Taking a SWAT at Changing Urban Creeks: A Combined Approach to Evaluate Changes in Flooding, Erosion, and Aquatic Life

SR-12-##, February 2012

Juan Moran-Lopez, Texas Water Development Board, Austin, Texas, USA.
Juan.moran-lopez@twdb.texas.gov

Leila Gosselink, Watershed Protection and Development Review Department, City of Austin, Texas, USA. Leila.gosselink@austintexas.gov

Roger Glick, Manager, Watershed Protection and Development Review Department, City of Austin, Texas, USA. rglick@austin.rr.com

Abstract

The City of Austin's (COA's) Watershed Protection Department (WPD) engineers and scientists use a multitude of tools to analyze trends and evaluate possible methods to remedy and minimize environmental impacts, such as flooding, erosion, and water-quality degradation due to development. Traditional methods usually analyze the impacts of extreme events at certain points in time, yet WPD is also interested in more long- term effects. Needless to say, different applications require different analysis methods. GOA used a holistic approach employing the Soil and Water Assessment Tool (SWAT)-a long-term, continuous hydrologic model to simulate flows to evaluate flooding , erosion, and water-quality impacts (Neitsch et al. 2005). This approach differs from more traditional methods based on design storms by allowing users to predict the continuous impacts of flow. Using this approach, GOA can simulate different development scenarios currently being considered for a master plan of the city; the impacts of the scenarios can then be assessed and included in the decision- making progress. This article details a combined urban-setting application of the SWAT model in analysis of impacts of different development scenarios on flooding and erosion potential, and assessment of aquatic life potential (AQP) under different development scenarios.

January-February 2012

Taking a SWAT at Changing Urban Creeks

A combined approach to evaluate changes in flooding, erosion, and aquatic life

Share Share Tweet

Thursday, January 19, 2012

By Juan Moran-Lopez, Leila Gosselink , Roger Glick
Comments

Article Tools

RSS Save Print Email

The City of Austin's (COA's) Watershed Protection Department (WPD) engineers and scientists use a multitude of tools to analyze trends and evaluate possible methods to remedy and minimize environmental impacts, such as flooding, erosion, and water-quality degradation due to development. Traditional methods usually analyze the impacts of extreme events at certain points in time, yet WPD is also interested in more long-term effects. Needless to say, different applications require different analysis methods. COA used a holistic approach employing the Soil and Water Assessment Tool (SWAT)—a long-term, continuous hydrologic model to simulate flows to evaluate flooding, erosion, and water-quality impacts (Neitsch et al. 2005). This approach differs from more traditional methods based on design storms by allowing users to predict the continuous impacts of flow. Using this approach, COA can simulate different development scenarios currently being considered for a master plan of the city; the impacts of the scenarios can then be assessed and included in the decision-making progress. This article details a combined urban-setting application of the SWAT model in analysis of impacts of different development scenarios on flooding and erosion potential, and assessment of aquatic life potential (AQP) under different development scenarios.

Create a Link to this Article

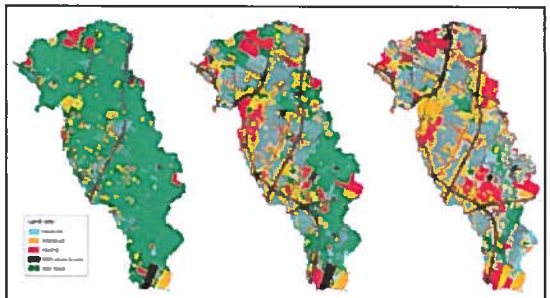


Photo: Figure 2. Walnut Creek land use assumptions for 1964, 2003, and future (left to right)

Additional Article Content

- Taking a SWAT at Changing Urban Creeks
- References

You may also be interested in...

