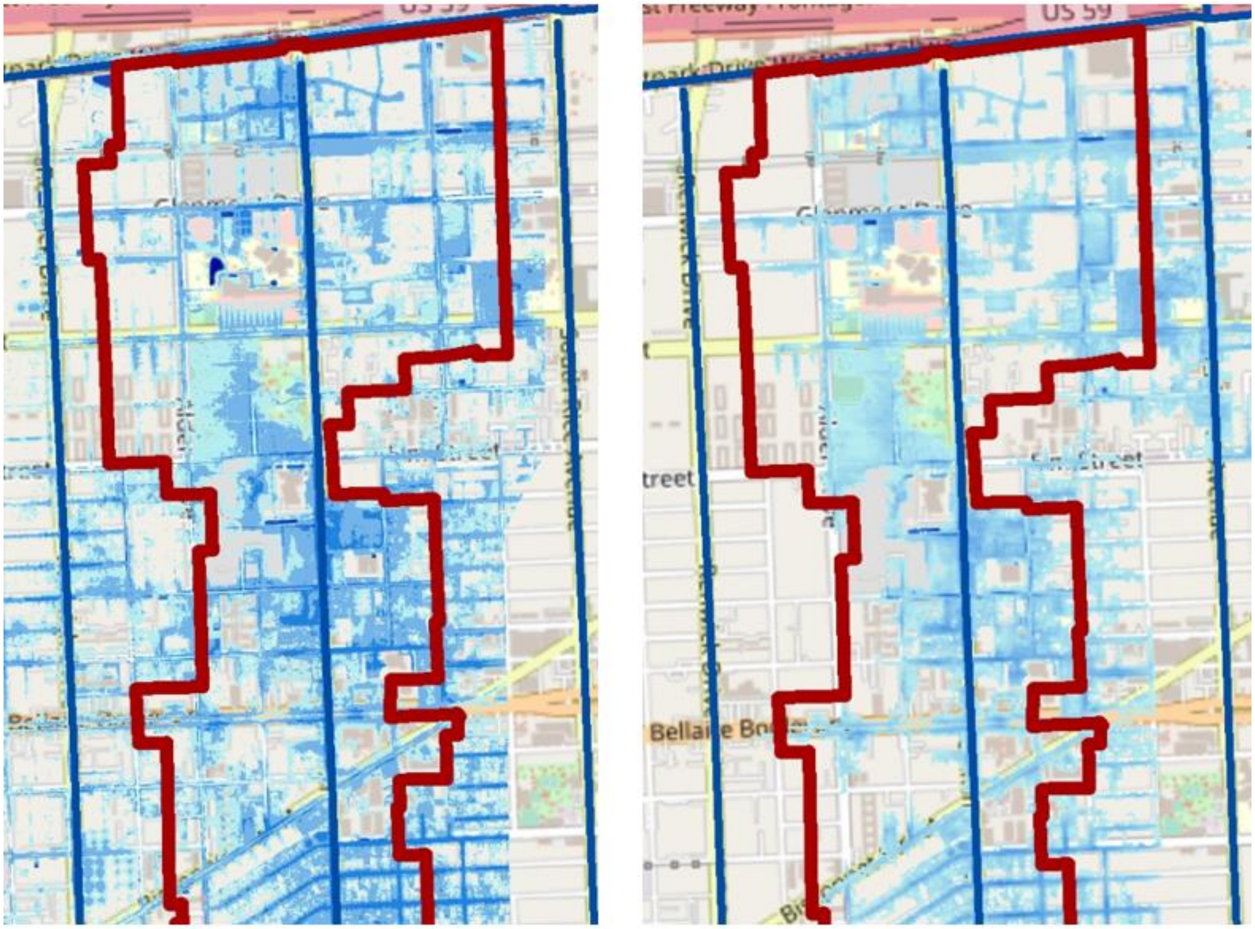


Figure 6: Comparison of Rain-on-Grid (left) and Detailed XPSWMM (right)

3.5 Trunkline Sensitivity Analysis Conclusions

The trunkline sensitivity analysis compared the level of detail of the ponding output based on the minimum modeling pipe size. The comparison of the various storm sewer scenarios shows that the extent of ponding within each area is contingent on the level of detail of the storm sewer system. The Chimney Rock model demonstrated that removing detail from the model does affect the accuracy of the model results due to the extensive 24-inch pipe network. It also showed that the accuracy increased with the higher rainfall events.

The Kashmere Gardens model showed that reducing the detail did not have as great of an affect on model results since most of the storm sewer was greater than 24-inches. It confirmed that modeling all 24-inch pipes shows more ponded areas, greater outflow volumes, and higher water surface elevations than truncating at the 48-inch storm sewer. However, the results also show that the differences between the 36-inch scenario and the 24-inch were minor compared to the effort that may be required to model every 24-inch pipe.

Therefore, it is recommended to generally model a minimum pipe size of 36" with exceptions for neighborhoods that are solely 24" or in roadside ditches.

4.0 Software Evaluation

The three software packages selected (InfoWorks ICM, XPSWMM, and FLO-2D) were further evaluated to identify major differences in model development, model management, and results that could impact the applicability for their potential use in the city-wide model development and implementation.

4.1 Process

The software evaluation included developing the same hydrologic and hydraulic model in each selected software package for the Chimney Rock area outlined in Section 3.0. This model was originally developed using XPSWMM in 2018 and covered a large area north of Brays Bayou. The model included closed conduits, roadside ditches, and open channels which provided a good comparison of the different drainage infrastructure components within the City.

A set of base information was constructed from the original model that would be used to develop the model in each of the selected software packages. The base information included:

- Drainage Basins – Polygon shapefile of the drainage basins for the Chimney Rock area
- Hydrologic Parameters – Table of parameters including: Area, Time of Concentration, impervious percentages, and Clark Storage parameters for each drainage basin
- Nodes – Point shapefile of the manholes and inlets used in the model. Included the ground elevation, invert elevation, and connection type to the 2D surface.
- Links – Line shapefile including the detailed storm sewer and open ditch information. Included the shape, size, invert elevations, length, slope, and node connections
- Terrain – GIS raster of the 2018 H-GAC LiDAR for the study area
- Roughness Polygons – Polygon shapefile of the different Manning's roughness zones used or the 2D surface
- Structures – Polygons of the structures within the study area
- Boundary Conditions – Hydrographs of the downstream tailwater conditions for Brays Bayou

These items are shown in **Figure 7**.

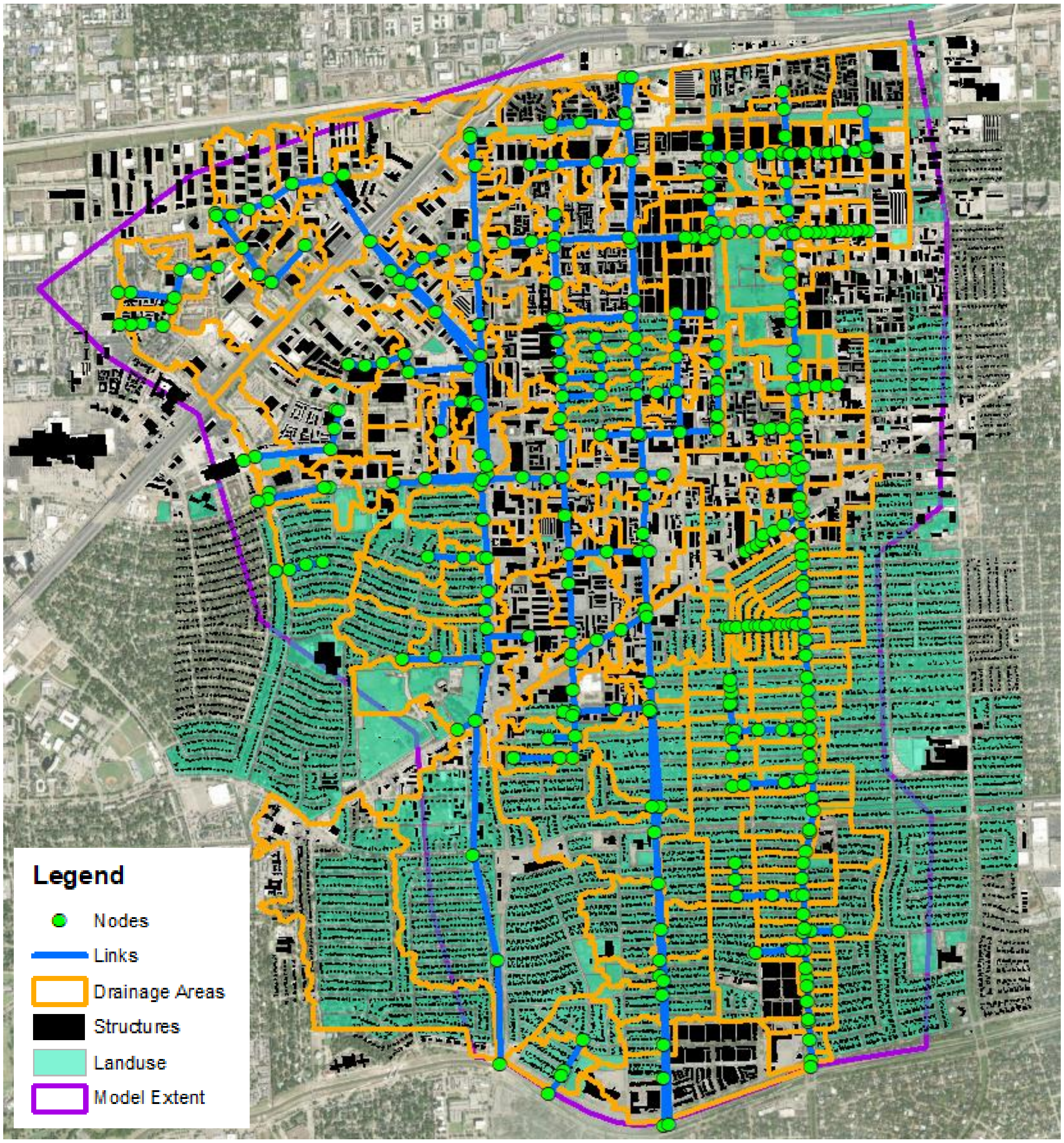


Figure 7: Chimney Rock Base Information

The base data was adjusted as needed to import into the different programs. During the model development process, adjustments to the information were noted to compare the data changes. Model development concerns were also noted, such as software stability, speed of the data import process, and use of the features within the program.

