Proposal For
Physics-based Flow Prediction: 4 Mile Canyon

Submitted to
Denver Urban Drainage and Flood Control District
(UDFCD)

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Qualifications

Vieux & Associates, Inc. (Vieux, Inc.) has supported flood management organizations with radar rainfall services for hydrologic applications since 1995. The Vieux, Inc. team is composed of engineers and scientists with hydrologic/hydraulic and rainfall expertise and software developers. This skilled team is adept at manipulating and analyzing large radar rainfall datasets, which allows for efficient performance of complex special studies. Analysis of archival rainfall events, quality control or near real-time operational radar and rain gauge data streams and projection of future rainfall is supported at multiple time and space scales.

For more than 10 years, Vieux, Inc. has offered distributed hydrologic modeling software/services that capitalizes on the full spatial, temporal, and resolution of radar data. With an engineering and hydrologic perspective, the company develops technology by integrating the principles of GIS, hydrology, radar rainfall in software, and services for the public and private sectors in the US, and internationally.

Services for stormwater runoff modeling and flood forecasting are supported by our system approach using V*flo*™. This model is a physics-based distributed hydrologic model designed to use radar rainfall for hydrologic input for distributed runoff modeling. Server hosting facilities are located in the National Weather Center building in Norman, OK where operational access to data from all NEXRAD radars in the entire network is available. Web-based flood services are supported with automated emergency power, failover server and storage units and real-time monitoring of software.

We serve many water management agencies, municipalities, and local organizations with rainfall and runoff monitoring and modeling. Currently we serve the City of Austin Flood Early Warning System and others with real-time radar rainfall and real-time hydrologic information. The City is using V*flo*™ for modeling basin responses in offline studies, and in real-time operational applications for emergency response.

Overview

Distributed hydrologic modeling has become an accepted method for representing rainfall-runoff processes. Given accurate representative of the land surface, a physics-based model can create realistic scenarios without making assumptions associated with lumped modeling or empirical unit hydrographs. The physics-based model, V*flo*™ simulates hydrologic response based on parameters that are estimated from physical characteristics of a basin.

At the heart of a hydrologic forecast system is the ability to extrapolate observed measurements to predict flooding at gauged and ungauged locations. Forecast hydrographs and predictive inundation maps are tools used to assess the severity of an impending flood. In post-analysis, Desktop V*flo*™ is useful in evaluating impacts of storm events and developing mitigation strategies to reduce flooding. By modeling effects of land use/cover changes, protective measures can be tested for mitigation of impacts associated with wildfires.

Modeling Approach

V*flo*™ relies on the conservation laws for mass and momentum to characterize the basin response to precipitation and snowmelt. The model uses a regular grid to compute infiltration, update soil moisture, overland and channel runoff routed with the kinematic wave approximation. Because the model uses a hydraulic approach to hydrology, runoff generation and routing are computed within the same equations. Precipitation can be derived from radar and gauge networks for model input. Infiltration excess, saturation excess, and mixed infiltration processes can be modeled. The gridded approach makes it possible to generate a hydrograph at any location in the drainage network. Model parameters are setup using GIS data for slope, landuse/cover, and soils. Channel hydraulic properties can be input directly based on geomorphic relationships, taken from DEM data, or from stage-discharge rating curves where they exist.

Flood event reconstruction can be used to enhance model accuracy in preparation for real-time operation. When V*flo*™ is combined with radar rainfall, representative geospatial data, and hydraulic channel characteristics a powerful tool results for understanding how a basin works, for making continuous flood forecasts, and evaluation and management of burn areas. Through a single model, a range of watershed sizes from smaller catchments up to river basin scale can be effectively modeled using the drainage network approach in V*flo*™.

Predicting flow rate and depth at any location in a watershed can be accomplished with the V*flo*™ distributed hydrologic model. The schematic shown in Figure 1 illustrates the network approach that avoids assumptions associated with lumped models.

