Title of Paper

Stream Modeling: Channel Stabilization and Visualization Using ArcView

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Abstract

Changing land use conditions such as urbanization and deforestation frequently lead to new hydrological flow regimes and changing stream channel morphologies. The visible effects of these changes often take the form of stream bank erosion, channel braiding, or increased turbidity. To combat the negative effects of a changing hydrologic regime, new channel morphologies can be imposed upon the stream by cutting and filling the landscape to form new, stable configurations. The incorporation of GIS and remote sensing into the stream modeling process allows for expedited land use classification and terrain modeling, facilitates the quantitative analysis, and allows for greater flexibility during the visualization of existing and proposed conditions.

Introduction

A braided channel with steep, eroding banks may be a familiar picture to people living in newly urbanized environments; however, the science behind it may be somewhat less familiar. The key to understanding why stream morphologies change in response to urbanization requires an examination of every component of the hydrologic cycle, from rainfall to runoff to channel dynamics. Mathematical models have been built to help stream engineers account for the major causes and effects of the factors involved. This paper discusses a combination of technologies, which have moved beyond pure mathematical models, and are designed to help engineers model, prepare for mitigation responses, and display the effects of urbanization on natural stream channels.

Hydrologic Cycle

When water falls on the terrain during a storm event, several things will happen. A portion of the water will be intercepted by vegetation, stored in surface depressions on the landscape, or evaporate. Another portion will infiltrate the ground and either slowly travel along ground water gradients to a stream channel, or be absorbed into the groundwater supply. The final portion will travel along the surface of the landscape as surface runoff until it enters into a stream channel or other waterbodies. It is the runoff portion of the storm event that is of the most interest to engineers and consultants as they will use this factor to determine how much water will enter a stream channel and the rate at which it will enter in the time following a storm event. Based upon this determination, they will build suitably sized pipes, stream channels and bridges to accommodate for the maximum flow, as well as determine flood boundaries based on runoff volumes.

Runoff is primarily determined by the amount of rainfall on the landscape, the land cover type, the pervious or impervious nature of the groundcover, the permeability of the soils (a function of numerous factors including soil porosity, soil moisture, and grain size), and surface storage or retention capacity. For example, water will travel over a paved surface much more quickly than over a forested land surface, thereby increasing runoff and decreasing infiltration in urban environments. The time for the runoff to travel from the point of interception with the terrain to the nearest stream is a function of slope, surface roughness, and slope length. Finally, the maximum flow in a channel and the lag time between the start of the rainfall and when that maximum flow occurs is dependent on the above-mentioned factors and the size of the watershed (USDA, 1986).

Urbanization

Due to the seemingly never-ending expansion of urban areas and land development, hydrologic modelers must frequently answer questions pertaining to the conversion of rural or natural land to urban areas. The urbanization of a watershed involves covering a significant portion of the watershed with impermeable surfaces such as roads, parking lots, roofs, sidewalks and driveways. In addition, natural meandering channels are frequently replaced or supplemented with storm drains or straightened channels in an effort to remove water from the landscape in the most efficient manner, thereby reducing the risk of flooding to roadways or buildings. This has the double disadvantage of reducing the amount of runoff naturally absorbed or stored by wetlands or waterbodies, as well as reducing the travel times to the stream channel, leading to higher discharge quantities and shorter times to peak flows. Obviously, a thorough understanding of these effects is required in order to design and implement measures that successfully mitigate the negative effects of urbanization on the hydrologic system.

Under natural conditions, a significant portion of rain will fall and infiltrate into the ground, before slowly following the ground water gradient through the ground to the stream channel. During the course of traveling through the ground, pollutants and/or nutrients in storm water may decay, be adsorbed by soils, or be consumed by plant life or bacteria. The water is eventually released from the ground days or months after the storm event into the stream channel, thereby providing the baseflow for the stream. This baseflow tends to be relatively cold, clean water due to a typically lengthy travel time underground prior to discharge.

Under urban conditions, this same significant portion of rain will likely fall on warm pavement, and travel rapidly across the landscape and into the stream channel. This water tends to be warm from the landscape and full of surface pollutants and sediments. The quick travel time leads to faster times of concentration, and when combined with increased discharge due to reduced infiltration or retention by landscape, “flash flooding” situations often become more prevalent. In addition, baseflows may be significantly lower due to the reduced infiltration and subterranean transport of water. Low baseflows and high-discharge storm events with turbid, erosive waters encourage the formation of braided or incised channels, serious bank erosion, and lowered water quality. Stream channel degradation can also result in a loss of aquatic habitat and presents a barrier to fish movement. Obviously, from both an environmental and a design perspective, it is very important to understand how urbanization will affect the natural system and the hydrologic regime and to plan accordingly.

Hydrologic Modeling

Complex mathematical models are frequently used in an attempt to quantify and understand the interactions between soil properties, land cover, terrain characteristic, and the hydrologic cycle. Although conceptually simple, the quantification of exactly how much water will enter a stream channel from the surrounding terrain proves surprisingly difficult due to the spatial variability of the influencing factors. Therefore, modelers have found that the best practice is to use the best available spatial data and mathematical models to come up with reasonable numbers, and then to calibrate those numbers with known events and runoff quantities. Once the runoff model has been calibrated to known events under existing conditions, proposed changes to the landscape can be modeled and the effects on the runoff quantities and timing examined with reasonable confidence.

The most common hydrologic model used in this process to estimate runoff and peak discharge is the Technical Release 55 (TR-55) computer model, as it is well suited for small watersheds. The TR-55 model assumes a uniform rainfall on the watershed with a specified time distribution. The amount of rainfall converted into runoff is based on a runoff curve number (CN). In theory, the CN is determined by soil properties, impervious areas, surface storage, land cover, and the condition of the land cover. In actual practice, the CN is determined by the soil's hydrologic soil group classification, the cover type, and the hydrologic condition of the cover. The hydrologic condition relates to the density of plant or residue cover, the amount of year-round cover, and the degree of surface roughness. The end product of the TR-55 model is a hydrograph based on the runoff quantities and travel time through segments of the watershed. The hydrograph shows two critical components of hydrologic modeling: the peak discharge rate and the lag time until the peak discharge occurs (USDA, 1986).

With the theoretical science behind the hydrologic processes in mind, the challenge of finding and integrating suitable data as required by the mathematical models takes center stage. The three major components to be gathered are as follows: landcover data, soil data, and terrain data. From that data set, all required data can be derived, including curve numbers, stream cross-sections, watershed areas, and surface roughness values.

Land Cover Classification Using Remote Sensing

Several methods can be used to determine land cover types including land use maps, field surveys, or airphoto/satellite imagery interpretation. Depending on the size of the area, the available data, and the accuracy required, each of these methods may be applicable. However, as remote sensing data becomes more common, due in no small part to ongoing federally-funded efforts to produce statewide high resolution digital orthophotography, one can only assume that the airphoto interpretation method will continue to gain popularity.

The most effective method of classifying remotely sensed imagery is to use the spectral signature of known areas to classify the remainder of the image. This method is called supervised classification, and allows the user to define as many or as few classes as required by establishing training areas from which the spectral signatures are derived. Using RSI's ENVI 3.6 remote sensing package, the maximum likelihood supervised classification method was used to collect the spectral signatures of seven land cover categories: grass, sand, forest, shrub, water, wetland, and pavement (see Fig. 1).