After development, the models were simulated for the 2-year and 100-year storm events to compare simulation runtimes and results.

4.2 Evaluation Matrix

A detailed evaluation matrix was created to compare the aspects of the three software packages. Eight categories, including 58 different software components, were identified and evaluated for each program.

For each category within the evaluation matrix, scores were assigned a value of 1 through 4 for each program. A score of 1 indicated the program does not have the functionality or only low functionality of that component. A score of 4 indicates the program has high functionality of the component. Each program was evaluated independently, which means that multiple programs can receive the same score for a given scoring component. The sections below discuss the main categories and summarize the scoring for each. **Appendix A** includes the complete comparison matrix for the three software packages.

4.2.1 Data

2D dynamic models require a large amount of data and information. This category summarizes the various components of data and model management, such as import/export to GIS, viewing and editing models, modeling scenarios, and global changes. A total of 48 points were possible for this category. **Table 11** shows the scoring for this category.

Table 11: Scoring Matrix for Data Components

Component	ICM	XPSWMM	FLO-2D
Data Management	4	2	2
Transporting Models for Review	4	3	3
Reviewing Models	2	4	3
Comparing Models	4	3	1
Importing from GIS	4	4	4
Tables and Grid Views	4	4	3
Tracking Changes	4	2	1
Scenario Modeling	4	3	1
Component Selection	4	2	1
Network Wide Changes	4	3	2
Model Saving	4	3	2
Model Management	4	2	2
Total (out of 48)	**46**	**35**	**25**

InfoWorks ICM

InfoWorks ICM scored 46 of the possible 48 points for the data category. The software has a sophisticated database to manage model development and result information. Some of the major highlights of the software are:

- Workgroup Database - ICM uses a workgroup database to compile modeling components and results. The database utilizes a check in/check out system for managing network and component changes. This process saves every version of the model which can be helpful for viewing changes and model development. *(Reviewing Models, Tracking Changes)*
- Multiple Editors - The database also allows multiple users to edit the same model simultaneously and is constantly saved so edits are never lost if the program crashes. *(Network Wide Changes, Model Saving)*

- Flagging - ICM has a flagging system for tracking changes and data sources in the model. Flags can be set to identify survey, as-built, or assumed information for future verification. Flagging assist in the asset management component of the program. *(Reviewing Models, Tracking Changes)*
- Queries – SQL queries can be developed to select and identify network objects, identify results that meet thresholds, and modify network components such as storm sewer sizes. Since the SQL syntax is used, the queries can be customized based on the user needs. One example of the query is identifying any storm sewer where the water surface elevations are not meeting the COH 100-year criteria. These allow for network wide identification to locate potential deficiencies within the software. *(Comparing Models, Component Selection, Tracking Changes)*
- Transportable Databases – Model files are compiled into a single file that can be transported to other entities, ensuring that all files are submitted. File compresses all information into the database for opening in other databases. *(Transporting Models for Review, Reviewing Models)*

XPSWMM

XPSWMM scored 35 of the possible 48 points for the data category. The program has GIS integration and a free viewer license for reviewing software. Some of the major highlights of the software are:

- XPSWMM Viewer – The viewer package is a free download from Innovyze and allows user to view models and results without accessing a full license. *(Reviewing Models)*
- GIS Integration – Model components and results can be imported and exported to ArcGIS which eases model development and results review*. (Data Management, Importing from GIS)*
- Scenario Manager – The scenario manager allows users to modify the base model and carry changes through the different scenarios. This product is helpful for alternative modeling. One drawback is the scenario manager can have known bugs and inflow hydrographs can be removed or modified in the scenarios. The manager also does not de-couple changes from the base scenario. *(Scenario Modeling, Model Management)*
- File Manager – The XPSWMM model consists of multiple files that are saved in a windows explorer folder. Model files consist of hundreds of sub files saved in one folder. Model management can be more difficult if developing multiple models within the same project. *(Data Management, Transporting Models for Review, Model Management)*

FLO-2D

FLO-2D scored 25 of the possible 48 points for data. The program has GIS integration and a free viewer license for reviewing software. However, the program had significant drawbacks for data management. Some of the major highlights of the software are:

- QGIS Requirement – FLO-2D does not have any built in GIS capabilities, but the free QGIS software can be downloaded and installed into the program to view the model and results. *(Reviewing Models, Importing from GIS)*
- GIS Integration – Model components and results can be imported and exported to ArcGIS which eases model development and results review. *(Reviewing Models, Importing from GIS)*
- File Manager – The model consists of multiple files that are saved in a windows explorer folder. Model files consists of hundreds of sub files saved in one folder. Model management can be more difficult if developing multiple models. *(Data Management, Transporting Models for Review, Model Management)*

- Limited Management – The program has limited data management and does not include any scenario modeling, model management, or tracking changes. This is a major drawback for large regional drainage models. *(Data Management, Tracking Changes, Scenario Modeling)*

4.2.2 Results Management

2D dynamic models have abundant results information for both the 1D and 2D flow regimes. Results may include flow, stage, and velocity information for the storm sewers, nodes, channels, and overland conveyance. This category summarizes the ability to collect and review that information after a model simulation. A total of 12 points were possible for this category. **Table 12** shows the scoring for this category.

Table 12: Scoring Matrix for Results Management Components

Component	ICM	XPSWMM	FLO-2D
Troubleshooting	4	4	3
Viewing Results	4	3	1
Exporting Results	4	4	2
Total (out of 12)	**12**	**11**	**6**

InfoWorks ICM

ICM scored 12 of the possible 12 points for results management. The software has the capability to analyze 2D results without model re-simulations and users can develop reports and queries to analyze system capacities throughout a large regional model. Some of the major highlights of the software are:

- 2D Results – The program can provide flows, elevations, and velocities across the 2D mesh without having to re-run the model. Lines and points can be added to the mesh and resultant hydrographs pulled instantly. *(Viewing Results, Exporting Results)*
- Reporting – Reports can be customized to pull flow, elevations, depths and others for all aspects of the model. The reports can be customized and saved for any user of the model. *(Viewing Results, Exporting Results)*
- Results Viewer – The results can be graphically viewed within the software and customized to the user needs. Information can include velocity flow patterns, ponding depths, elevations, and flows. *(Troubleshooting, Viewing Results)*
- Queries – As mentioned in the data management section, the user has the ability to write scripts to analyze results such as storm sewer capacity and maximum ponding depths. Queries are customizable based on the end goals. *(Viewing Results)*

XPSWMM

XPSWMM scored 11 of the possible 12 points for results management. The software has the capability to analyze 2D flows, water surface elevation, and velocities. However, developing hydrographs on the 2D surface requires a re-run of the simulation. 1D results can be viewed graphically and in tabular form similar to ICM InfoWorks. Some of the major highlights of the software are:

- 2D Results – The program can provide flows, elevations, and velocities across the 2D mesh where lines are set before running the model. Unlike ICM, it cannot pull information on these lines if they are placed after the model is run. *(Viewing Results, Exporting Results)*
- Troubleshooting Help – The model will review the geometry developed prior to simulation for both 1D and 2D and provide a list of errors prior to simulation. After the simulation, the software will present errors and instabilities with details, descriptions, and coordinates of where errors have occurred. *(Troubleshooting)*
- XPSWMM Viewer – As mentioned in the data management section; XPSWMM has a free license that allows viewing of models and results. *(Viewing Results)*

FLO-2D

FLO-2D scored 6 of the possible 12 points for results management. The mapping results must be viewed in a separate software outside of QGIS to analyze depth and WSEL grids. Results can also be exported to GIS but troubleshooting messages before and after the simulations are exported to the output file. Some of the major highlights of the software are:

- 2D Results – Grid results must be viewed in a separate software outside of QGIS. This creates an extra step required before reviewing and analyzing results. *(Viewing Results, Exporting Results)*
- Troubleshooting Help – Errors and warnings are exported to an output file. *(Troubleshooting, Exporting Results)*
- Reporting – All relevant results data are exported to output files. The output files cannot be directly viewed within the program creating an extra step before reviewing information. *(Viewing Results, Exporting Results)*

4.2.3 Hydrology

Various traditional hydrologic routing and loss as well as rain on grid approaches allow for flexibility in calculating flow hydrographs for the drainage system. This category summarizes the ability to conduct hydrology within the program including drainage area calculation, variety of methods and approaches, and compatibility with programs such as HEC-HMS. A total of 16 points were possible for this category. **Table 13** shows the scoring for this category.