- Information-Oriented Watershed Planning
- The Shape of Streams to Come
- The Shape of Streams to Come
- Here's a web-only article
- Weather Monitoring and Mapping
- Reforest the Bluegrass

Study Area and Model Development

The Walnut Creek watershed in Austin was chosen as the study area due to the availability of long-term flow records; the US Geological Survey (USGS) has collected continuous flow data since 1966, and COA has collected sub-daily data since 1986 in the lower portion of the watershed. The entire 145.8-square-kilometer watershed stretches from northwest to east Austin, discharging into the Colorado River (Figure 1).

Data at four study sites along Walnut Creek were evaluated for the purpose of the flooding and erosion studies. Aquatic life was studied at seven additional sites in the Little Walnut (LWA, shown in red in Figure 1) and Buttermilk (BMK, orange in Figure 1) tributary watersheds. Three Walnut Creek SWAT models, differing in the extent of development, were created, each with a land-use data set based on aerial photography from 1964, from 2003, and on a future build-out scenario. Figure 2 illustrates the temporal change in land use, with the watershed 21% developed in 1964, 71% in 2003, and with expected land use if fully developed (leaving 10% open space).

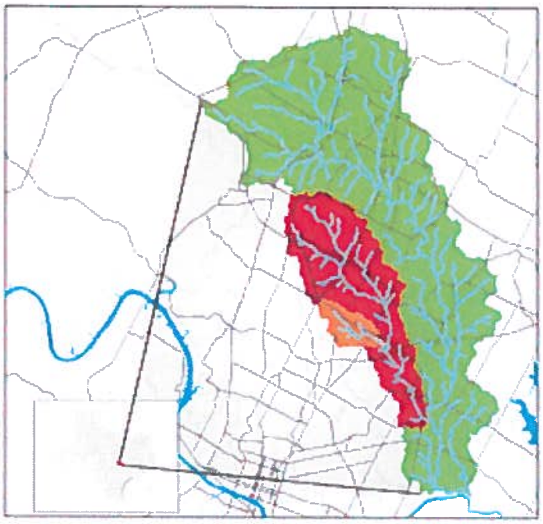


Figure 1. Walnut Creek watershed in Austin, TX

Aerial photography was available for 2003, a period with a rigorously developed land-use data set and good, small time-step USGS flow data for the period from 2002 to 2004. Development of land use and characteristics, such as impervious cover for each, was conducted by city planning staff using extensive geographic sampling in conjunction with planimetric data for accuracy. Eighteen rain gages were available for the Walnut Creek watershed.

Historic Land Use (1964). The 1964 model and data were chosen for the availability of aerial photography and flow data necessary to use as a validation period. Current planimetric maps were compared with the 1964 aerial photographs—impervious cover in the 1964 photos was assumed to have remained developed through the present. Pasture was assumed to be the 1964 land use where there was no impervious cover in the aerials. Precipitation was a limiting factor in terms of data for the validation period because distributed Flood Early Warning System (FEWS) data were not available for 1964; therefore, hourly data from the National Weather Service was assumed to be evenly distributed over 15-minute intervals for the sub-daily model rather than the broader network of rain gages and smaller time-step of precipitation data available for later periods.

Future Land Use (Full Build-Out). To test a future development scenario, WPD created a future land-use scenario in the Walnut Creek watershed. The future land-use zoning was assumed to be the same as the 2003 land use zoning within city limits. Parcels in the future set were assumed to have developed to their maximum allowed density with current zoning and impervious cover regulations.

Areas with no existing zoning or neighborhood plan required other assumptions. Future land use in these areas was based on current proportions of land uses, although nonresidential land uses were more heavily weighted in areas within a 150-meter or 350-meter buffer surrounding minor and major roadways, respectively (Table 1). These include existing and planned roadways.