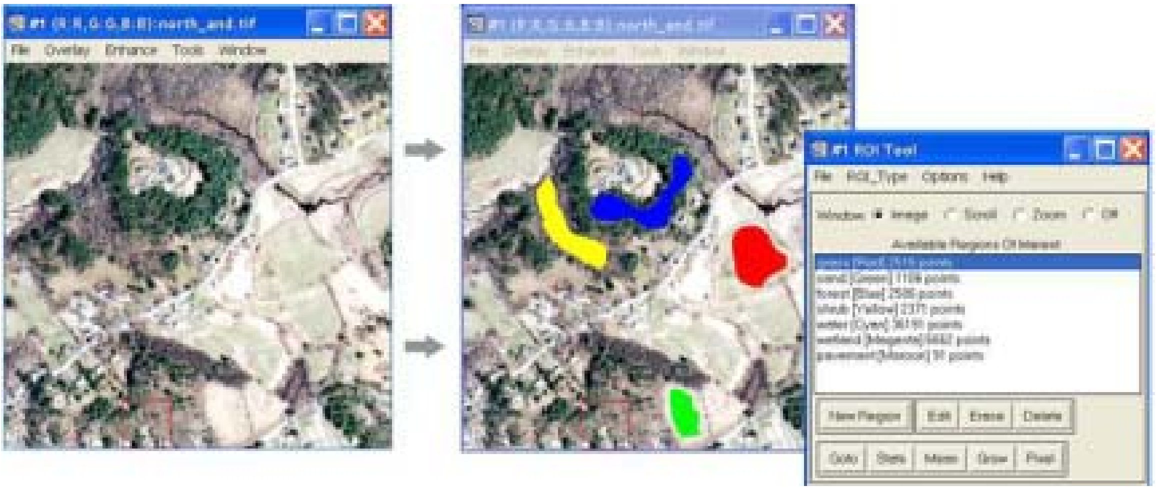


Figure 1. The collection of training areas, or Regions of Interest (ROI) in ENVI.

The information from the ROIs was used to classify the entire image, which was then imported into ArcGIS 8.3 for further manipulation. The classified features were clipped to the extents of the watershed boundaries, as determined by the study and interpretation of survey plans and construction drawings (see Fig. 2).

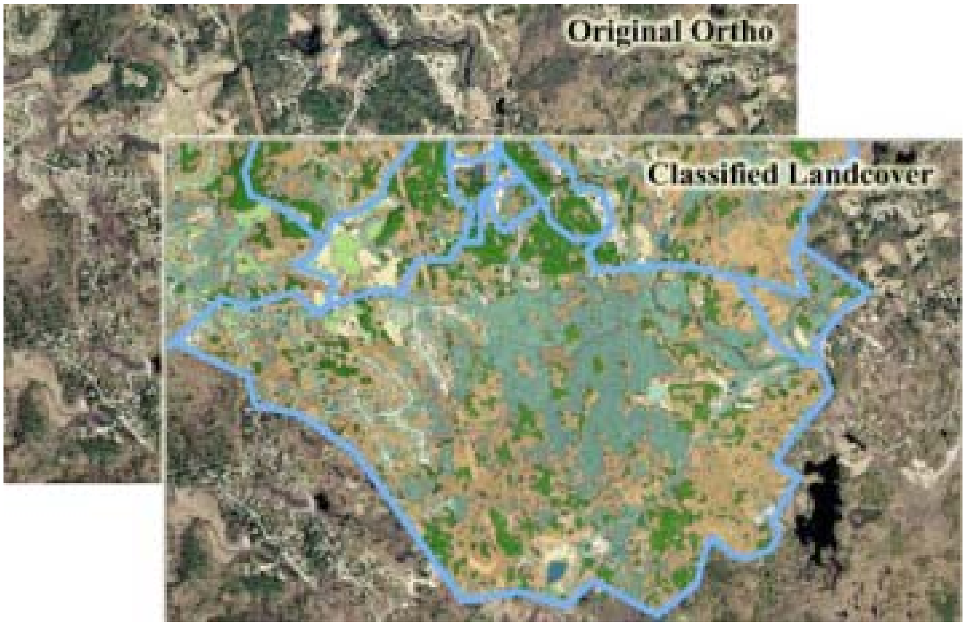


Figure 2. The supervised classification of a color airphoto.

To accurately depict the extents of the residential neighborhoods, several methods were attempted. Due to the limited resolution and spectral bands available, the remote sensing method did not accurately classify the houses as residential, as they were too similar to sand and pavement signatures. It was observed that most houses were located near roads and had an average lot depth of approximately 250 feet. To accurately capture the residential areas, roads with houses adjacent to them were selected from the road network (see Fig. 3).

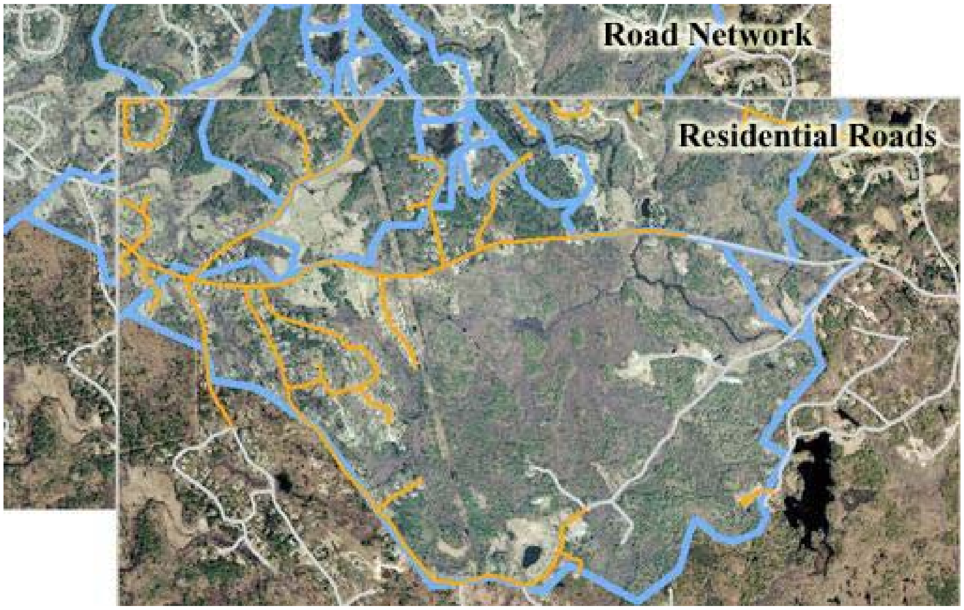


Figure 3. Roads with residential buildings adjacent to them.

The roads were then buffered out 250 feet, and then manually expanded to include any areas that were missed, and clipped back to exclude any non-residential areas that were erroneously included (see Fig. 4). Urban areas were delineated manually, as there was only one section in the study area.

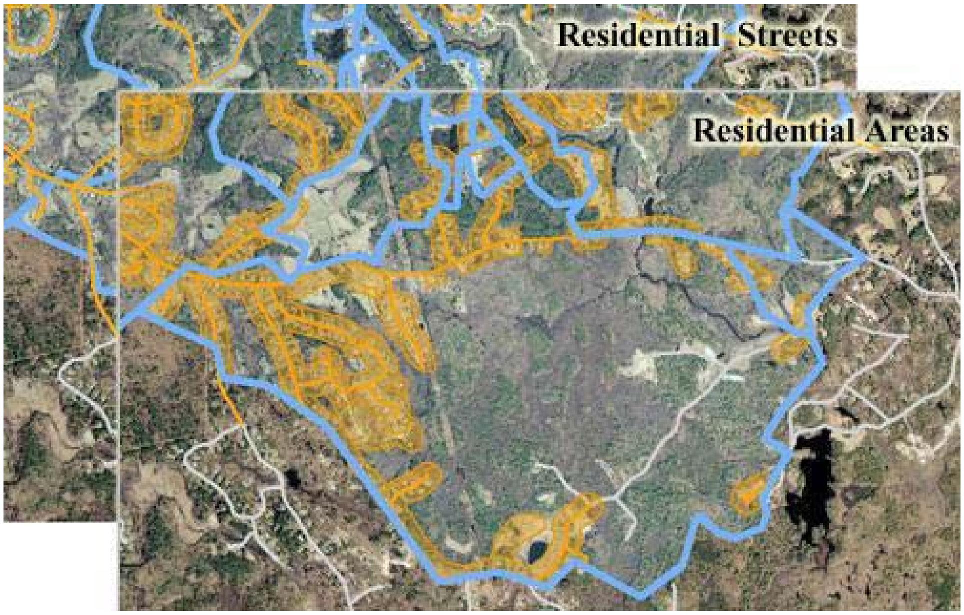


Figure 4. Modified buffers accurately depict the residential areas.