Table 13: Scoring Matrix for Hydrology Components

Component	ICM	XPSWMM	FLO-2D
Drainage Catchments	4	4	1
Hydrograph Methodology	4	4	1
Loss Methods	4	4	2
HEC-HMS Compatibility	2	2	1
Total (out of 16)	**14**	**14**	**5**

InfoWorks ICM

ICM scored 14 of the possible 16 points for hydrology. The software has the capability to run most hydrology methods within the software itself and results compare well to HEC-HMS. Some of the major highlights of the software are:

- Drainage Areas – Drainage areas can be imported and adjusted from GIS. *(Drainage Catchments)*
- Inflow Import – While HEC-HMS models cannot be imported directly, flows can be imported through a CSV template provided by ICM. Allows other programs to be used if needed and flows can be directly applied to the 1D system. *(HEC-HMS Compatibility)*

XPSWMM

XPSWMM scored 14 of the possible 16 points for hydrology. The software has the capability to run most hydrology methods within the software itself and results compare well to HEC-HMS. Some of the major highlights of the software are listed below:

- Drainage Areas – Drainage areas can be imported and adjusted from GIS. *(Drainage Catchments)*
- Inflow Import – While HEC-HMS models cannot be imported directly, flows can be imported through a CSV template. Allows other programs to be used if needed and flows can be directly applied to the 1D system. *(HEC-HMS Compatibility)*
- Hydrology Methods – There are several methods for both hydrograph development and loss methods within the software. *(Hydrograph Methodology, Loss Methods)*

FLO-2D

XPSWMM scored 5 of the possible 16 points for hydrology. The software has the capability to simulate rain on grid and copy inflows from other sources (spreadsheets, HEC-HMS). FLO-2D does not have the capability to generate hydrographs. Some of the major highlights of the software are listed below:

- Rain on Grid – Rainfall can be applied to the grid using a cumulative distribution. *(Hydrograph Methodology)*
- Inflow Import – Inflows can be added into relevant inlet nodes. Must be created manually and cannot be imported into the model using a CSV or spreadsheet file. *(HEC-HMS Compatibility)*
- Hydrologic Losses – Can model rainfall abstraction for the rain on grid simulations using typical traditional loss methods. *(Loss Methods)*
- Hydrology Methods – No traditional hydrology capabilities. *(Hydrograph Methodology)*

4.2.4 River Modeling

Much of the City's stormwater infrastructure drains into channel systems maintained by either the City or the HCFCD. Channel capacity can affect the tailwater and capacity of the upstream infrastructure. This category summarizes the ability to model cross sections, interact with HEC-RAS, and interact with the 2D mesh. A total of 28 points were possible for this category. **Table 14** shows the scoring for this category.

Table 14: Scoring Matrix for River Modeling Components

Component	ICM	XPSWMM	FLO-2D
River Cross Sections	3	3	3
Roughness Values	4	3	1
HEC-RAS Import	3	4	4
Outfalls	4	4	3
1D Mapping	3	3	2
1D Structure Modeling	2	3	3
1D/2D Connection	4	3	2
Total (out of 28)	**23**	**23**	**18**

InfoWorks ICM

ICM scored 32 of the possible 28 points for river modeling. The software has the ability to model rivers/channels, import HEC-RAS models, and model 1D/2D interaction. Some of the major highlights of the software are:

- Roughness Zones – Roughness zones can be added to the 1D river reaches to extract n-values for calibration purposes. Using the zones allows for quick adjustments of the n-values along stretches of cross sections. *(Roughness Values)*
- 1D/2D Connections – The 1D/2D connection consists of a line using a weir equation for flow entering or leaving the 1D reach. By using the weir equation, the coefficient can be adjusted based on the type of connection and calibration considerations. The program also presents the flow hydrograph of each bank between the modeled cross sections. *(1D/2D Connection)*
- Structures – Culverts and bridges can be represented in the 1D network. However, the configuration can be challenging especially for non-symmetrical bridge openings. Bridges and culverts can be sources of instability in the model if not configured properly. *(1D Structure Modeling)*

XPSWMM

XPSWMM scored 23 of the possible 28 points for river modeling. The software has the ability to model rivers/channels, import HEC-RAS models, model 1D/2D interaction. Some of the major highlights of the software are:

- RAS Models – Capable of importing the complete HEC-RAS model including bridge structures. The software does require some adjustments prior to the simulation. *(HEC-RAS Import)*
- 1D/2D Connection – XPSWMM uses the 2D shallow water equation to model flow into and out of the river reach which is typically more stable than the weir equation. One downside is that the flow cannot be calibrated to real conditions by adjusting the weir coefficient. Another is that the program does not provide the flow into and out of each river bank if that information is needed. *(1D/2D Connection)*
- Structures – Culverts and bridges can be represented in the 1D network. The configuration of the bridge or culvert only allows for a single elevation for the bridge deck which is not always representative of real conditions. Bridges and culverts can be sources of instability in the model if not configured properly. *(1D Structure Modeling)*

FLO-2D

XPSWMM scored 19 of the possible 28 points for river modeling. The software has the ability to model rivers/channels, import complete HEC-RAS models, and model hydraulic structures. Some of the major highlights of the software are:

- RAS Models – Capable of importing the complete HEC-RAS model. With modifications the simulation can be run. *(HEC-RAS Import)*
- Structures – Structures can be modeled consisting of culverts. *(1D Structure Modeling)*

4.2.5 Storm Drain Modeling

Storm sewer shapes, sizes, and interconnectivity vary throughout the City. This category summarizes the types of storm sewer available for modeling and the node types for link connections, inlets, and detention. A total of 28 points were possible for this category. **Table 15** shows the scoring for this category.

Table 15: Scoring Matrix for Storm Drain Modeling Components

Component	ICM	XPSWMM	FLO-2D
Pipes	4	4	3
Multiple Links	4	4	4
Headlosses	4	3	3
Ditches	4	4	3
Node Types	4	4	1
Inlets	4	4	3
Detention	4	4	2
Total (out of 28)	**28**	**27**	**19**

InfoWorks ICM

ICM scored 28 out of possible 28 points for storm drain modeling. The software has the ability to model several types of conduits and inlets with a large library of shapes and node types. Some of the major highlights are:

- Pipe Network – There are multiple types of pipes - including user defined - that can be included in the model. *(Pipes, Multiple Links)*
- Headlosses – ICM can automatically assign headloss coefficients to each storm sewer based on the incoming and outgoing angles at the nodes. This allows for a quick inclusion of the headlosses at junctions without significant effort. *(Headlosses)*
- Detention – Detention ponds can be modeled using either 1D storage nodes with an applied elevation/storage curve or simulated in the 2D mesh. *(Node Types, Detention)*

XPSWMM

XPSWMM scored 27 of the possible 28 points for storm drain modeling. The software has the ability to model several types of conduits and inlets with a large library of shapes and node types. Some of the major highlights of the software are:

- Pipe Network – There are multiple types of pipes - including user defined - that can be included in the model. *(Pipes, Multiple Links)*
- Headlosses – Headlosses can be applied to the conduits but can only be input manually. *(Headlosses)*
- Detention – Detention ponds can be modeled using either 1D storage nodes with an applied elevation/storage curve or simulated in the 2D grid. *(Node Types, Detention)*

FLO-2D

FLO-2D scored a 19 out of a possible 28 points for storm drain modeling. Manhole and inlet nodes can be imported using a GIS shapefile and parameters can be set based on fields within the shapefile. Shapefiles of conduits are also imported in a similar fashion. Some of the major highlights of the software are:

- GIS Shapefiles – Node and link layers can be imported into the QGIS software via GIS shapefiles. *(Pipes, Node Types)*
- Conduits – Multiple conduits and varying shapes can be modeled within the storm drain system. *(Pipes, Multiple Links)*
- Inlets – Five different types of inlets can be modeled: sag, grated, rating curve controlled, and standard manholes. *(Node Types, Inlets)*

4.2.6 2D Surface

The 2D surface is essential for determining overland conveyance. This category summarizes the types of terrains available for use, the detail of the 2D surface, roughness value assignments, and terrain modifications. A total of 32 points were possible for this category. **Table 16** shows the scoring for this category.