Table 1. Future Land-use Distribution

Land Use	Within Buffer	Outside Buffer
Residential	0.36	0.47
Commercial	0.30	0.07
Industrial	0.19	0.18
Civic	0.06	0.05
Open Space	0.09	0.23

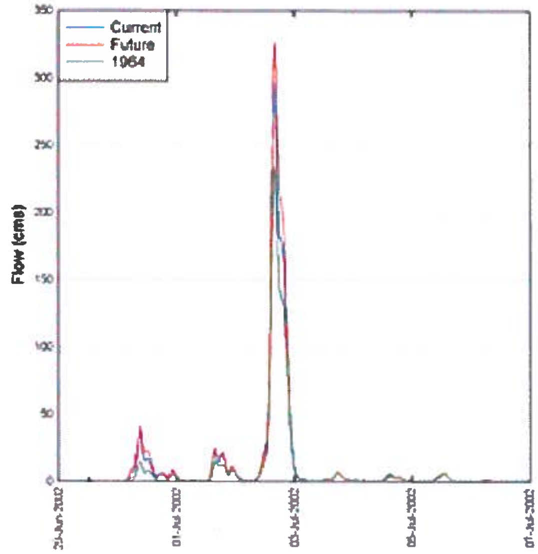


Figure 3. Measured and predicted hydrographs in Walnut Creek, November 2004.

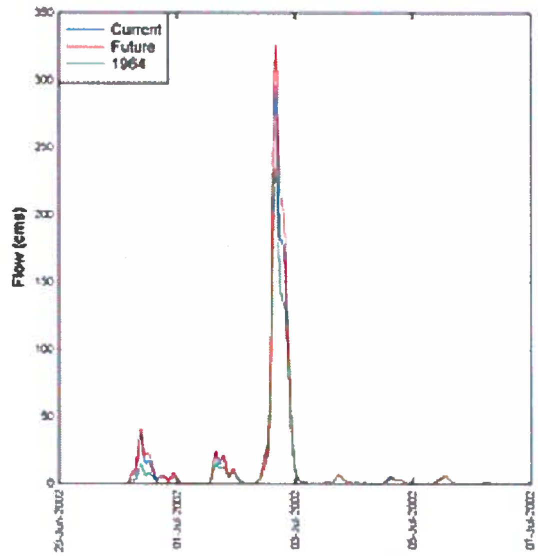


Figure 4. Flows predicted with SWAT for Walnut Creek under different development conditions (17OCT02 - 06NOV02)

Table 2. Evaluation Site Cross-section Dimensions, Slope, and Bank-full Flow Rate

Site Name	Slope (m/m)	Depth (m)	Width (m)	Q Bank-full (m^3/s)
Metric Blvd	0.0059	2.44	19.81	62.0
I-35	0.0045	3.05	25.60	119.0
Old Manor Road	0.0012	3.35	21.18	110.0
SP Railroad Bridge	0.0042	5.18	32.00	225.0

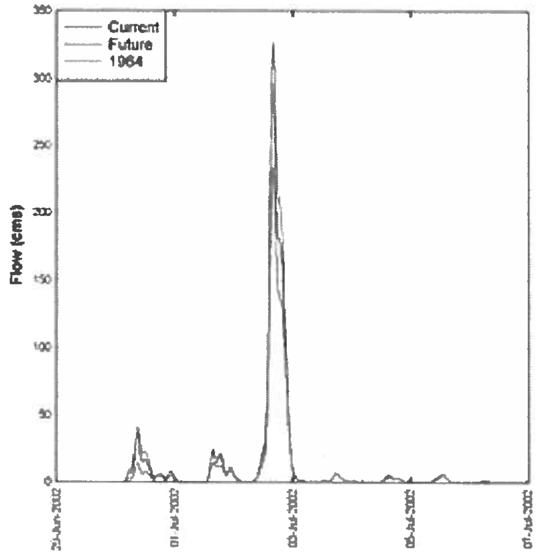


Figure 5. Channel cross-sections of evaluation sites in Walnut Creek

Calibration and Validation. An initial SWAT model using SSURGO soils and a 10-meter digital elevation model (DEM) for this project was created with a single outlet location at the creek's confluence with the Colorado River. The model was calibrated with data from Walnut Creek at Webberville Road (USGS 08158600). Daily rainfall and temperature inputs served as a starting point to create a subsequent model with 15-minute rainfall and daily temperature inputs. The sub-hourly rainfall inputs more accurately represent short-duration, high-intensity storms. The daily input model for Walnut Creek was previously calibrated with a Nash-Sutcliffe Efficiency (NSE) of 0.81, yet an unmodified run with the daily settings created a sub-daily model with a NSE of -1.78. Manual calibration by Glick and Gosselink (2011b) focused on parameters impacting the sub-daily model while minimizing effects on the daily model.