The urban and residential areas were then added to the landcover shapefile, to take precedence over all classifications, except for pavement and water (see Fig. 5).

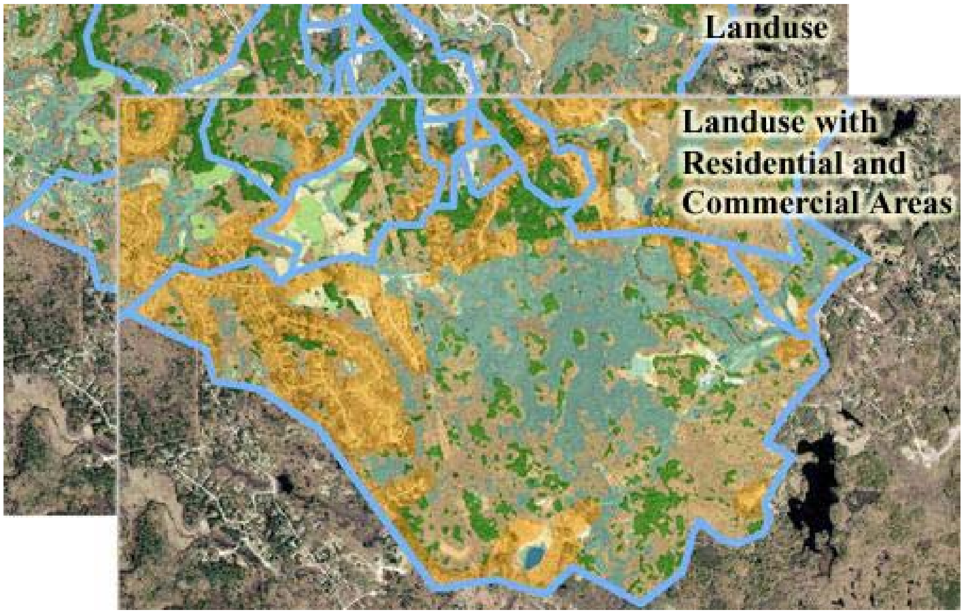


Figure 5. Complete landcover classification with urban and residential areas.

Soil Impacts on Runoff

Soils are classified into Hydrologic Soil Groups (HSG's) based upon their minimum infiltration rate, which is calculated using bare soil after prolonged wetting. The Natural Resources Conservation Service (NRCS) includes the HSG as part of their Soil Survey

Geographic (SSURGO) digital soil database. Alternatively, the HSG may be determined from soil survey reports from the NRCS. In addition, the infiltration rates of disturbed soils (such as those frequently occurring in urban areas) tend to be quite different from their undisturbed state due to the removal of native soil, the mixing of the soil profile, or the addition of fill material. Fortunately methods exist to determine the HSG of disturbed soils based on soil texture (USDA, 1986).

As a final step in the data preparation, the digital soil information was added to the land cover features (see Fig. 6).

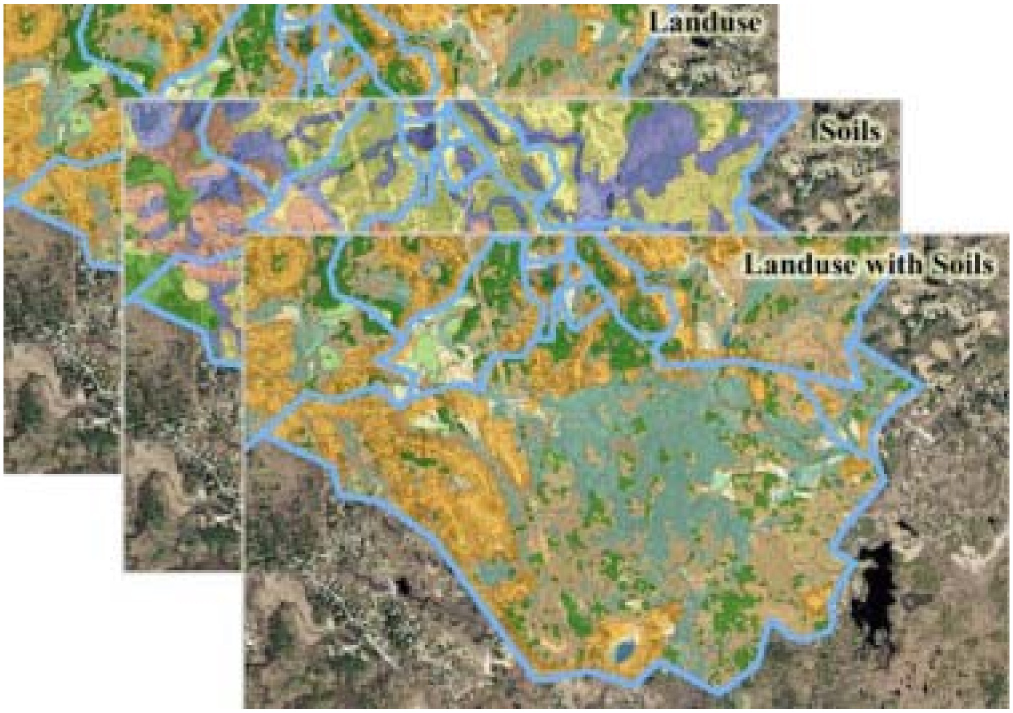
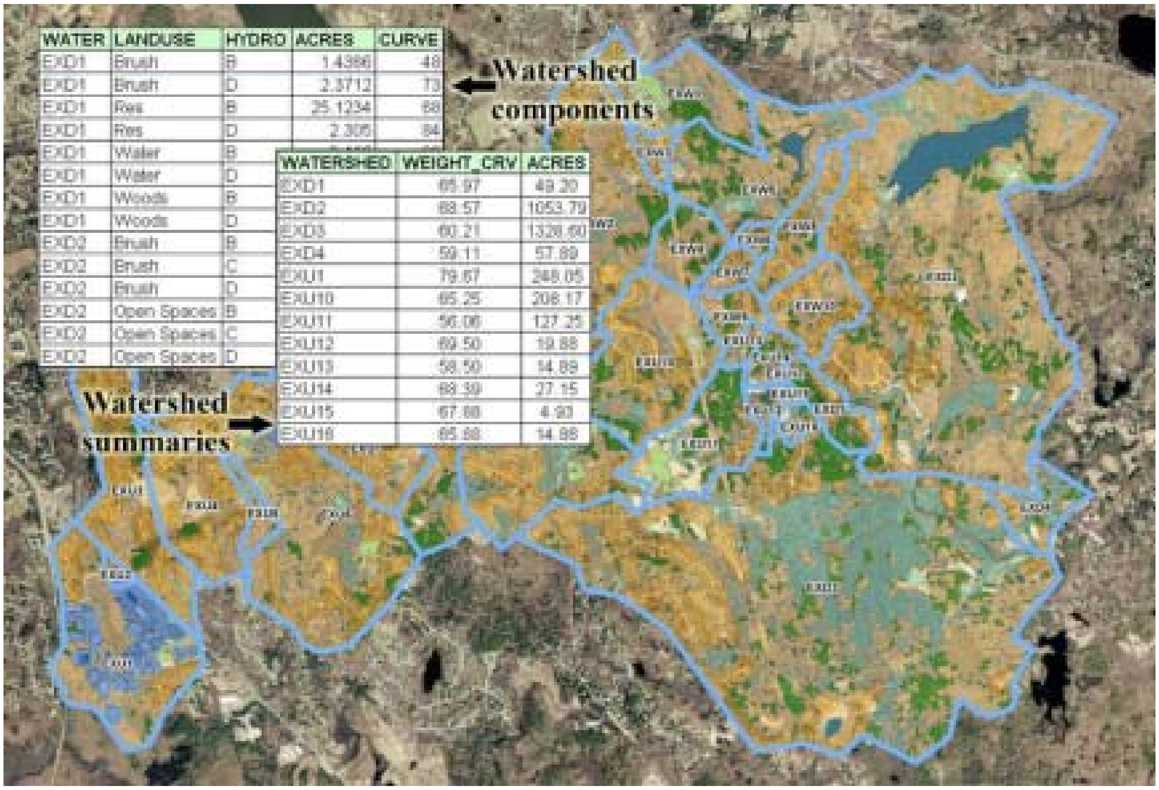