Table 16: Scoring Matrix for 2D Surface Components

Component	ICM	XPSWMM	FLO-2D
Terrain	4	3	3
Surface Type	4	2	2
Detail	4	2	2
Boundary Types	4	4	4
Minor Modifications to Terrain	4	4	1
Voids/Inactive Areas	4	3	4
Roughness Polygons	3	4	4
Meshing	4	4	3
Total (out of 32)	**31**	**26**	**23**

InfoWorks ICM

ICM scored 31 out of the possible 32 points for 2D surface. The software uses an irregular triangle mesh to simulate the 2D overland conveyance. The mesh allows for a variety of detail within the same boundary to include detail where needed. Some of the major highlights of the software are:

- Terrain - A gridded raster or Triangular Irregular Network (TIN) can be imported into the ICM model for use in the program. The grid will import and load quickly and does not slow the software. *(Terrain, Surface Type)*
- Triangular Surface – By using the triangular surface, the detail of the model can be adjusted by using breaklines at points of elevation changes. This allows for detail to be added to the model without sacrificing simulation time or model complexity. *(Detail, Boundary Types, Meshing)*
- Terrain Modifications – The triangles can be adjusted within the program to simulate ground adjustments as required. Adjustments can be global such as a reduction in elevation to model a detention or channel feature. *(Surface Type, Detail, Minor Modifications to Terrain)*
- Meshing – Since the mesh is irregular, the triangles must be re-developed anytime the mesh changes. Meshing using raster is generally quick but can be cumbersome if there are issues or errors that prevent or slow the process. *(Meshing)*

XPSWMM

XPSWMM scored 26 of the possible 32 points for 2D surface modeling. The software uses a rigid grid to simulate overland flows. The grid consists of squares with the same orientation and size. Some of the major highlights of the software are:

- Terrain – Using a GIS raster or point file, an XPTIN is developed within XPSWMM to incorporate the 2D surface. The size of the TIN within the program can be limited, but rasters can be referenced if they are too large in size for the program. *(Terrain, Surface Type)*
- Rigid Surface – The rigid grid consists of a simple square network for the entire 2D surface. Cell sizes are specified, and elevations are obtained from the terrain. The singular elevations and lack of breaklines can require small cells needed to model in detail specific areas since not all overland conveyance features are designed in a grid fashion. Smaller cells typically mean longer simulation times. However, meshing is not required for the surface. *(Surface Type, Detail, Meshing)*
- Roughness Zones – Roughness polygons (n-values) can be overlapping which simplifies the GIS development process. *(Detail, Roughness Polygons)*

FLO-2D

FLO-2D scored 23 of the possible 32 points for 2D surface modeling, FLO-2D is capable of importing either a TIFF or ASCII terrain file and uses a gridded surface to model the 2D surface. Roughness values and voids can be assigned within the grid area. Some of the major highlights of the software are:

- Grid – 2D surface is modeled using a grid surface. Cell sizes can be adjusted to produce more or less detail. Elevations and roughness values are assigned to each cell when prompted using the grid tools. Voids can be established within the grid to model structures. *(Surface Type, Detail, Voids/Inactive Areas, Roughness Polygons)*
- Terrain – Terrain used to create 2D surface must either be in TIFF or ASCII format. Terrain cannot be modified. *(Terrain, Minor Modifications to Terrain)*

4.2.7 Simulation

Model simulation times affect the future usability of the model. Simulation times that exceed several hours will be more difficult to modify and maintain for future use by the City. This category summarizes the runtimes, stability information during simulations, and results output available to the user within the program. A total of 32 points were possible for this category. **Table 17** shows the scoring for this category.

Table 17: Scoring Matrix for Simulation Components

Component	ICM	XPSWMM	FLO-2D
Simulation Options	4	4	2
Run Time	4	3	1
Simulation Interface	4	4	3
Stability Checks	4	3	1
Results	4	3	1
2D Inflow Capture	4	3	2
2D Flow Line	4	3	2
Simulation Controller	4	3	1
Total (out of 32)	**32**	**26**	**13**

InfoWorks ICM

ICM scored 32 of the possible 32 points for simulation. The simulation controller does allow the use of multi-cores and a GPU within the computer to increase computation speed of the software. Some of the major highlights of the software are:

- Simulation Time – A simulation using the Chimney Rock model developed for the study was completed in 20 minutes using a 1 second time step. The reduced time is attributed to the GPU and ability to group triangles for the simulation run. *(Run Time)*
- Simulation Interface – Hydrographs are displayed within the program showing the combined inflow and outflow. The shape and stability of the hydrographs can indicate good model health for debugging during the simulation run. The interface also shows the limiting 2D component and any nodes/links that are failing. Since the controller is separate from the model window, model geometries can be edited while the model is running. *(Simulation Interface, Stability Checks, Simulation Controller)*
- Results Formatting and Viewing - One of the benefits of the ICM software is providing additional information and formatting options for viewing results in the model. The program provides hydrographs and elevations throughout the model for every time step as well as color schemes, labels, and search queries for gathering and sorting additional data. *(Simulation Options, Results)*

XPSWMM

XPSWMM scored 26 of the possible 32 points for simulation. The simulation controller does allow the use of multi-cores within the computer to increase computation speed of the software. Some of the major highlights of the software are:

- Simulation Time – A simulation using the Chimney Rock model developed for the study was completed in 2 hours using a 1 second time step. *(Simulation Options, Run Time)*

- Separation Option – Hydrology and hydraulics can be modeled separately or simultaneously. This is helpful for evaluating or calibrating hydrology prior to the full model simulation. *(Simulation Options)*
- Simulation Window – The window will show current time step, expected simulation time remaining, flow change, and continuity errors for debugging during the simulation. *(Simulation Interface, Stability Checks, Simulation Controller)*

FLO-2D

FLO-2D scored 13 of the possible 32 points for simulations. Simulation results must be analyzed within the output files while depth and water surface elevation mapping must be analyzed using a separate FLO-2D software. Some of the major highlights of the software are:

- Real Time Graphics – During the simulation, real time results are shown with 2D mapping versus the model time step. *(Simulation Interface, Results)*
- Results – 1D results can be analyzed through the output files while 2D mapping results need a separate software in order to view (MapperPro). *(Simulation Interface, Results)*
- Simulation Controller – The runs create simulations on the user's computer, which inhibits the user to make changes to the model while the simulation is running. *(Simulation Controller)*

4.2.8 Application

The application start-up time and stability will affect the usability during model development and maintenance by the City. This category summarizes the program stability, start up, setup, and customer support. A total of 16 points were possible for this category. **Table 18** shows the scoring for this category.

Table 18: Scoring Matrix for Application Components

Component	ICM	XPSWMM	FLO-2D
Program Stability	4	3	3
Program Start-Up	4	3	4
Model Setup	4	4	1
Customer Support	4	4	4
Total (out of 16)	**16**	**14**	**12**

InfoWorks ICM

ICM scored 16 of the possible 16 points for application. The ICM program rarely crashes and offers customer support. The program is not as intuitive as other software, however it is relatively easy to use once understood. Some of the major highlights of the software are:

- Program Stability – ICM program is relatively stable and does not crash often. It also will open large models easily. *(Program Stability, Program Start-Up)*
- Customer Support – Help is available, and responses are received within a few business hours. Their experts are also available for model reviews as needed. Also, Innovyze Online is a user forum and is often helpful in quickly finding model solutions outside of formal customer support. *(Customer Support)*

- Themes—Themes are used in a GeoPlan Window to graphically present parameters. Themes help differentiate common categories by allowing the user to change the appearance of any model feature. Themes can be saved and loaded from the master database. *(Model Setup)*
- Labels—Configurable Autolabels and Custom Labels can contain network object parameters, user defined text or field values. The user can select which layers they want Autolabels to reference. *(Model Setup)*

XPSWMM

XPSWMM scored 14 of the possible 16 points for application. XPSWMM provides a simple interface for drainage model development. Most of the aspects of the program are intuitive and easy to use. Some of the major highlights of the software are:

- Ease of Setup – XPSWMM provides a simple interface for drainage model development. Most of the aspects of the program are intuitive and easy to use. *(Program Start-Up, Model Setup)*
- Customer Support – Help is available, and responses are received within a few business hours. Their experts are also available for model reviews as needed. Also, Innovyze Online is a user forum and is often helpful in quickly finding model solutions outside of formal customer support. *(Customer Support)*

FLO-2D

FLO-2D scored 12 of the possible 16 points for application. The software opens relatively quickly, usually taking less than a minute. Some of the major highlights of the software are listed below:

- Program Start Up – The QGIS software usually takes less than a minute to open. *(Program Start-Up)*
- Program Stability – The model crashes occasionally. Saving the project often is needed to ensure all model changes are incorporated. *(Program Stability, Model Setup)*
- Customer Support – FLO-2D has available customer support through their website. *(Customer Support)*

4.2.9 Summary

The table below reflects the score in each category of the analyzed programs in the 2D Hydraulic and Hydrologic Modeling Software Comparison matrix.

Table 19: Summary of Scoring Matrices for Software Evaluation

Category	ICM	XPSWMM	FLO-2D
Data	46	35	25
Results Management	12	11	6
Hydrology	14	14	5
River Modeling	23	23	18
Storm Sewer	28	27	19
2D Surface	31	26	23
Simulation	32	26	13
Application	16	14	12
Total (out of 204)	**202**	**176**	**121**
SCORE	**95**	**83**	**57**

InfoWorks ICM ranked highest with a score of 95. The high score is attributed to the data management, 2D surface, and simulation categories. FLO-2D scored the lowest due to limited capabilities in hydrology, storm sewer modeling, and the simulation interface.

Table 20 below summarizes agency approval and potential costs for the model packages. The costs shown are based on a 2,000 nodes license with typical 2D limitations. The cost will vary based on the license needs and will need to be verified with the vendor prior to purchase.

Table 20: Summary of Approval for Software Packages

Category	InfoWorks ICM	XPSWMM	FLO-2D
FEMA Approval	Not Currently	Yes	Yes
Agency Approval	• City of Houston, • City of Austin, • Town of Addison, • City of Fort Worth, • City of San Marcos, • City of Sugar Land	• City of Houston, • Town of Addison, • City of Richardson, • City of San Antonio, • City of Austin, • HCFCD, • City of Dallas	• FEMA, • USACE, • Municipalities located in the Western US (California, Arizona, New Mexico, Colorado)
Cost	$60,100	$54,600	$2,000

$

4.3 Results Comparison

The simulation results from the Chimney Rock model for each software package were compared to identify any major differences in flows, water surface elevations, or ponding depths. In general, the flow rates, water surface elevations, and ponding extents were similar between ICM and XPSWMM. The FLO-2D rain on grid model tended to show larger ponding extents due to the methodology.