The adjustments improved the modeled outputs for both time steps, with an aggregated daily NSE and correlation coefficient of 0.86 and 0.87, respectively. Sub-daily modeled flows also simulated COA's measured flow data more accurately (NSE = 0.74, r2 = 0.78). While the daily model's storm flow to base flow ratio was reasonably simulated, the sub-daily results showed some scatter and hysteresis, which could be an issue with the timing of the model. Although COA engineers calibrated with the best available data, the model's limitations did not allow for simulation of flow irregularities due to leaking water lines or alterations caused by best management practices (BMPs) and consequently over-predicted the average rate of flow increase and decrease. Despite the limitations, the sub-daily model improved on the predictions of the original daily model, and COA staff concluded that the SWAT model performance satisfies the intended use of evaluating current conditions and comparing different development scenarios. Using the 1964 land use data, WPD staff ran a 13-year simulation from 1960 to 1972, excluding outputs from the first two years that are used as a warm-up period for antecedent conditions. Validation from 1967 to 1970 resulted in NSE = 0.57, r2 = 0.56. The lower NSE and correlation values may be due to the lack of data and use of hourly rainfall, because this model did not predict peak runoff very well. The modeled total flow for 1964 land use was over-predicted by 10%, and baseflow was over-predicted during multiple events, possibly indicating non-natural flow regimes due to development caused under-prediction in the original model. Despite the lower NSE and r2 values in the validation model, the AQP metric outputs were in a range similar to those of the calibration model.

Modeling Flow Conditions

The 2003 and 1964 models were run for long-term simulations using climatic data from 1992 to 2007. The future land -use set was then used to simulate flow conditions at full build-out of the watershed with the same long-term climate data. Flow comparisons between land-use scenarios are based on the same long-term climatic data, allowing direct comparisons of development impacts. The future model produced flows compared to those of the 2003 land use scenario, illustrated in Figure 3. Changes between the future and 2003 scenarios were of the same nature as those between 1964 and 2003 as expected with an increase in impervious cover; changes included increased peaks and lower baseflow. Some variations were not expected. The July 2 storm, for instance, clearly shows an increased peak flow rate during events from June 29 to July 7, 2002. Yet it was the more moderate events on June 30 and July 1 that produced the largest flow percentage increase. The hydrograph for the creek from October 17 to November 6, 2002, (Figure 4) shows a series of storms after a dry period. In that series of storms, it appears that water percolates through pervious surfaces into the shallow aquifer to the point of saturation, as the October 26 and November 4 storms created more streamflow within the 1964 scenario than produced in the more developed watershed scenarios. The results from the continuous simulations under different development scenarios were consistent with expectations for flashier storm events. However, results also demonstrated where increased runoff may occur within the long-term hydrograph. Unlike event-based analyses, it also reflects overall changes such as the increased frequency of smaller storm events.

Results: Flood and Erosion Potential
SWAT-modeled flow for the three land-use scenarios was used to analyze flooding and erosion potential, which WPD aims to minimize. Common methods for quantifying and predicting flood events include design storms such as 50-year or 100-year storms. Useful in their own right for existing conditions, these empirical methods do not account for possible changes in frequency or duration of events, nor do they evaluate increased erosion potential from changing flow regimes, particularly from short-duration, high-intensity storms that do not always result in flooding.