Figure 6. Land cover and soil information as a continuous coverage across the study area.

Weighted Runoff Curve Numbers

Curve numbers were assigned to each of the features based on their land cover type, hydrologic condition, and the hydrologic soil group (USDA, 1986). The area of each section of the coverage was calculated as a percentage of the total watershed area, and that percentage multiplied by the curve number. The curve number percentage values were summarized by watershed to give a weighted curve number for each watershed (see Fig. 7).



WATER	LANDUSE	HYDRO	ACRES	CURVE
EXD1	Brush	B	1.4386	48
EXD1	Brush	D	2.3712	73
EXD1	Res	B	25.1234	68
EXD1	Res	D	2.305	84
EXD1	Water	B		
EXD1	Water	D		
EXD1	Woods	B		
EXD1	Woods	D		
EXD2	Brush	B		
EXD2	Brush	C		
EXD2	Brush	D		
EXD2	Open Spaces	B		
EXD2	Open Spaces	C		
EXD2	Open Spaces	D		

WATERSHED	WEIGHT_CRV	ACRES
EXD1	65.97	49.20
EXD2	68.57	1053.79
EXD3	60.21	1328.60
EXD4	59.11	57.89
EXU1	79.67	248.05
EXU10	65.25	208.17
EXU11	56.06	127.25
EXU12	69.50	19.88
EXU13	58.50	14.89
EXU14	69.39	27.15
EXU15	67.88	4.93
EXU16	65.88	14.98

Figure 7. Weighted Curve Numbers By Watershed Based On Constituent Parts.

Stream Channel Characterization

To determine the effects of urbanization on a stream channel, the existing conditions must be fully understood. This is accomplished by importing data from terrain models, roughness values from land cover along the stream corridor, and the TR-55 derived flow data for storm events into a numeric stream modeling package such as HEC-RAS. HEC-RAS was developed by the United States Army Corps of Engineers (USACE), and performs one-dimensional hydraulic calculations under steady and unsteady flow conditions for a full network of natural and constructed channels (USACE, 2002a). Urbanization scenarios can then be explored by modifying the flow data as predicted by the TR-55 model under changing landuse conditions, and exploring the effects on the channel dynamics and geometry. Modified channel geometries are proposed and tested within the hydrologic model framework until an optimal, stable geometry is produced and ultimately constructed.

Stream Modeling in HEC-RAS

HEC-RAS can calculate water surface profiles for steady gradually varied flow through a full network of channels or a single channel reach. It can model the water surface profile of subcritical, supercritical, and mixed flow regimes, as well as obstructions such as bridges, culverts, levees, weirs or structures in the floodplain. Multiple plan analysis, profile computations, bridge or culvert opening analysis and split flow optimization make

HEC-RAS an attractive choice when modeling unconstrained channel flow and assessing the changes in profiles due to channel modifications (USACE, 2002a).

HEC-GeoRAS

The USACE has developed a tool called HEC-GeoRAS that facilitates the characterization of a stream channel from within the ArcView 3.x (or ArcInfo) environment using a graphical user interface (GUI), and then importing that data into the HEC-RAS model. Once the HEC-RAS model has been run, the results are exported back into ArcView for analysis and visualization (USACE, 2002b). By using the data entry and spatial analysis tools within ArcView, a significant savings in time and increased accuracy has been well documented (Dodson and Li, 2000). The data visualization capabilities of GIS allow results and what-if scenarios to be explored in a detail that simply wasn't possible using only the HEC-RAS model.

Cross-sections across the stream channel are derived from a digital terrain model using a polyline coverage and the HEC-GeoRAS extension (see Fig. 8). This process is repeated throughout the length of the corridor so that all reaches of the channel are included in the stream model (see Fig. 9). The time saved in not having to input terrain data manually point by point, cross-section by cross-section, as was done prior to the use of HEC-GeoRAS is a significant savings and more than justifies the initial cost/learning of HEC-GeoRAS. It should be noted, however, that the cross-sectional data is only as good as the terrain model from which it is derived. USGS based topography may be suitable for a quick over-view look at the natural system, however, construction grade drawings should only use a terrain model derived from survey information or as-built plans.

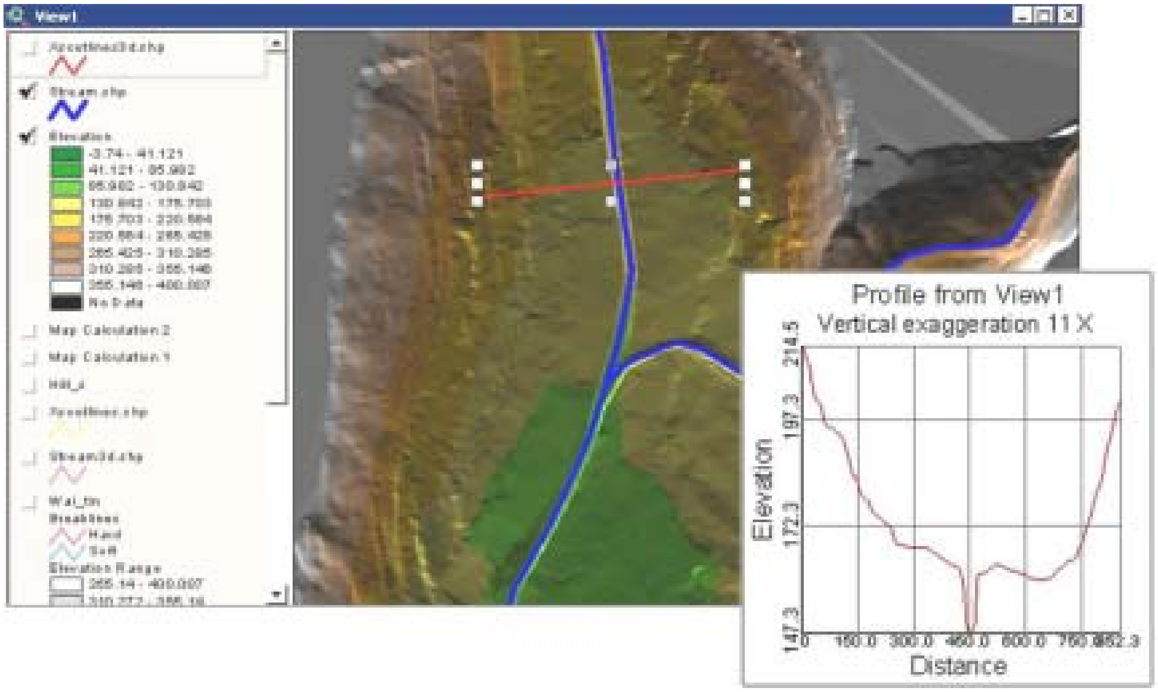


Figure 8. Single cross-section across the stream channel.