Flow rates for the drainage basins were compared for 258 drainage basins within InfoWorks ICM and XPSWMM. FLO-2D does not have flow hydrograph calculation ability and therefore was not included in the hydrology comparison. The average difference of peak flow between ICM and XPSWMM was 0.3%, indicating that the hydrology calculations between the two software are very similar.

Peak elevations within the 1D nodes in the models were compared to identify any differences in the model results. Elevations within the model packages were relatively close to each other, with the median difference in elevation of approximately 0.13 feet. The minimal difference indicates that commonality of input for each software package provides similar results.

Peak flows within the 1D links were compared to identify any differences in the flow rates through the storm sewer network. Flow rates did vary between the software packages but not enough to cause any major differences in ponding or water surface elevation. The median difference in flow rates of the model links was 13 cubic feet per second, or a 20% difference.

Ponding depths and extents were also reviewed and compared. In general, ponding was similar between the software packages. FLO-2D had wider and more granular extents due to the limitation of cell size and the rain on grid methodology. The Figures 8-10 show the ponding results in a portion of the study area.

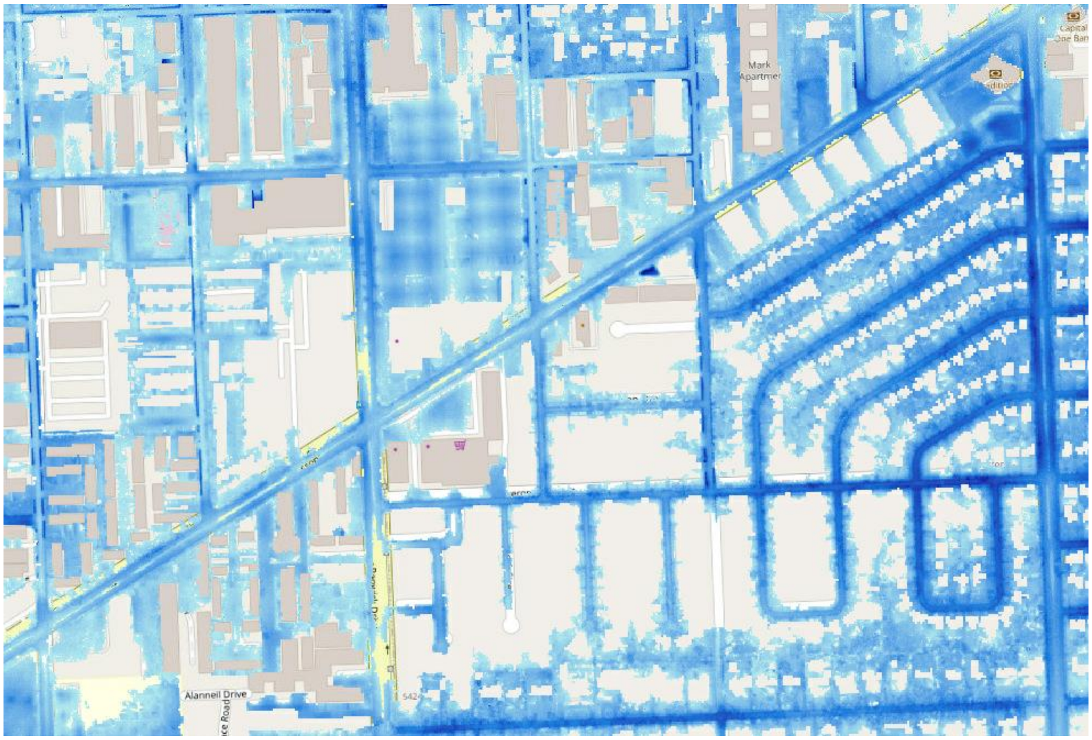


Figure 8: InfoWorks ICM Model Results

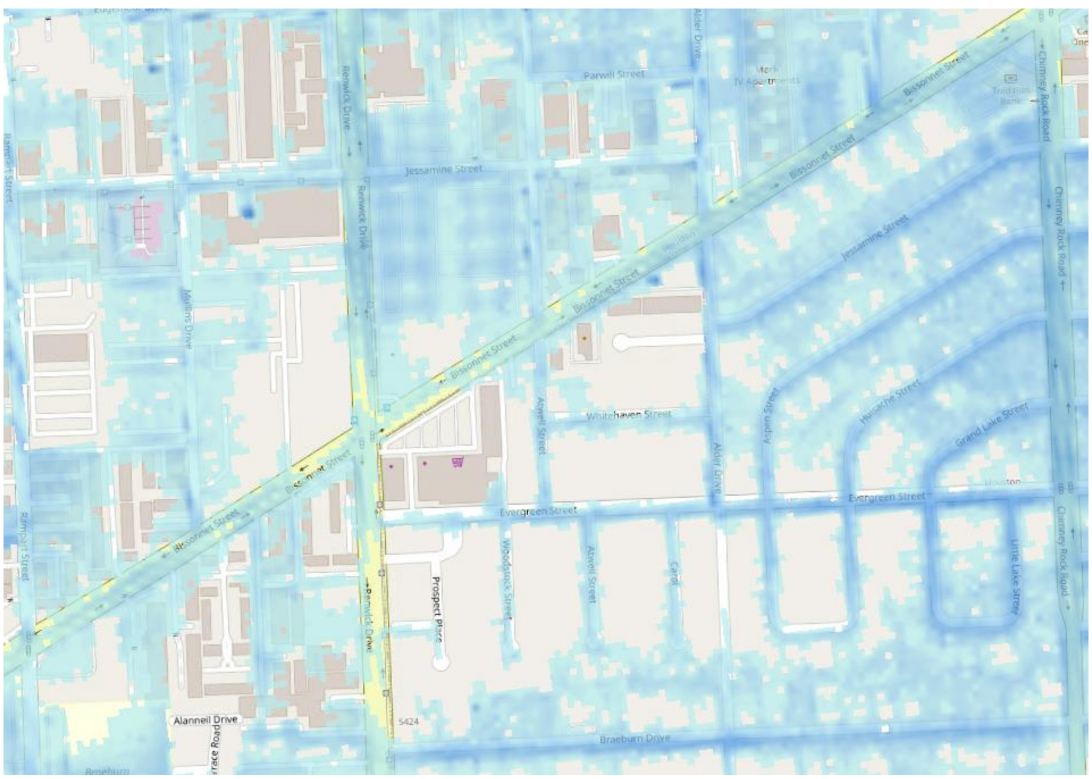


Figure 9: XPSWMM Model Results

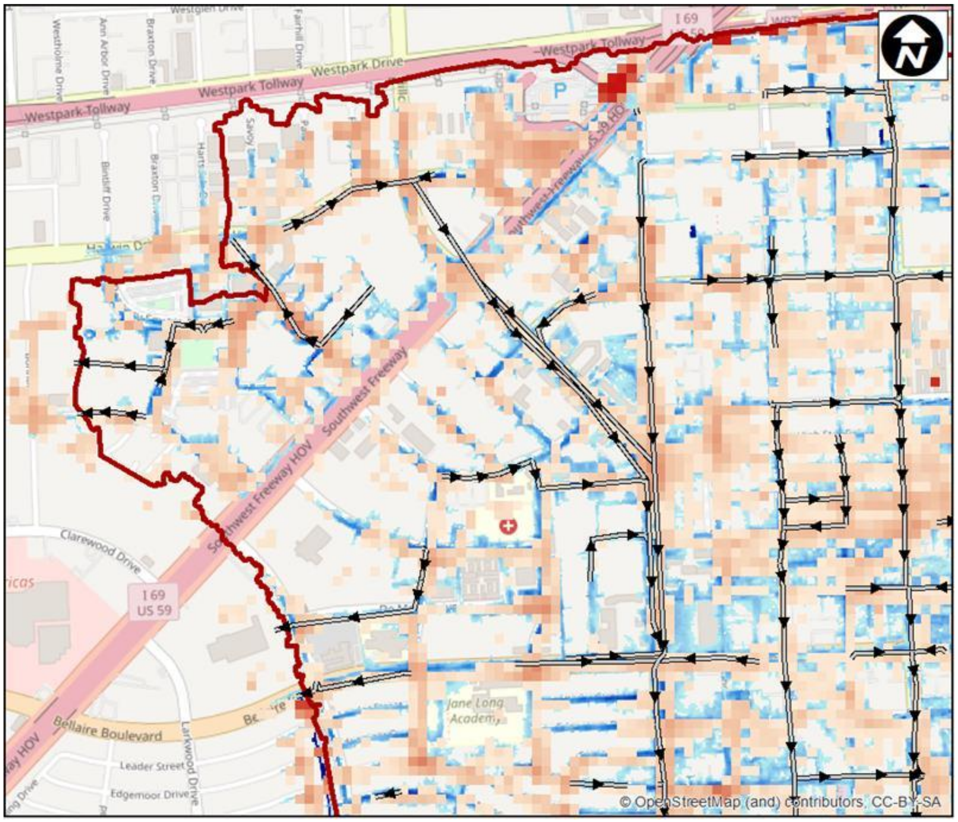


Figure 10: FLO-2D Model Results

4.4 Software Evaluation Conclusions

The detailed software evaluation showed that FLO-2D was significantly limited in its ability to analyze storm sewer systems for a large regional study. The program provided ease of use when developing rain on grid models, but the simulation runtime, meshing, and ability to incorporate storm sewer were limited. The evaluation showed that while FLO-2D was significantly cheaper than ICM or XPSWMM, it would not be able to meet the goals identified by the City for the stormwater infrastructure model.