The evaluation sites differed in physical and geological characteristics such as slope, particle-size distribution, soil type, and channel dimensions. These features—representative of the watershed's diverse geomorphology—are listed in Table 2, showing cross-sections and bank-full flow rate values at the sites. These flow rate estimates are based on design storm flood models and historical flood information. Slope and cross-sections were derived from 10-foot DEMs and are illustrated in Figure 5.
Flood Analysis. Impacts due to flooding were evaluated based on the frequency of flow exceedance over bank-full flow rates and the duration of exceedance (Glick and Gosselink 2011a). Using 15 years of modeled flow for each development scenario (1964, 2003, and 2040), WPD staff analyzed the number of contiguous exceedance events and their total duration. As predicted, increased impervious cover resulted in more frequent high-flow events per year (Figure 6). The 2003 development scenario produced 33% to 50% more high flow events than did the 1964 scenario. There was an additional 25% to 30% increase between 2003 and 2040. While increased development induced higher peaks during events, the duration of these events decreased; this reflects increased variability and flashiness of the creek. Precipitation events result in more acute flow events, with higher peaks and shorter duration, proportional to development for the most part. However, despite shorter duration of flow per event, the total time of flood inundation increases due to the increased frequency of high-flow events per year (Figure 6).

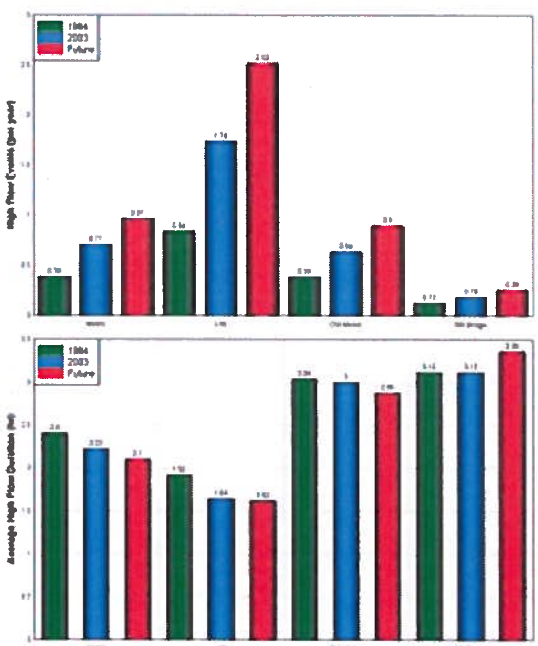


Figure 6. Number of high-flow events per year (top) and average high-flow duration (bottom) on Walnut Creek under different development scenarios

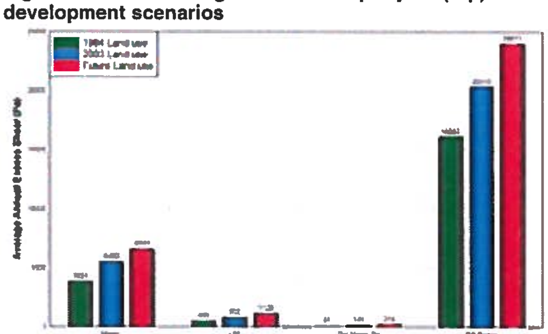


Figure 7. Annual average cumulative excess shear under different development scenarios