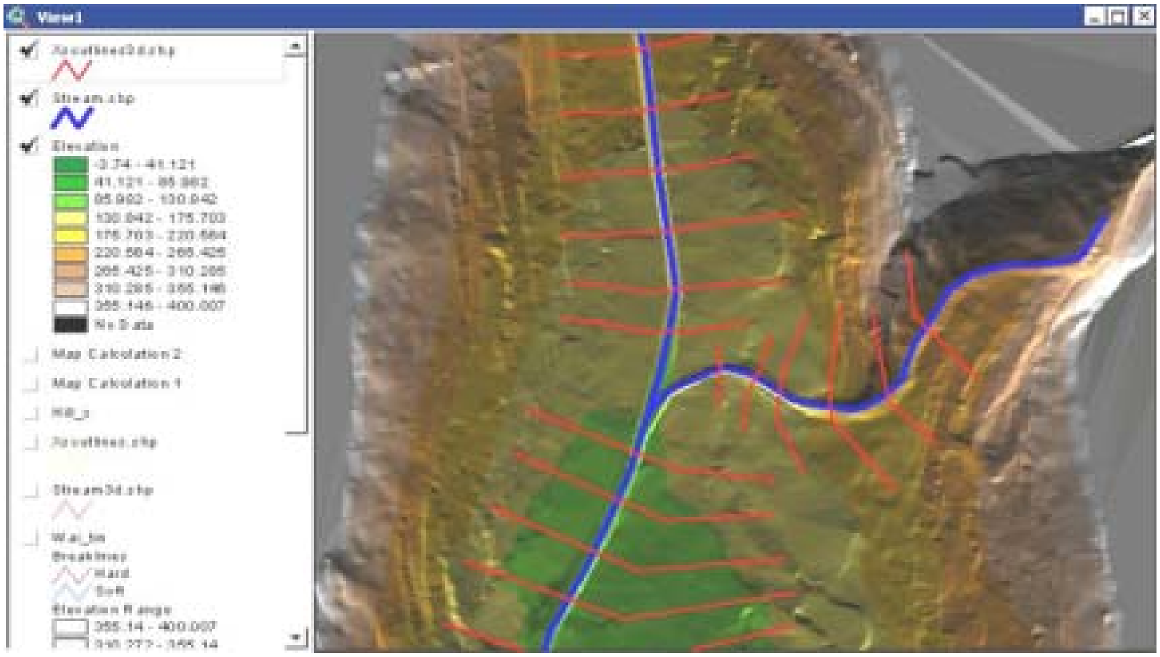
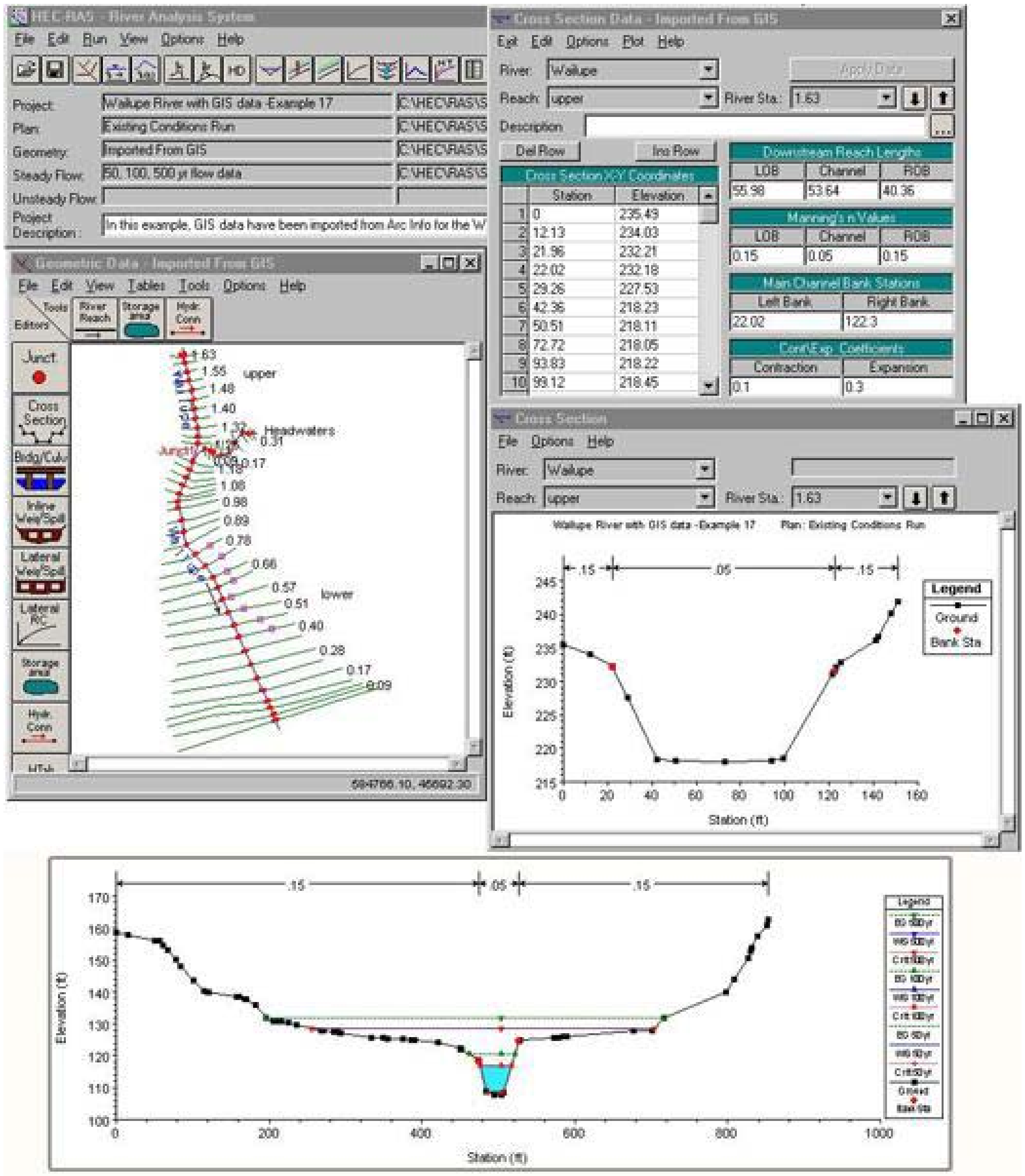


Figure 9. Cross-sections spaced along the length of the stream corridor.

Other data layers are derived from the terrain surface including the stream centerline, flow path centerlines, and main channel banks. The main channel banks are useful when determining the extents of landuse classifications, from which roughness coefficient values are assigned. The cross-sections are attributed with elevation values and roughness coefficients and imported into HEC-RAS. The TR-55 modeling results are also imported into HEC-RAS, and this combination of data allows flood extents and velocity profiles to be calculated for storm events (see Fig. 10).