Of the two-remaining software, InfoWorks ICM has the highest overall score based on the comparison categories. The main benefits from this software package are the data management, 2D surface, and simulation capabilities.

Data management will be essential for the city-wide stormwater infrastructure model. The models will consist of multiple trunklines, channels, and bayous and managing this data will be an arduous task. The ICM flagging system, queries, check in/check out, and scenario manager will assist the City consultants during the model development, and the City during implementation of the stormwater models.

The 2D surface thoughout the City of Houston is complex and consists of various built and natural systems with topographic changes. Some of the City is also conveyed by roadside ditches which may need to be modeled in the 2D terrain. The flexibility of the ICM mesh will assist in adding detail to the overland conveyance where needed while managing simulation runtime.

Simulation runtime will affect the model development as well as the overall implementation. As the City identifies high level projects, multiple simulations will need to be run. Models that can be run quickly will be more efficient for City staff to identify the necessary infrastructure. The ICM software provided the quickest runtime by leveraging the GPU capabilities.

Due to these factors, InfoWorks ICM is recommended for use for the stormwater infrastructure modeling effort.

5.0 Recommendations

The City of Houston is planning to develop a citywide model to facilitate evaluations of infrastructure capacity deficiencies and develop planning-level infrastructure improvements. The city-wide model will include both the subsurface (storm sewer) and surface infrastructure, including streets, overland conveyance, ditches, and bayous. The model will allow for watershed-wide analyses of the drainage infrastructure capacity with consideration of overflows and sheet flow.

The results of the desktop software evaluation and analysis are intended to provide guidance to the City for developing criteria for a city-wide model. The software screening identified the top three software (FLO-2D, InfoWorks ICM, and XPSWMM) that have the capability perform a city-wide analyses for larger areas of the city's stormwater infrastructure.

The trunkline analysis evaluated the infrastructure detail needed to accurately model the City's drainage patters while managing the detail needed in the model results. The analysis showed that storm sewers equal to or greater than 36 inches in diameter should be included in the model to reduce the amount of trunkline pipe needed while providing similar ponding and flow results. Storm sewers less than 36 inches in diameter should be used only when they provide the singular drainage conveyance from an area of interest.

Finally, the software evaluation recommended the software package to use for the analysis. InfoWorks ICM should be used for hydrologic and hydraulic modeling for the Citywide stormwater infrastructure model. The next steps in the process include conducting a pilot study for a defined area of the City and using InfoWorks ICM to develop a process and modeling guidelines for conducting development of the city-wide model.

APPENDIX A

SOFTWARE EVALUATION MATRIX

2D HYDRAULIC AND HYDROLOGIC MODELING SOFTWARE COMPARISONS

A program comparison of 2D hydraulic modeling softwares InfoWorks ICM, XPSWMM, and Flo-2D. Each topic is a component of the software and typical model building. Comments discuss the different ways each program models certain hydrologic and hydraulic aspects of a stormwater system. Scores indicate a user opinion on the quality of the software modeling. The scoring system is as follows: 4 - Excellent, 3 - Good, 2 - Fair, 1 - Poor.

Data

Comparison Item		InfoWorks ICM	Score	XPSWMM	Score	Flo-2Dw/QGSIS Plugin	Score
Data Management	How and were is data stored?	Models are saved in an ICM database located locally or on a server. Multiple models can be saved in the same database. Networks are used for the model geometry and input. Networks use a checkin/checkout system for saving data permanently.	4	Models are saved in individual folders and include several data and results files.	2	Files are stored with a geopackage file (.gpck) of the project	2
Transporting Models for Review	How are models sent to other entities?	Model parts can be combined into a transportable database to be sent to other entities. Database size can be large depending on the size of results.	4	Models sent to other entities are the model files created. Database size can vary depending on the size of the model and results.	3	Copy and save the .gpck file to the desired location	3
Reviewing Models	How can other entities view the model?	InfoWorks ICM Viewer license can be purchased to view models and results without editing.	2	XPSWMM viewer license is available for free download to view models and results without editing.	4	Download Flo2D Basic. More Limited capabilities than Flo2D Pro	3
Comparing Models	How can the software package compare two different model results and data?	Models and alternative scenarios are saved and viewed within the same program window. Models can be compared by viewing the models visually. ICM also can compare model tabular results within the same window.	4	Models can be compared in the same window using the scenarios tab. Two models can be viewed by running the program in separate applications.	3	Model comparison not available	1
Importing from GIS	Can GIS data be imported easily from ArcGIS or similar program?	Yes. Several options are available for import including shapefiles and geodatabases	4	Yes. Several options are available for import including shapefiles.	4	GIS data can be dragged in from Windows Explorer and assigned easily.	4
Tables and Grid Views	Can tables be used to manipulate and modify data?	Default tables of all data input and results are set-up and can be customized to user preferences. Tables can be used to modify the model.	4	The user can create tables of each of the parameters in the model setup to view or modify model input. Can view both results and input. Tables created can be saved. No "default" tables for viewing input or output so user has to set them up.	4	Componenets of the model act as GIS layers and can be edited through the editing tool.	3
Tracking changes in model setup	How can each package track data input and changes made?	User defined flags can label where data came from (i.e. Survey, as-builts, assumed, etc.) These flags can be sorted to show only the improvements made to the model, or show where the base data came from. Typical flagging is PR-Proposed, CY-data from city, AB- data from as-builts. Users can add notes to document version or changes.	4	No current way to "flag" or track changes made or document where source data came from.	2	Model cannot track information changes	1
Scenario Modeling	How are alternative scenarios managed?	Scenarios can be modeled using the scenario manager or through a separate network. The scenario manager allows changes made to the base (existing conditions) model to be carried through to the attached scenarios.	4	Scenarios can be modeled using the scenario manager or through a separate network. The scenario manager allows changes made to the base (existing conditions) model to be carried through to the attached scenarios.	3	Scenario modeling not available	1

2D HYDRAULIC AND HYDROLOGIC MODELING SOFTWARE COMPARISONS							
A program comparison of 2D hydraulic modeling softwares InfoWorks ICM, XPSWMM, and Flo-2D. Each topic is a component of the software and typical model building. Comments discuss the different ways each program models certain hydrologic and hydraulic aspects of a stormwater system. Scores indicate a user opinion on the quality of the software modeling. The scoring system is as follows: 4 - Excellent, 3 - Good, 2 - Fair, 1 - Poor.							
Data (cont.)							
Comparison Item		**InfoWorks ICM**	**Score**	**XPSWMM**	**Score**	**Flo-2Dw/QGSIS Plugin**	**Score**
Component Selection	**Can the software select certain model components and save these selections?**	Can save selections and make queries to select objects with certain qualities. For example, you can set up an expression to select all links where headloss is greater than 1 foot, then save that selection to be used in the future.	4	Selection lists and queries currently unavailable. Can use XP tables to select certain data.	2	Tables of model components can be accessed. Can select components manually but does not have selection lists.	1
Network Wide Changes	**How can the software make global adjustments to model components?**	Can copy and paste using the Table Views. Can also use queries to set specific information.	4	Copy and Paste function allows the user to copy input from one data source and paste to all relevant model components. Can also copy and paste using the XP tables.	3	Use tables to adjust parameters	2
Model Saving	**How is the model information saved?**	All changes are automaticially saved. An Undo button is available.	4	User has to save periodically and can set up an automatic save every X minutes. Undo button is unavailable. If model crashes without being saved, all changes are lost.	3	Saving, but no autosaving	2
Model Management	**How are model steps saved during the model building process?**	Through the commit system	4	Any iterations or steps needed to be saved for later use have to be saved as new individual models, or exported into an XPX file to be imported at a later time.	2	Any iterations or steps needed to be saved for later use have to be saved as new individual models, or exported into an XPX file to be imported at a later time.	2
Data Score (48 Potential Points)		**InfoWorks ICM**	**46**	**XPSWMM**	**35**	**Flow-2D**	**25**

2D HYDRAULIC AND HYDROLOGIC MODELING SOFTWARE COMPARISONS

A program comparison of 2D hydraulic modeling softwares InfoWorks ICM, XPSWMM, and Flo-2D. Each topic is a component of the software and typical model building. Comments discuss the different ways each program models certain hydrologic and hydraulic aspects of a stormwater system. Scores indicate a user opinion on the quality of the software modeling. The scoring system is as follows: 4 - Excellent, 3 - Good, 2 - Fair, 1 - Poor.