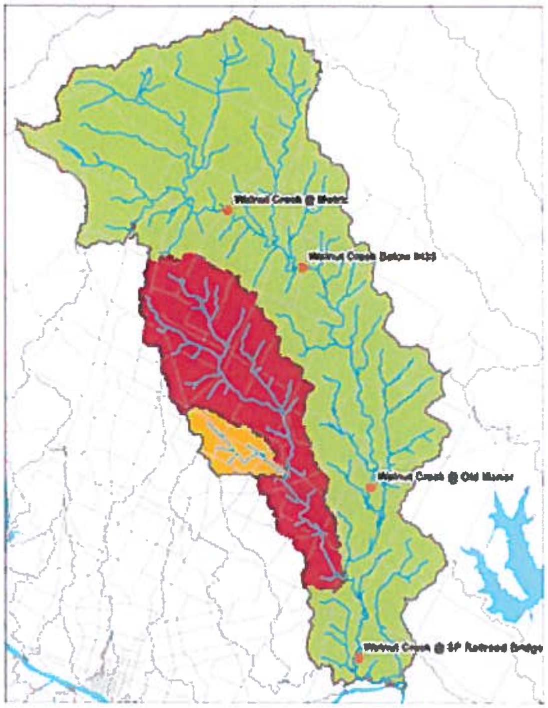


Figure 8. Aquatic life potential evaluation sites

Table 3. Median Particle Size and Critical Shear Stress at Walnut Creek Erosion Study Sites

Site Name	d_{50} min (mm)	d_{50} max (mm)	τ_c min (Pa)	τ_c max (Pa)	τ_c avg (Pa)
Metric Blvd	30	43	22.80	32.69	27.75
I-35	54	75	41.05	57.01	49.03
Old Manor Road	19	27	14.44	20.52	17.48
SP Railroad Bridge	14	21	10.64	15.96	13.30

Erosion Potential Analysis. Erosion potential was analyzed as a function of particle size and average annual cumulative excess shear over the same 15-year period used for the flooding analysis. The data are presented in Table 3, illustrating the minimum and maximum median particle sizes (d50).

The channel hydraulic properties at each point were estimated using WinXSPRO 3.0 (Hardy, Panja, and Mathias 2005). The program created a stage-discharge relationship based on Manning's equation using the channel slope and cross-section. Flow-rate-dependent estimates of Manning's n value developed by Jarrett (1984) were used in the study; the equation for the n-value is
n = 0.39S0.38R-0.16
where
S = slope of the channel
R = hydraulic radius

The shear and critical shear values were calculated using the following relationships:
τ = γw × Dh × Sw
and
τc = θc (Sg – 1) × γw × d50
where:
γw = density of water
Dh = depth of water
Sw = channel slope
Sg = specific gravity of soil, 2.65
d50 = median particle diameter (mm)
θc = critical Shield's parameter, 0.047

The critical shear values are listed in Table 3 along with the particle diameter data. Cumulative excess shear was

calculated using the following relationship:
Σ (τ - τc for all $\tau > \tau$ c)

Excess shear was calculated using the modeled SWAT flow output for each 15-minute interval of the 15-year run and summed to obtain cumulative excess shear at each of the four sites. The results, illustrated in Figure 7, show the average annual excess shear at each site for all three development scenarios. Old Manor Road and the site by I-35 showed the largest percentage increase between 2003 and the projected 2040 scenario, with 47.3% and 40% increases respectively. The total magnitude of the increase, however, is relatively small (68.6 and 321.2 Pa, respectively).

The minimum median particle size at I-35 is larger than the maximum median particle size at all the other sites, proportionally increasing the critical shear at the site. Walnut Creek at Old Manor Road, on the other hand, has a slope noticeably smaller than all the other sites, reducing the energy in and consequently shear forces due to flow.

Aquatic Life Potential
By statistically analyzing flow parameters and correlating them to aquatic life, WPD was able to predict the possible impacts of different development scenarios using a regression model developed by COA staff (Richter 2011). This analysis can be an effective tool for estimating the impacts of development and the effectiveness of BMPs while accounting for flow permutations they may create.

The analyses were performed using the same Walnut Creek flow data from the SWAT models for the three development scenarios; flow was also extracted from the models for the BMK and LWA creeks at sites where biological data had been collected. Figure 8 shows the aquatic life sampling sites corresponding to the reaches evaluated along Walnut Creek and its tributaries. A COA Environmental Integrity Index monitoring program collects data at these sites to gauge the health of biological communities (COA 2002).

These location sites comprised differing development conditions despite their close proximity. The BMK and LWA tributaries contained the majority of development by 2003, while the main Walnut Creek watershed consisted of 40% open space (Figure 9).