Project: Wailupe River with GIS data -Example 17 C:\HEC\RAS\S

Plan: Existing Conditions Run C:\HEC\RAS\S

Geometry: Imported From GIS C:\HEC\RAS\S

Steady Flow: 50, 100, 500 yr flow data C:\HEC\RAS\S

Unsteady Flow:

Project Description: In this example, GIS data have been imported from Arc Info for the W

River: Wailupe

Reach: upper River Sta.: 1.63

Description:

Cross Section X/Y Coordinates

	Station	Elevation
1	0	235.49
2	12.13	234.03
3	21.96	232.21
4	22.02	232.18
5	29.26	227.53
6	42.36	218.23
7	50.51	218.11
8	72.72	218.05
9	93.83	218.22
10	99.12	218.45

Downstream Reach Lengths

LOB	Channel	ROB
55.98	53.64	40.36

Manning's n Values

LOB	Channel	ROB
0.15	0.05	0.15

Main Channel Bank Stations

Left Bank	Right Bank
22.02	122.3

Cont\Exp Coefficients

Contraction	Expansion
0.1	0.3

River: Wailupe

Reach: upper River Sta.: 1.63

Figure 10. Numerical stream modeling within the HEC-RAS environment.

Existing Channel Visualization

By importing the stream modeling results back into ArcView, the effects of storm events on flood extents (see Fig. 11), or flood depth and velocity profiles (see Fig. 12), can be visualized with ease. This information can then be used for floodplain mapping, flood damage analysis, ecosystem restoration, channel stabilization, or flood warning response system optimization (USACE, 2002b)

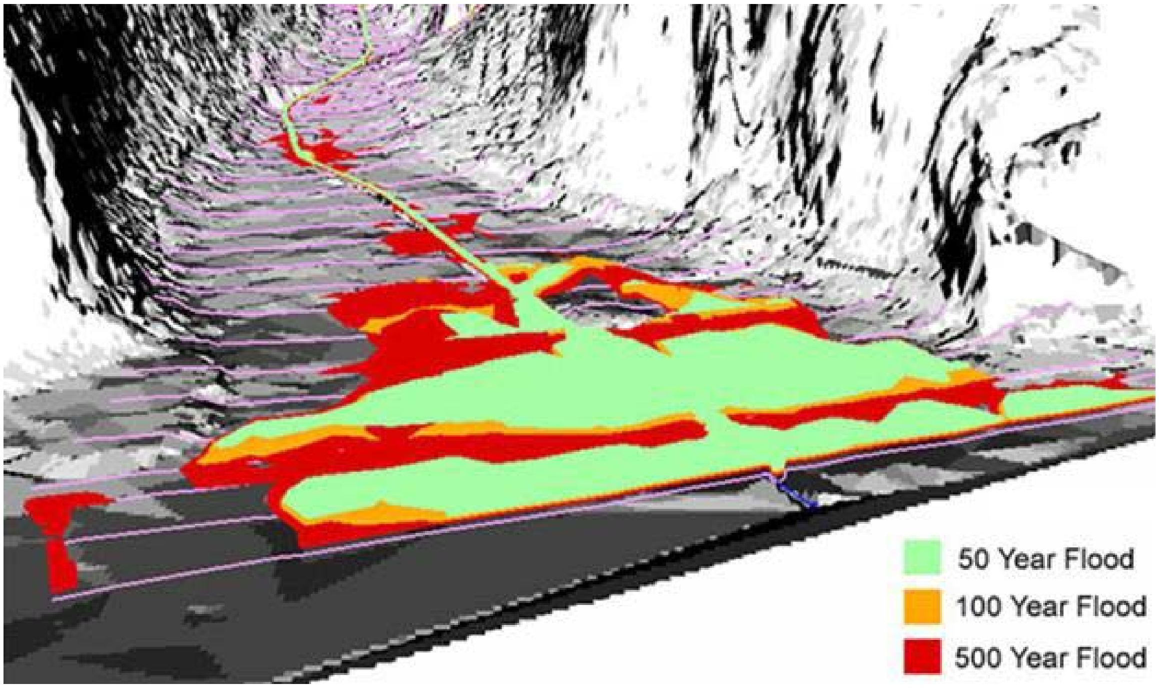


Figure 11. Flood extents for various storm events.

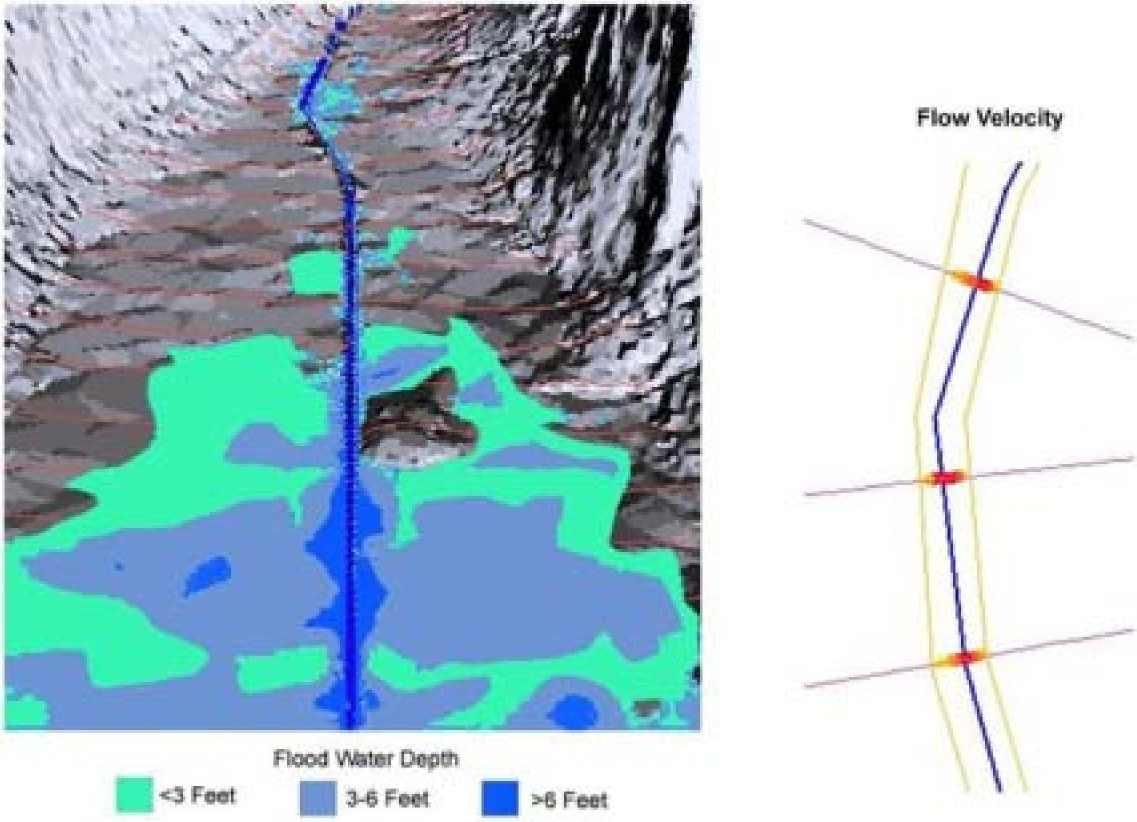


Figure 12. Flood depth analysis for the 500 year storm event.

