Real-time optimization of a stormwater management program in Johnson County, KS for flood forecasting and asset management prioritization

A real-time flood and risk management model was developed in Johnson County, KS leveraging the county's StormWatch Alert 2 early flood warning system, GIS datasets, and previous hydraulic/hydrologic models. In 2016, the County's stormwater management plan implemented a watershed-based approach to fund projects that incorporate flooding, water quality, and system management. By linking the modeled performance of the system to asset conditions, key performance indicators (KPIs) were developed to better understand the baseline conditions of the system towards meeting the level of service provided to the community. These KPIs are currently in implementation by the NEER team. Once the dashboard and KPIs are properly connected the all the database in the backend, the real-time capabilities of the NEER platform will constantly track these KPIs enabling the county to see in a web-enabled dashboard where the SMP is succeeding and where it is falling short to help guide and prioritize future investment in asset rehabilitation, inspection, replacement, and new stormwater assets. A major goal of this effort is to provide transparency to all stakeholders to help better drive both capital and operational expenditure to optimize performance, investment, and efficiency in an open way to better serve the community. We believe the successful implementation of the real time hydraulic modeling, risk management, and web enabled tracking of KPIs in Johnson County, KS can be implemented throughout the United States in more than 3000 counties.

TEAM

ELANGO THEVAR

Elango Thevar is the Founder & CEO of NEER. He is a certified professional engineer and floodplain manager. He has more than 20 years of experience with drinking water modeling, hydrology and hydraulic modeling, water quality modeling, floodplain mapping, master planning and risk management.

Project Assignment

Principle-In-Charge - Team Lead

Education

Master of Business Administration, University of Missouri-Kansas City, 2016

Master of Science in Environmental Engineering, Oklahoma State University, 2004

Bachelor of Technology in Chemical Engineering, University of Madras, 2002

Roles and Responsibilities

His responsibilities include solution architect for the development of Machine Learning models for stormwater real time modeling, forecasting and risk management.

SCOTT JEFFERS, PE, PhD

As President of Anthropocene Engineering, Scott brings over 10 years of hydraulic/hydrologic modeling experience, capital improvement master planning, optimization/prioritization for asset management, IoT deployment, and a background in novel digital water techniques.

Project Assignment

Technical Lead - QA/QC for Models

Education

Doctor of Philosophy in Environmental, Drexel University, 2017

Master of Science in Civil Engineering, Master and Bachelors of Science of Environmental Engineering, Drexel University, Cum Laude 2012

Roles and Responsibilities

Hydraulic and hydrologic model development and calibration. Analysis of real-world data, sensitivity analysis, data and geospatial analysis, and graphical representation of results. Assist in report write up and technical review.

SARAH SMITH

Sarah is a Project Manager for the Johnson County Stormwater Management Program (SMP). She has been with Johnson County since 2013.

Project Assignment

Project Manager

Education

Master of Science in Civil Engineering, University of Kansas, 2006

Bachelor of Science in Architectural Engineering, University of Kansas, 2002

Roles and Responsibilities

Review of project tasks, scope, and budget, and project deliverables

MADISON CROWL

Madison is a Stormwater Engineer for the Johnson County Stormwater Management Program (SMP). She has been with Johnson County since 2019.

Project Assignment

Assistant Project Manager

Education

Master of Science in Environmental Engineering, University of Kansas, 2019

Bachelor of Science in Biological Engineering, University of Arkansas, 2017

Roles and Responsibilities

Assist with the review of project tasks, scope, and budget, and project deliverables

PROBLEM STATEMENT

The Stormwater Management Program (SMP) in Johnson County, Kansas partners with the 20 cities in the County to manage stormwater and is funded by a 1/10th of one percent county-wide sales tax. It administers these funds on behalf of the Cities historically by providing matching funds to Cities for eligible projects, including study, design, and construction projects.

CHALLENGE 1

The SMP has invested significantly on the StormWatch Alert 2 system (www.stormwatch.com) over the past 30 years to implement an early flood warning system through real-time data acquisition of rainfall and water levels throughout the urban catchment.

The program has funded the installation and maintenance of many of the sites throughout the region and has utilized the web-enabled data generated from the system for SMP-sponsored studies and projects. Johnson County directly owns 68 of the 108 sites in the system in collaboration with the City of Overland Park, Kansas Department of Transportation, and the City of Kansas City, MO who manage their own associated sensor systems.

Currently, the SMP with the help of the City of Overland Park uses manual process of forecasting flooding conditions and implements emergency management procedures within the county based on existing stream level and National Weather Service forecasted weather information. However, this process is very tedious, time consuming and often not reliable to accurately forecast future flood conditions.