Results Management

Comparison Item		InfoWorks ICM	Score	XPSWMM	Score	Flo-2Dw/QGSIS Plugin	Score
Troubleshooting - Before and After model simulation	How is input data checked before and during a simulation?	Validation is completed before model is simulated to ensure there is no missing or incorrect data. Errors and warnings are logged and displayed to the user. Log Reports are used after the model runs to identify problematic areas. Error polygons can also be used to show errors in the 2D mesh setup.	4	Before simulating model, XP goes through a preliminary error checker. This is checking values and make sure everything makes model sense, not necessarily engineering sense. Before a 2D simulation, it will also do a 2D check. If it finds issues, the model will not run and will present the errors to the user. The errors presented will have a error number, detail and the coordinates of where the error occurred. If instability occurs in the model (1D or 2D), XP will tell the user what link, node or the location of the grid where the instability occurs.	4	Error results are exported to a separate file which can be viewed outside the Flo-2D interface.	3
Viewing Results	How can simulation results be viewed?	Results and be viewed graphically and in tabular form. Graphic results include time step velocity, flow, water surface elevation, and depth data. Tabular results show detailed conduit and node information for each time step.	4	Results and be viewed graphically and in tabular form. Graphic results include time step velocity, flow, water surface elevation, and depth data. Tabular results show detailed conduit and node information for each time step.	3	Results are not included within the software. The information must be exported to GIS for viewing.	1
Exporting Results	What data can be exported to GIS?	Can export conduits, nodes and flood extents as shapefiles or feature classes	4	Can export conduits, nodes, and flood extents as shapefiles or GRIDs. The file sizes can limit the mapping capablities.	4	Modeling building elements can be exported and results can be exported to other programs.	2
Results Management Score (12 Potential Points)		InfoWorks ICM	12	XPSWMM	11	Flow-2D	6

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Hydrology

Comparison Item		InfoWorks ICM	Score	XPSWMM	Score	Flo-2Dw/QGSIS Plugin	Score
Drainage Catchments	How are drainage areas input?	Subcatchments can be drawn or imported through GIS.	4	Catchments can be drawn by hand or imported from GIS. Catchments are connected to nodes through import or drawing a link from catchment to node.	4	Drainage areas are not included within the program.	1
Hydrograph Methods Available	What hydrograph routing methods are available?	Clark, Desbordes, HEC Snyder, Kadoya, Large Catchment, Non-linear, ReFH, SCS Unit, Snyder, Sprint, SWMM, Unit Hydrograph, Wallingford, Rational, Cascade, RAFTS	4	Runoff, Kinematic Wave, Laurenson, SCS Hydrology, Unit Hydrograph, Rational Formula, UK Hydrology. Unit Hydrograph method includes Nash, Rational, Santa Barbara Urban, Snyder, time area, Snyder, Clark	4	No hydrograph routing	1
Loss Methods Available	What infilitration/loss methods are available?	Fixed PR Model, Wallingford Procedure Model, New UK PR Model, SCS Model, Horton Infiltration Model, Green-Ampt Model, Constant Infiltration Model, CN, SCS Model, Horner Model, ReFH Model, Horton Infiltration Model, Simple Runoff Model, Probability Distributed Model, Deficit and Constant Loss Model	4	Horton, Green Ampt, UniformLoss, SCS Curve Number	4	Losses are included for the rain-on-grid simulations only.	2
HEC-HMS Import	Can you import hydrograph information from HEC-HMS?	Cannot directly import from HEC-DSS. hydrograph data can be imported using .csv files.	2	Cannot directly import from HEC-DSS. Flow data can added using import database options.	2	Cannot directly import from HEC-DSS. Inflows must be copied in manually.	1
Hydrology Score (16 Potential Points)		**InfoWorks ICM**	**14**	**XPSWMM**	**14**	**Flow-2D**	**5**

2D HYDRAULIC AND HYDROLOGIC MODELING SOFTWARE COMPARISONS

A program comparison of 2D hydraulic modeling softwares InfoWorks ICM, XPSWMM, and Flo-2D. Each topic is a component of the software and typical model building. Comments discuss the different ways each program models certain hydrologic and hydraulic aspects of a stormwater system. Scores indicate a user opinion on the quality of the software modeling. The scoring system is as follows: 4 - Excellent, 3 - Good, 2 - Fair, 1 - Poor.

River Modeling

Comparison Item		InfoWorks ICM	Score	XPSWMM	Score	Flo-2Dw/QGSIS Plugin	Score
River Cross Sections	How are river cross sections added to the model?	Import through GIS, RAS, or draw them in.	3	Cross sections can be defined directly from the terrain inside the model. Bank stations, n-values, and elevations can be altered inside the cross section editor. HEC-RAS cross sections can be directly imported into the model.	3	Import from RAS or draw manually	3
Roughness Values	How are roughness values applied?	Using roughness zones or assigning default roughness values.	4	imported shapefiles can be assigned roughness values, and a general n value can be assigned	3	Doesn't seem to apply roughness to natural channel sections	1
Importing HEC-RAS models	Can the package import an existing HEC-RAS model?	ICM will bring in model cross sections and alignment. Structures will need to be input.	3	XPSWMM will bring in the complete model. Modifications are necessary in order to run the simulation.	4	RAS models can be imported including the cross sections and structures.	4
Outfalls	What outfall/tailwater conditions can be used?	Outfalls can be free, fixed elevation, tidal or user-defined stage, flow, or rating curves. 2D boundaries can be elevation or flow boundary conditions.	4	Outfalls can be free, fixed elevation, tidal or user-defined stage, flow, or rating curves. 2D boundaries can be elevation or flow boundary conditions.	4	Boundary conditions can be applied on the channel outflow node	3
1D Mapping	How can the 1D River Reach floodplain be mapped?	1D River Reaches can be mapped using flood contours produced using the gorund model.	3	1D Channels can be mapped in 2D by creating water lines along the channel reach. Water lines must be developed before simulation in order to view results.	3	1D reaches cannot be mapped directly in the program	2
1D Structure Modeling	How can 1D structures be modeled within the River Reach?	Bridges and culverts can be modeled in 1D. Bridge setup is more challenging than other programs	2	Any structure can be modeled. Bridge Links have limited input such as a constant weir/deck elevation.	3	Culverts and bridges can be included.	3
1D/2D Connection	How is the 1D connected with the 2D surface?	Bank lines have "boundary connections" that link the 1D river reach to the 2D surface.	4	The 1D is connected to the 2D through 1D/2D interface lines that are typically along the top of bank of the channel. 1D/2D connection lines connect the water surface elevation in the 1D node to the 1D/2D interface lines.	3	Nodes can be placed to connect the 1D and 2D systems.	2
River Modeling Score (28 Potential Points)		InfoWorks ICM	23	XPSWMM	23	Flow-2D	18

2D HYDRAULIC AND HYDROLOGIC MODELING SOFTWARE COMPARISONS

A program comparison of 2D hydraulic modeling softwares InfoWorks ICM, XPSWMM, and Flo-2D. Each topic is a component of the software and typical model building. Comments discuss the different ways each program models certain hydrologic and hydraulic aspects of a stormwater system. Scores indicate a user opinion on the quality of the software modeling. The scoring system is as follows: 4 - Excellent, 3 - Good, 2 - Fair, 1 - Poor.

Storm Drain Model

Comparison Item		InfoWorks ICM	Score	XPSWMM	Score	Flo-2Dw/QGSIS Plugin	Score
Pipes	What types of pipes can be modeled?	Arch, archspung, circle, cnet, egg, egg2, oval, rectangle, utop, channels, and user defined shapes	4	Circular, rectangular, User defined, Special, trapezoidal, power fn, natural	4	Circular, rectangular, trapezoidal, triangular, ellipse, arch, irregular, custom, etc.	3
Multiple Links	How are multiple conduits between to nodes modeled?	For identical conduits, a barrel can be specified. For different conduits, multiple links can be drawn between nodes. They will given designated suffixes.	4	For identical conduits, multiple barrels can be set in Conduit Factors. For different types of conduits, multilinks are used and can have up to 7 different types including weirs, pumps, orificies, & rating curves.	4	Multiple conduits should be identified in a attribute field stating the number of barrels along the link.	4
Headlosses	Can minor headlosses across pipes be modeled?	Minor losses can be modeled in conduits.	4	Entrance and exit losses can be set in the Conduit Factors.	3	Yes. entrance and exit losses.	3
Ditches	How are ditches modeled?	Ditches can be modeled as channel links, 2D, or 1D river reaches.	4	Ditches can be set as 1D channel conduits with cross sections taken directly from terrain. Modeling ditches in 2D is difficult as it requires small grid cells which is set for the entire grid area.	4	Ditches can be modeled as a channel using floodplain cross sections. Geometries can be imported from HEC-RAS.	3
Node Types	What types of nodes are available?	Available node types are manhole, storage, break, outfall, pond, outfall 2D, connect 2D.	4	Node types are None, Allowed, Sealed, Spill Crest to 2D, and Invert to 2D.	4	Node types are defined by types of inlets. There are no ponding types for nodes.	1
Inlets	How can inlets be modeled?	Available inlet types are continuous curb opening, Continuous grate, sag combination, sag curb opening, sag grate, UPC grate.	4	Inlets can be modeled as a user defined rating curve, HEC-22 equations, weir linked to a node or power equation noted by 2D inflow capture.	4	5 types are used. The first 3 types are various styles of Inlet nodes (sag, grated, etc.). The 4th type is a rating curve controlled inlet. The 5th type is a standard manhole.	3
Detention	Can detention be modeled?	Detention can be modeled as 1D nodes or as a part of the 2D surface.	4	Detention can be modeled as a 1D node with associated depth/area curve or added to the 2D surface	4	Detention can be modeled in 2D.	2
Storm Drain Model Score (28 Potential Points)		**InfoWorks ICM**	**28**	**XPSWMM**	**27**	**Flow-2D**	**19**

2D HYDRAULIC AND HYDROLOGIC MODELING SOFTWARE COMPARISONS

A program comparison of 2D hydraulic modeling softwares InfoWorks ICM, XPSWMM, and Flo-2D. Each topic is a component of the software and typical model building. Comments discuss the different ways each program models certain hydrologic and hydraulic aspects of a stormwater system. Scores indicate a user opinion on the quality of the software modeling. The scoring system is as follows: 4 - Excellent, 3 - Good, 2 - Fair, 1 - Poor.