The incorporation of a true 3D modeling package such as 3D Nature's World Construction Set allows the user to render life-like simulations of what the natural system looks like using the GIS information as a base (see Fig. 13). However, it is important to gather field photos in addition to data derived from a terrain and runoff model. In this case, the site photos show a drastically different environment than that originally envisioned by the modeler (see Fig. 14). Fortunately, World Construction Set is flexible enough allow for changes to all aspects of the landscape to match the actual conditions as shown by the site photos (see Fig. 15).

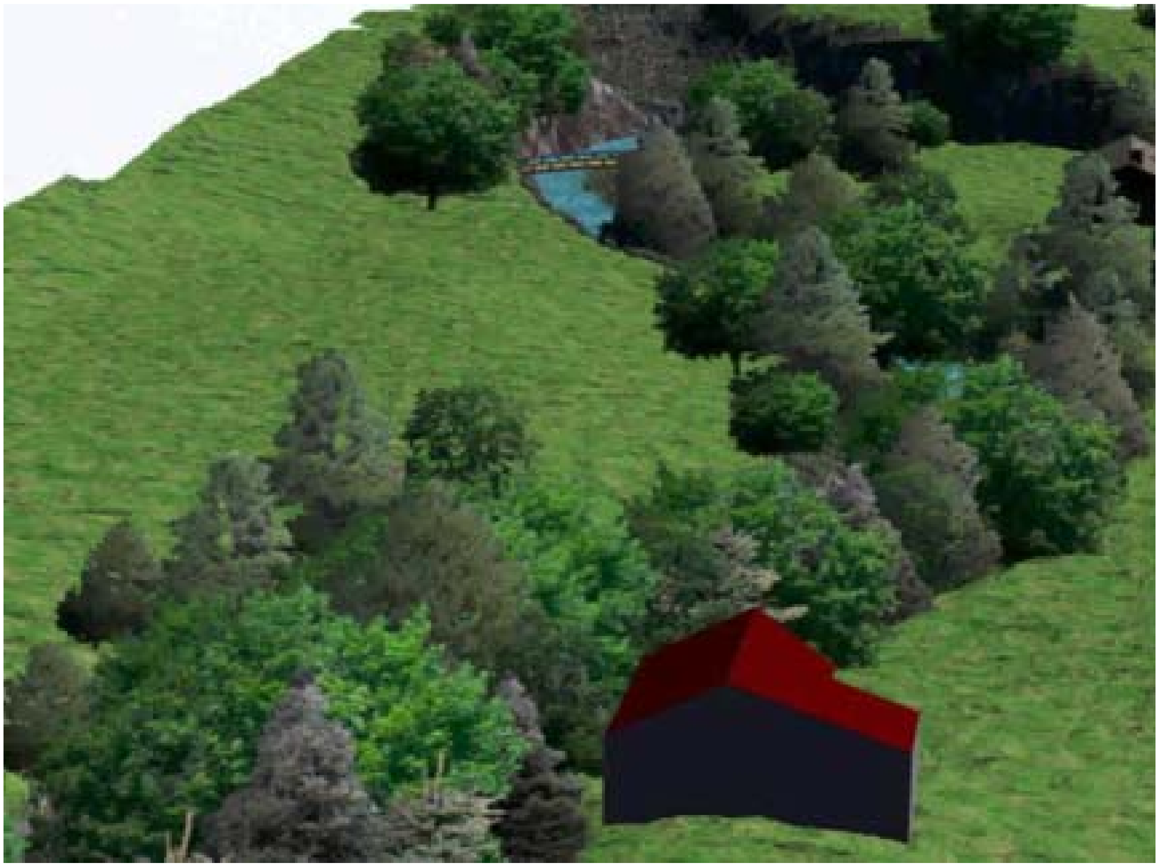


Figure 13. Initial computer rendering of the landscape based only on GIS information.

Figure 14. Actual site photos.

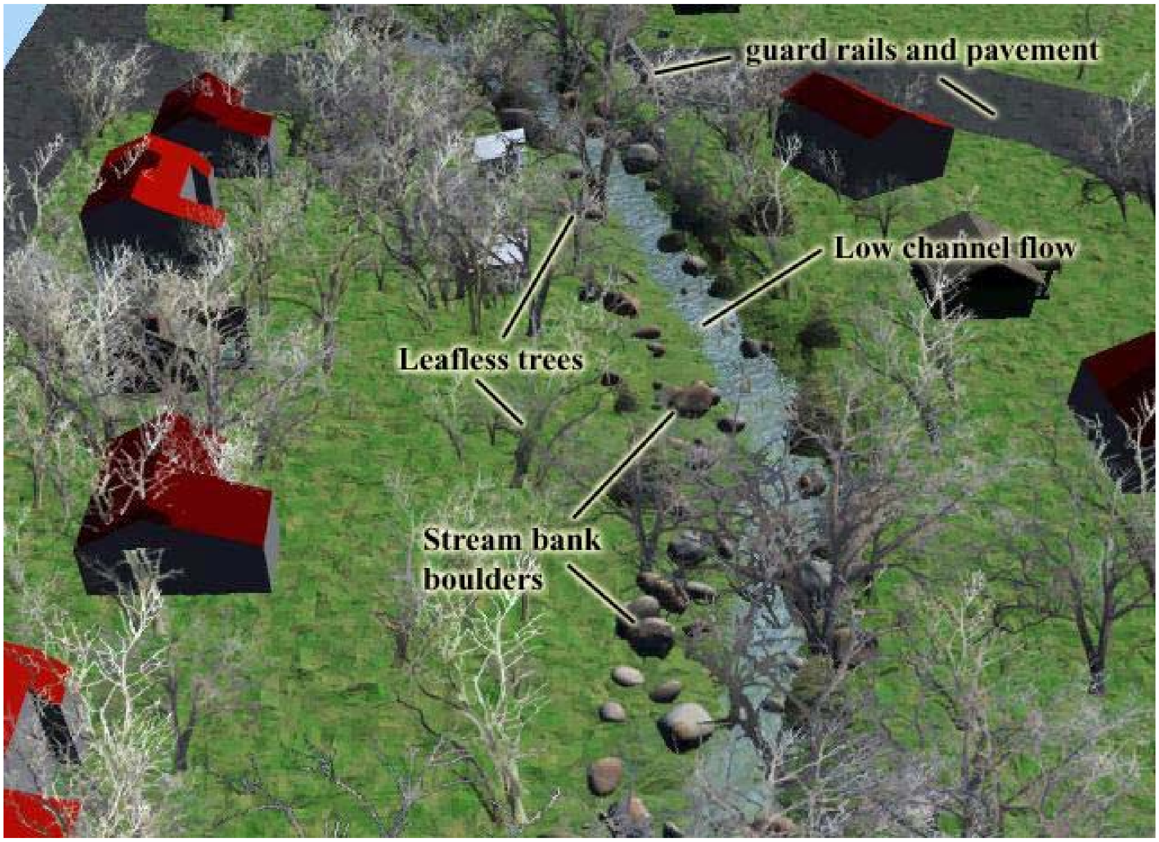


Figure 15. Computer model of existing conditions based on GIS information and site photos.

Once the 3D model is constructed, flood levels for various storm events as calculated in HEC-RAS can be incorporated into the model. The visualization of flood extents in a life-like rendering with known features (such as houses or roads) makes a powerful argument for channel improvements or mitigation efforts during watershed urbanization, impact analysis recommendations, or problem-area highlighting (see Fig. 16).