CHALLENGE 2

In 2016, the SMP as part of a new strategic asset management program implemented a watershed-based approach to fund projects that incorporate flooding, water quality, and system management. Under the "System Management" program, the SMP started funding inspection, rehabilitation, and replacement of stormwater asset projects.

As part of this program, the program developed a risk-based tool to prioritize stormwater assets. This tool is used to assign a prioritization score to all eligible assets contained in a County-wide asset database. This prioritization score is calculated using Likelihood of Failure (LoF), Consequence of Failure (CoF), and total risk (Business Risk Score, BRE).

The two fundamental building blocks for defining total risk (BRE) are LoF and CoF. LoF describes the chance of an asset failure occurring and CoF measures the severity of the impacts if an asset were to fail.

Total Risk or BRE = LoF * CoF

Currently, the SMP employs a linear age-based degradation model and incorporates an adjustment factor for increased salt load in estimating LoF to prioritize inspection of stormwater assets (hard assets). For rehab/replacement projects, a field verified condition score is determined using the National Association of Sewer Service Companies' (NASSCO) Pipeline Assessment and Certification Program (PACP). This standard rating initially developed for wastewater systems, however, does not capture the environmental factors and other variables specific to stormwater pipes. Currently, no standardized methods exist for assessing the condition of stormwater pipes and structures in the United States. Given these challenges, the SMP is seeking a data driven Machine Learning approach to optimize their risk management program.

THE INTELLIGENT STORMWATER SYSTEM

Given these challenges, the SMP engaged with NEER for a pilot study to develop cloud-based Machine Learning (ML) solutions to automatically forecast an early flood warning system (upto 24 hours) for the Watershed Organization 1 using existing hydraulic models and StormWatch real time datasets. Further goals were to develop a ML solution to identify risk conditions of stormwater assets and implement a proactive data driven asset management program.

As part of this project, NEER developed a cloud based intelligent platform to forecast flooding and predict risk for stormwater assets. NEER obtained existing HEC-1 and HEC-RAS models from FEMA for Watershed Organization 1. After verifying the integrity of the models, NEER converted existing HEC-1 and HEC-RAS models into an EPA-SWMM model. During the conversion process, NEER followed standard engineering practices to update the existing hydrology (subbasin and storage data) and hydraulic characteristics (open channel geometry, culverts, and bridge data). After updating the model parameters, the hydraulic model was calibrated using StormWatch gage data collected during 2016 to 2020. There are a variety of statistical measures used to measure the goodness-of-fit between a long term continuous measured and modeled hydrograph. For this study, statistical measures Integral Square Error (ISE) and Nash–Sutcliffe efficiency (NSE) were used as a single, non-subjective, statistical measure of model calibration (https://www.chijournal.org/C414). Generally, calibration results showed very good to excellent NSE and ISE range for all the gage locations.

After the calibration, NEER set up a continuous real time and forecasting stormwater simulation model. In this step, StormWatch gage data (rainfall and stage collected every 5 minutes) was obtained and stored in a Time Series Database. In addition, the 24-hour forecasted rainfall data obtained from the National Weather Service was used in forecasting the stage and water surface elevation along the Brush and Turkey Creek (Figure 1). This real time and forecasting model is scheduled to run every 3 hours, (Figure 2) provides a predicted and forecasted floodplain boundary, depth grid, water surface elevation grid, velocity grid, and flood severity grid (Figure 3) that can be used for operational decisions. The total number of structures, roads flooded, and operational recommendations (such road closings and evacuation of structures) for every 3 hours is stored and displayed in a web-based dashboard.

As a part of this project, NEER also developed a ML Model that is specific to the Johnson County SMP to calculate LoF for all the hard assets such as inlets, junction boxes, bridges, culverts, and enclosed gravity pipes. All of these assets are represented either as Links or Nodes.

During the ML model creation, all the data obtained from the Johnson County Automated Information Mapping Systems (AIMS) and local municipalities (physical, functional/operational) were standardized. The NEER team developed micro-ML models to populate several missing parameters for few nodes and links. In addition, several environmental parameters were also superimposed to the existing datasets.

After the normalization of the datasets, the original datasets (113,124 links and 122,957 nodes) that had field verified conditions were selected for model training and validation. There were 39,814 links (35% of total links) and 44,600 nodes (36% of total nodes) that had field verified conditions. NEER was able to develop a best performing ML model using 80% of the data (field verified conditions data) for model training and the rest of the 20% of the data (field verified conditions data) for model validation. This ML model is able to predict LoF with an accuracy of 90% & 91% respectively for the existing nodes and links. This SMP specific LoF prediction ML model was configured to continuously train and optimize itself to improve accuracy over time. NEER also adopted the same methodology that is currently being used by the SMP to calculate the CoF and Business Risk Exposure (BRE)/Total Risk score. This CoF and BRE/Total Risk score calculation was implemented in the NEER Platform, so that the SMP can calculate CoF and BRE/Total Risk for each asset in Watershed Organization 1.