Statistical Model. Aquatic life assessments integrate the cumulative effects of various stressors. WPD staff developed hydrologic metrics for all available USGS and COA flow sites, for which biological data were also available, and developed regression models correlating hydrologic metrics, biological measures, and aquatic health (Glick and Gosselink 2011a). The Aquatic Life Potential model using the best predicted parameters resulted in r2 = 0.8216 and adjusted r2 = 0.6493 and is shown below:
AQP = 87.7539 – 1.5961(Qpeak /Area) + 4.3842 × 1n(Q90) – 21.2655(Riseavg)
where
Qpeak /Area = peak flow rate (cms/km2)
Q90 = 90th percentile flow rate (cms)
Riseavg = mean positive difference between consecutive rising values (rise rate, cms/sec)

It should be noted that climate and natural hydrology can play a large role in determining the best metrics to predict aquatic life potential. Baseflow in particular can be a limiting factor to healthy aquatic communities. In Austin, for example, developed areas with more impervious cover are often coupled with a little or no baseflow. Small watersheds with limited capture area are also susceptible to loss of baseflow. The AQP equation—not normalized to the reference sites—models the relative changes in hydrology corresponding to aquatic health response.

Modeled Flow Parameters. Flow was output for the creek reaches using the previously discussed 1964, 2003, and projected 2040 Walnut Creek models. The 15-minute outputs from the calibrated models were used to calculate the parameters in the AQP model. Figure 10 summarizes the calculated metrics of the sub-basin sites for each scenario. It may appear watershed size influences the metrics, yet this could be due to other factors such as time of concentration and stream order. The aforementioned difference in development patterns with the tributary watersheds containing a higher percentage of impervious cover may also have an effect on the parameters, which may at first appear to be related to drainage area.

The metrics gave some insight to the watershed hydrology. Peak flow and the natural log of the 90th percentile flowrate (90% of recorded flow is below this value) showed a relationship with watershed size. In arid climates like Austin's, this indicates a move toward flashier events with higher peaks and reduced flow and duration in between peaks. Although the Walnut Creek SWAT model overpredicted the rises and falls, the relative changes due to development are clearly shown in the AQP model (Glick, Gosselink, and Herrington 2002), illustrated in Figure 11. The largest changes to flow regime and consequently aquatic life occurred between 1964 and 2003, showing the cumulative effects of development in the area. The drop in AQP between 2003 and 2040 was more subtle, possibly due to the fact that there are fewer areas left to develop. The impacts could be further reduced, or even reversed, when BMPs to reduce flooding and improve water quality are incorporated in the analyses.

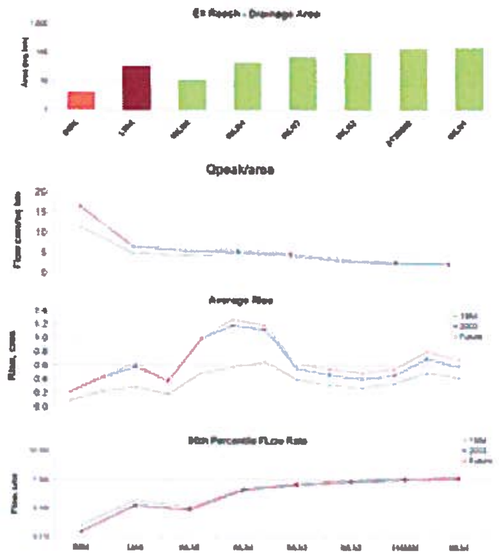


Figure 10. SWAT model hydrologic metrics for Walnut Creek, under three development scenarios