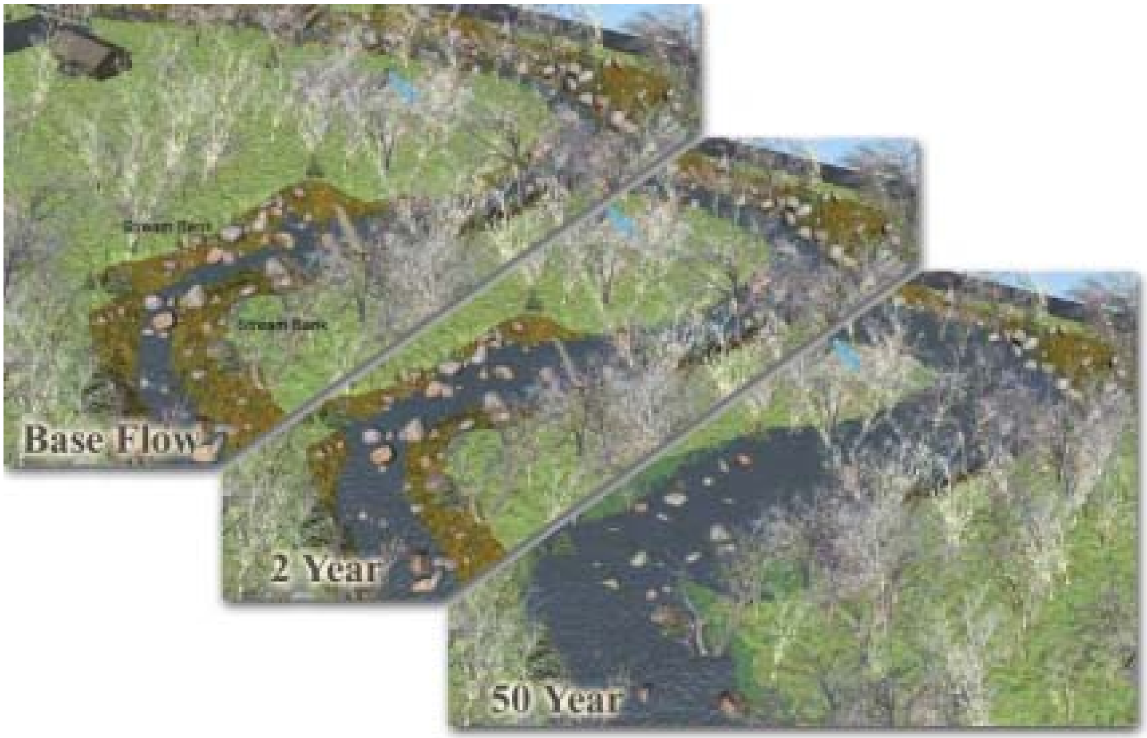


Figure 16. Flood extents for storm events visualized in World Construction Set.

Terrain Modification and Proposed Channel Visualization

The analysis of the data produced during the HEC-RAS modeling run allows stream restoration experts to make informed decisions with regard to the optimal stream channel configuration. Depending on the situation, this may involve a complete realignment of the stream, the design of upstream storm water management methods, or simply in-channel design solutions. In-channel design solutions may include terrain re-grading, the planting of stream bank stabilizing vegetation, or the construction of stream channel features designed to dissipate the erosive energy of the channel flow (see Fig. 17). These modifications may be visualized in detail prior to construction, thereby facilitating an informed discussion of options and the exploration of various ‘what-if’ scenarios before deciding on the preferred alternative.

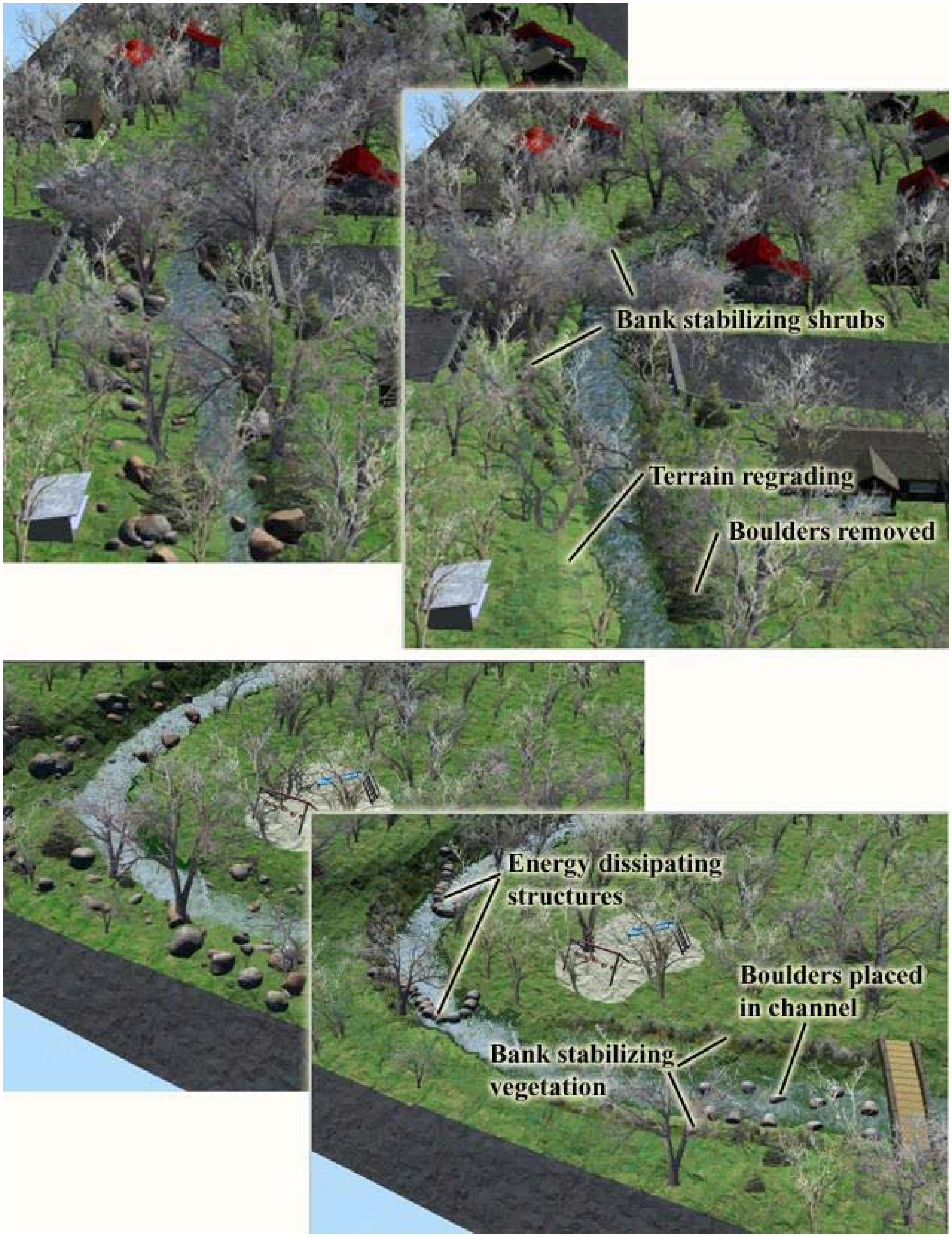


Figure 17. Channel improvements in a before and after scenario.

Conclusion

The integration of software and technologies allows a vastly improved method of watershed and stream channel characterization. The process is faster, more accurate, and the results can be displayed and visualized on a number of platforms depending on the intended audience. Simple 2D diagram may suffice for a flood zone analysis, whereas complex, life-like 3D renderings may be required when displaying results to a public audience or to convey the message in an easy-to-understand format. 'What-if' scenarios can be explored in a detail never before possible, resulting in significant time and cost savings by having jobs done right the first time. Finally, by forging links between software programs, each modeling package capitalizes on its strengths, but they also perform together in a 'big picture' context, thus allowing the presentation of an ecosystem story from start to finish.

Acknowledgements

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