Figure 1: Hindcasted and Forecasted Stage for Site 16005 in Brush Creek

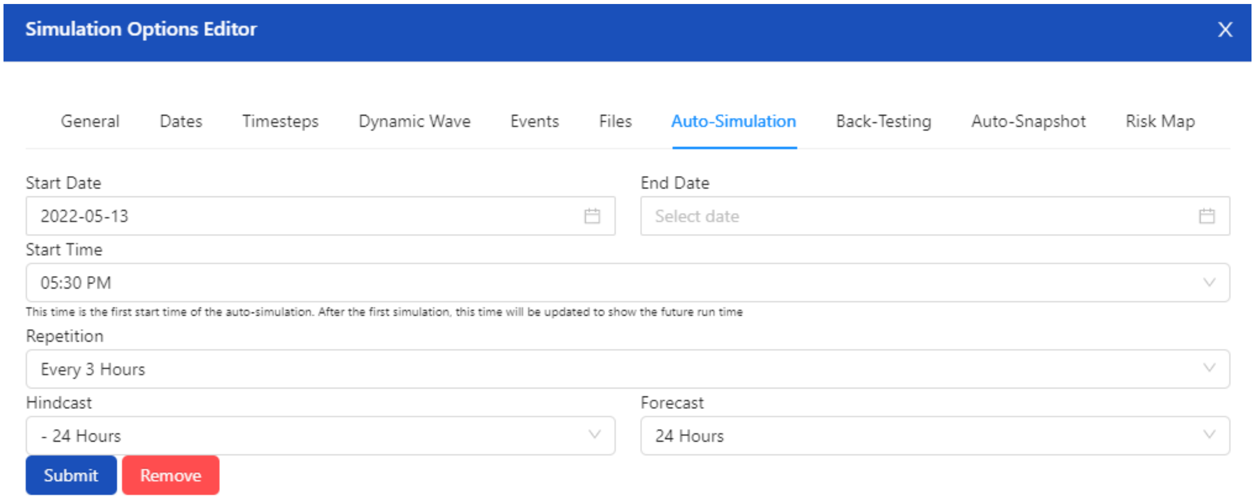

Figure 2: Auto Simulation Editor

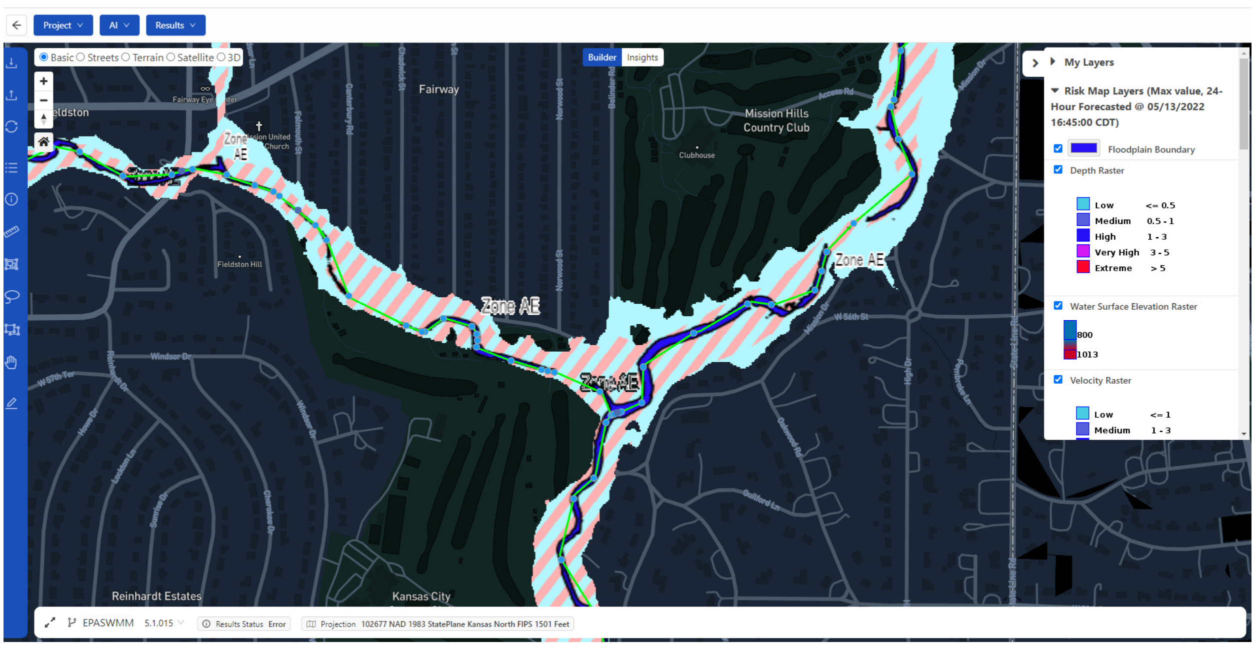

Figure 3: Forecasted Floodplain Boundary, Depth, Velocity, WSE, and Flood Severity Raster