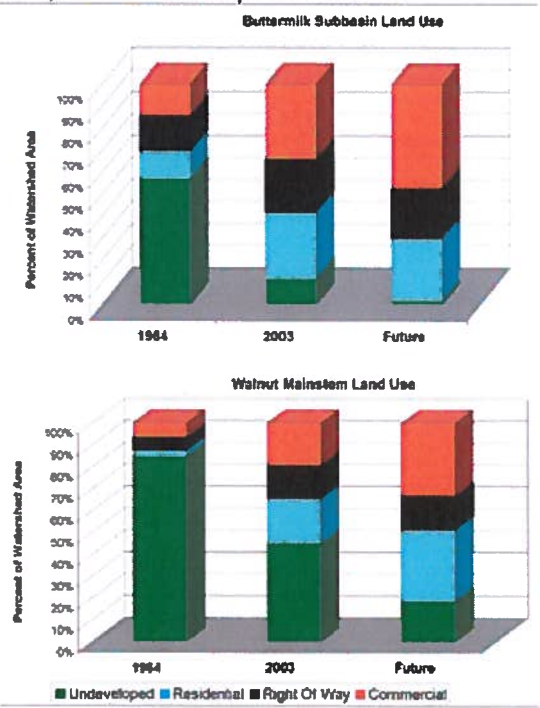
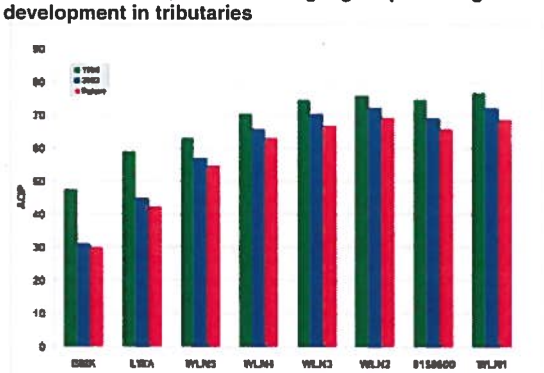


Figure 9. Land-use changes in Buttermilk tributary vs. Walnut mainstem, demonstrating higher percentage development in tributaries



Again, the future land-use set was developed using current regulations, which are more stringent than those in place when the LWA and BMK watersheds were being developed. This could be another reason for the smaller decline in AQP between 2003 and 2040.

Conclusions

A well-calibrated and validated model provides quantifiable estimates of stressors and can possibly help developers and engineers plan more efficiently and divert resources where they are most likely to result in improved conditions. Modeled SWAT flow in this project has proven to be a useful and versatile tool for simulating the outcomes of different development scenarios, in this case with only minimal calibration. The successful simulations using the 1964 land-use data along with parameters from a model with a 2003 data set validated the notion that reasonable flow estimates can be modeled for different development scenarios. Consequently, understanding the effects of these scenarios can give engineers insight and direction when implementing BMPs to minimize erosion, flooding, and impacts to aquatic life. Like any model, SWAT has its limitations; there is work in progress, however, to add BMP functionality and smaller time-steps to increase the accuracy of simulations.

These models show the impact of several development scenarios on water quality, flooding, and erosion. It is important to understand the numerous variables that can create stressors, for a solution at one location may be ineffective at another site. Indeed, identifying flow regimes and patterns can help prevent unnecessary expenditures on capture and treatment systems for water-quality improvement that may have little or no effect in streams unable to maintain aquatic life due to limited baseflow, for example. Altogether, model simulations are instrumental in planning for future development and reversing degradation caused by existing development.

Figure 11. Aquatic life potential for three different development scenarios using SWAT 15-minute modeled flow

Author's Bio: *Juan Moran-Lopez, EIT, is with the Texas Water Development Board; he was previously an engineering associate developing SWAT watershed models for the city of Austin, TX, Watershed Protection Department.*

Author's Bio: *Roger Glick, P.E., Ph.D., is the manager of the Water Quality Monitoring Section of the Austin Watershed Protection Department and has worked closely with SWAT model development for urban applications.*

Author's Bio: *Leila Gosselink is an engineer with the Austin Watershed Protection Department developing watershed models and applications for SWAT.*

Topics:

- Erosion Control
- Restoration
- Software

take responsibility for any content supplied by third parties that appear on our website. **"All comments are subject to *approval*"**

CAPTCHA Validation

Code:

Display Name:

Email:

POST A COMMENT