2D Surface

Comparison Item		InfoWorks ICM	Score	XPSWMM	Score	Flo-2Dw/QGSIS Plugin	Score
Terrain	**What type of terrain can be used?**	ASCII or TIN may be used. 5-6 minute processing time.	4	The model uses an .xptin which can be generated from mass points, grid or tin file. The conversion process can take 1-2 hours. On model startup up, loading the .xptin can take 5-10 minutes.	3	Tiff or AsSCII	3
Surface Type	**How is the 2D surface represented in the software?**	Irregular triangles meshed based on terrain and size	4	Rigid grid based on terrain and size	2	Rigid grid based on terrain and size	2
Detail	**How can the 2D surface be adjusted to increase the level of detail?**	Detail can be added using mesh zones, decreasing cell size, breaklines, as well as, checking "terrain sensitve meshing" when creating the 2D mesh.	4	Detail can be added by reducing cell size. There are no breaklines so a more refined area requires a separate grid with smaller cell size.	2	Detail can be added by reducing cell size. There are no breaklines so a more refined area requires a separate grid with smaller cell size.	2
Boundary Types	**What is the water interaction when it is adjacent to the 2D boundary?**	Available boundary conditions are normal condition, vertical wall, critical condition, dry, and supercritical condition	4	The grid boundary acts as a wall. Head boundaries can be added along the grid perimeter to allow 2D flow to leave the grid.	4	Uses boundary conditions	4
Minor Modifications to Terrain	**Can the terrain be altered within the program?**	Mesh level zones can be used to modify the terrain within ICM	4	Elevation shapes can be used to modify terrain.	4	Terrain cannot be modifed.	1
Voids/Inactive Areas	**Can voids be used in the model to add detail the 2D surface?**	Polygons can be included for the voids	4	Voids can be added to the model as inactive areas or high n-values. Inactive areas crossing cells make the entire cell inactive.	3	Yesm either created in the program or imported via a GIS shapfile.	4
Roughness Polygons	**Can roughness values be used to define the terrain friction loss?**	Polygons can be used to vary the roughness zones. Polygons cannot be overlapping or completely enclosed.	3	Landuse polygons can be used to define roughness values. Polygons can overlap with prioritzation.	4	Yesm either created in the program or imported via a GIS shapfile.	4
Meshing	**Is meshing required to build the 2D surface?**	Meshing is required anytime the 2D triangles change	4	2D surface is generted prior to simultion. The meshing time depends on the size of the model.	4	Meshing process is slow, but only need if mesh changes. Process can take several hours.	3
2D Surface Score (32 Potential Points)		**InfoWorks ICM**	**31**	**XPSWMM**	**26**	**Flow-2D**	**23**

2D HYDRAULIC AND HYDROLOGIC MODELING SOFTWARE COMPARISONS

A program comparison of 2D hydraulic modeling softwares InfoWorks ICM, XPSWMM, and Flo-2D. Each topic is a component of the software and typical model building. Comments discuss the different ways each program models certain hydrologic and hydraulic aspects of a stormwater system. Scores indicate a user opinion on the quality of the software modeling. The scoring system is as follows: 4 - Excellent, 3 - Good, 2 - Fair, 1 - Poor.

Simulation

Comparison Item		InfoWorks ICM	Score	XPSWMM	Score	Flo-2Dw/QGSIS Plugin	Score
Simulation Options	Are the hydrology and hydraulics simulated together or seperately?	Together	4	Hydrology and hydraulics can be modeled seperately or simultaneously.	4	Hydrology and hydraulics can be modeled seperately or simultaneously.	2
Run Time	What is the runtime for the model developed?	1 Second timestep - 20 minutes 10 Second Timestep - 5 minutes	4	Simulated 24-hour rainfall. For a 1-Second timestep, the runtime was over 2 hours. For a 10-Second Timestep, the runtime was 35 minutes.	3	Runtime is reasonable for Rain-on-Mesh analysis (<10 mins).	1
Simulation Interface	During the simulation, is any information regarding the process shown?	yes, you can see the inflow/outflow, timestep, minimum timestep, failing nodes/links	4	The simulation interface can show model status including current time step, expected simulation time remaining, flow change, and continuity error.	4	The detailed graphics interface shows the ponding depths in real time along the with inflow hydrograph into the model.	3
Stability Checks	Is there any method of viewing stability as the model is simulating?	Through the job control window	4	The stability of the model can be viewed by monitoring the volume change and continuity error.	3	Errors can only be checked in the output files once the simulation is done.	1
Results	How are results used? What results are available?	Results can be viewed within ICM or exported to GIS. Maximum ponding as well as at any results timestep can be viewed. Animations as well as flow hydrographs for each element area available.	4	Results are viewed directly in the model. Max/min/timestep results each component of the model is available. Graphical and tabular results are can be viewed in the model along with animations of 2D results.	3	Need a seperate software to view mapping results (MapperPro).	1
2D Inflow Capture	Is the 1D/2D flow recorded?	Flow through 1D/2D banks is recorded as well as flow into 2D nodes.	4	Flow through the 1D/2D interface line is not recorded. Flow into 1D nodes can be recorded by developing a "dummy" node with the same name	3	1D/2D flow is not recorded.	2
2D Flow Line	Can the package show the flow along the 2D Surface?	Yes. The flows can be analyzed after a run simply by drawing a new line.	4	Flow lines can be created to attain flows/velocity across a given line. Flow lines must be created prior to running the model.	3	Program cannot show flow over the 2D surface	2
Simulation Controller	How is the simulation run?	Simulation window is separate from the file and the model can be edited while the simulation is being conducted. Multiple models can be run simultaneously	4	The simulation is run on the users computer and no work can be done on the model while the simulation is running.	3	The simulation is run on the users computer and no work can be done on the model while the simulation is running.	1
Simulation Score (32 Potential Points)		**InfoWorks ICM**	**32**	**XPSWMM**	**26**	**Flow-2D**	**13**

2D HYDRAULIC AND HYDROLOGIC MODELING SOFTWARE COMPARISONS

A program comparison of 2D hydraulic modeling softwares InfoWorks ICM, XPSWMM, and Flo-2D. Each topic is a component of the software and typical model building. Comments discuss the different ways each program models certain hydrologic and hydraulic aspects of a stormwater system. Scores indicate a user opinion on the quality of the software modeling. The scoring system is as follows: 4 - Excellent, 3 - Good, 2 - Fair, 1 - Poor.

Application

Comparison Item		InfoWorks ICM	Score	XPSWMM	Score	Flo-2Dw/QGSIS Plugin	Score
Program Stability	How often does the software crash?	The program is relatively stable and will only crash occasionally. Since work is saved automatically, there is no lost effort from a software crash.	4	During the development of the model, the program crashed 2 or 3 times, but had to close and reopen the program mulitple times to view the error log in between fixes. Sometimes things would work only after restarting the program	3	Software crashes occasionally.	3
Program Start up	How quickly does the software open?	Model opens within 1 minute	4	The program typically takes a couple minutes to open, but then loading the .xptin takes several more. For the Chimney Rock model, the whole process takes up to 5 minutes.	3	Opens relatively quick, opening geopackage takes less than 1 minute.	4
Model Setup	How quickly was the Chimney Rock model created?	The model took approximately a week to setup and simulate from the base data.	4	The model took approximately a week to setup and simulate from the base data.	4	Model was developed within 1 week.	1
Customer Support	Does package have customer support?	Customer support is available and responses are usually within a few business hours. Innovyze online also contains helpful information.	4	Customer support is available and responses are usually within a few business hours. Innovyze online also contains helpful information.	4	Yes, within 1-year of purchase or renewal	4
Application Score (16 Potential Points)		InfoWorks ICM	16	XPSWMM	14	Flow-2D	12

Summary

Comparison Item		InfoWorks ICM	Score	XPSWMM	Score	Flo-2Dw/QGSIS Plugin	Score
Direct Rainfall	Is direct rainfall hydrology method available?	Direct rainfall is available.	Yes	Direct rainfall is available with the same rainfall options that are used in the normal hydrology mode.	Yes	Yes	Yes
2D Infiltration Losses	Can ground infiltration be modeled? What loss types are available?	Infiltration methods include Green-Ampt, IL/CL, and Horton.	Yes	Infiltration methods include Green-Ampt, IL/CL, and Horton.	Yes	Yes, need landuse and soil shapefiles to define infiltration parameters.	Yes
FEMA Approval	Is the package approved by FEMA?	In order to be FEMA approved, the local sponsoring agency would need to be responsible for the technical review. To date, no ICM models have been approved.	No	In order to be FEMA approved, the local sponsoring agency would need to be responsible for the technical review. XPSWMM models have been approved in the past.	Yes	Yes	Yes
Agency Approval	What agencies are currently using or approving models from the software package?	City of Houston, Town of Addison, City of Fort Worth, City of San Marcos, City of Sugar Land		City of Houston, Town of Addison, City of Richardson, City of San Antonio, City of Austin, Harris County Flood Control District, City of Dallas		Municipalities located in the Western US (California, Arizona, New Mexico, Colorado)	
Estimate License Price	What is the average license price?	2000 nodes/Unlimted 2D is $50,000 with an additional yearly maintenance fee of $10,000. ICM has different packages		2000 nodes 300k cell is $44,000 with $9,000 yearly fee. XPSWMM has differentiating costs per amount of 2D available.		Unlimited nodes/unlimited 2D is $2,400 per year. Discounts for mutliple licenses.	
Overall Score (212 Potential Points)		Total	202	Total	176	Total	121
		95%		83%		57%	