SOLUTION

As discussed in the previous plan submission, the team selected key performance indicators (KPIs) in six categories to help drive SMP initiatives. The real-time flood inundation model was adapted to help better define the total risk (BRE) and help drive asset management-based decision making for Johnson County effectively linking the modeling effort to asset management prioritization to improve the level of service provided throughout the area. The KPIs selected in the six categories are listed below in Table 1 (National Benchmarking Initiative, Canada).

Table 1 - Level of Service Categories and KPIs

Goal	KPI	Units
Ensure Adequate Capacity	# Rainfall Events > Major Storm	occurrences
	# Rainfall Events > Minor Storm	occurrences
	Calls Regarding Flooding due to Public System Issues	#
	Culverts Inspected	%
	Bridges Inspected	%
	Ditch Length Cleaned	%
	Ditches Inspected	%
	Inlets, Junctions, and Manholes Visually Inspected	%
	Storm Sewer Length CCTV Inspected	%
	Storm Sewer Length Cleaned	%
Have Satisfied and Informed Customers	Calls Regarding Flooding due to Public System	# / 1,000 People Served
	Issues relative to People Served	
	Cost of Stormwater Education Program	$ / 1,000 People Served
	Percent Attainment of Target Emergency Response	%
	Time After Working Hours	
	Percent Attainment of Target Emergency Response	%
	Time During Working Hours	

	Serviced Properties Experiencing Flooding relative	# / 1,000 People Served
	to People Served	
	Serviced Properties Experiencing Flooding	#
	Stormwater Related Customer Complaints	# / 1,000 People Served
Meet Service Requirements with Economic Efficiency	Linear O&M Cost	('000 $) /mile of Storm Sewer and Ditches
	Stormwater O&M Cost relative to Catchment Area	('000 $) / acre of Catchment Area
	Unit Cost of Catch Basin Cleaning	$ / basin
	Unit Cost of Catch Basin Inspections	$ / basin
	Unit Cost of Storm Sewer Cleaning	$ / mile
Protect Public Health and Safety	Days Streams Not Available for Recreation	%
	Days Roads Closed for Driving due to Flooding	%
Protect the Environment	Area of Permeable Pavement	acre
	Catch Basin Sumps Cleaned	%
	Cost of Stormwater Monitoring Program	$ /acre of Catchment Area
	Maintenance Visits per Outlet to Receiving Waters	# / outlet
	Maintenance Visits per Stormwater Pond	# / pond
	Number of Spills	#
	Percent of Arterial Roads Cleaned	%
	Percent of Catch Basins Inspected for Sediment Accrual	%
	Percent of Collector Roads Cleaned	%

	Rural Riparian Setback	ft
	Spills that Reached the Receiving Environment	#
	Urban Riparian Setback	ft
	Percent of Local Roads Cleaned	%
Provide a Safe and Productive Workplace	Lost Hours due to Field Accidents	# / 1,000 O&M Labor Hours
	Sick Days Taken	# / O&M Employee
	Total Available O&M Hours / Total Paid O&M Hours	%
	Total Overtime Hours / Total Paid O&M Hours	%
Provide Reliable Service and Infrastructure	Emergency Repairs	#/100 mile of Storm Sewer Length
	Non-Emergency Repairs	#/100 mile of Storm Sewer Length
	Stormwater O & M Cost	('000 $) / mile of Storm Sewer and Ditches
	Stormwater Capital Reinvestment Cost	('000 $) / mile of Storm Sewer and Ditches

Future Plan

Currently, the NEER team is implementing these KPIs in a web enabled dashboard to track these parameters in real time. There are several databases that need to be connected on the backend through Application Programming Interface (APIs) so that SMP can track these KPIs in real time. This tool will be used by SMP to track where the program is succeeding or failing short to help guide and prioritize future investment. A major goal of this effort is to provide transparency to all stakeholders to help better drive both capital and operational expenditure to optimize performance, investment, and efficiency in an open way to better serve the community.

This proposed project is a pilot study and the estimated timeline for this proposal is six months with final deliverables by December 31, 2022.