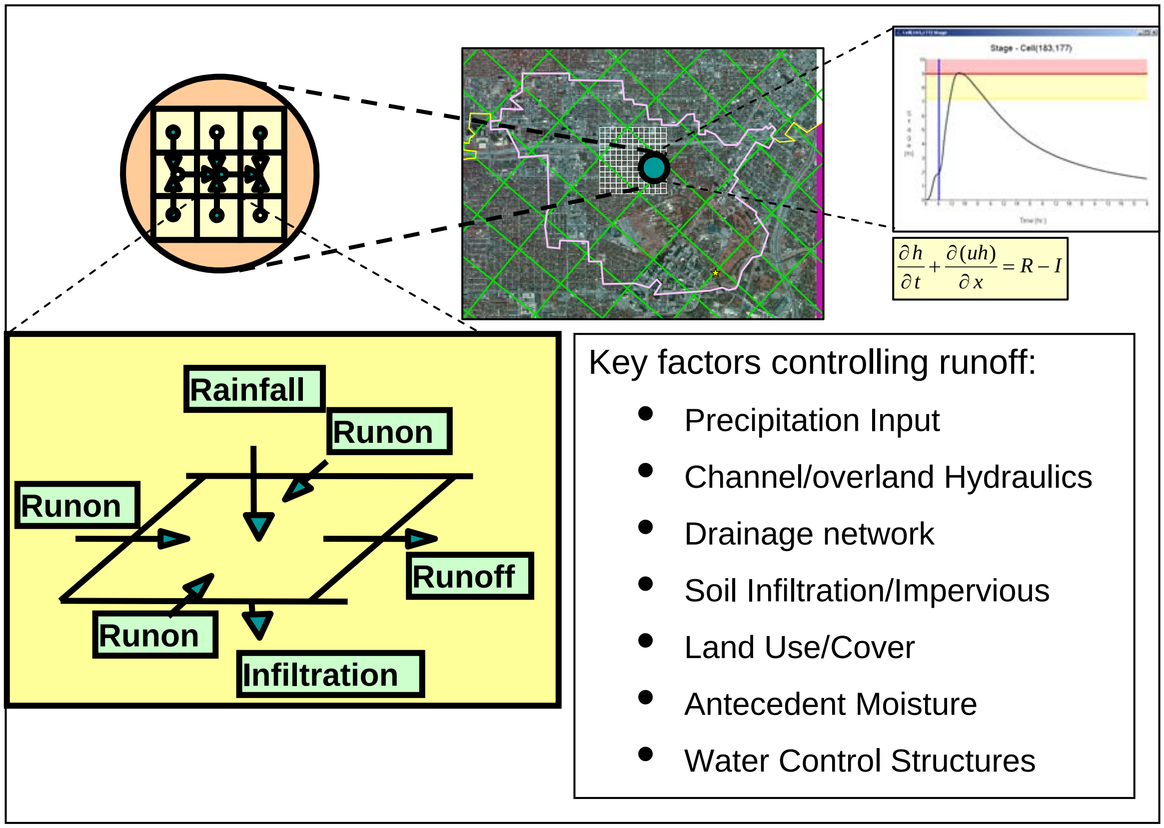

Figure 1 Network approach that accounts for the spatial distribution of factors controlling runoff

V*flo*™ addresses these factors by using geospatial data, rainfall inputs, channel characteristics and rainfall inputs as listed below.

Geospatial Data

- Digital elevation model (DEM) for derivation of slope and flow direction
- Maps of landuse/cover for overland hydraulic roughness
- Impervious area and soil characteristics for derivation of Green and Ampt infiltration parameters and soil depth

Precipitation Inputs

- Precipitation input can be spatially interpolated from gauge data, input using the storm builder or design storm tool for generation of hypothetical storms that are either stationary or dynamic, or taken from rainfall events processed to produce Quality Controlled gauge-adjusted radar rainfall (GARR).

Streamflow Routing

- Kinematic wave equations are solved on a grid cell basis within a drainage network composed of finite elements representing both overland and channel hydraulics.
- Complex channel hydraulics are represented by: 1) rating curves for stage area/discharge, 2) DEM or surveyed channel cross-sections with slope and Manning's roughness, 3) trapezoidal cross-sections with slope and Manning's roughness.

Soil Moisture and Infiltration

- Infiltration is modeled with the Green and Ampt equation for a single layer with moisture redistribution
- Once the soil moisture storage capacity is filled, then saturation excess runoff is computed.
- Soil moisture is modeled in long-term simulations, which takes into account the local rainfall rate, infiltration rate and climatologically evapotranspiration (ET) rate.

Desktop V*flo*™ model is used to setup the geospatial data that represents the conditions in a burn area, as well as, other contributing watersheds for modeling hydrologic impacts of a wildfire. Figure 2 shows the 4 mile Canyon burn area and the remainder of the watershed draining to Boulder Creek. A channel cross-section extracted from the digital elevation model is shown in the lower right, and is used for routing flow through the stream channel network.

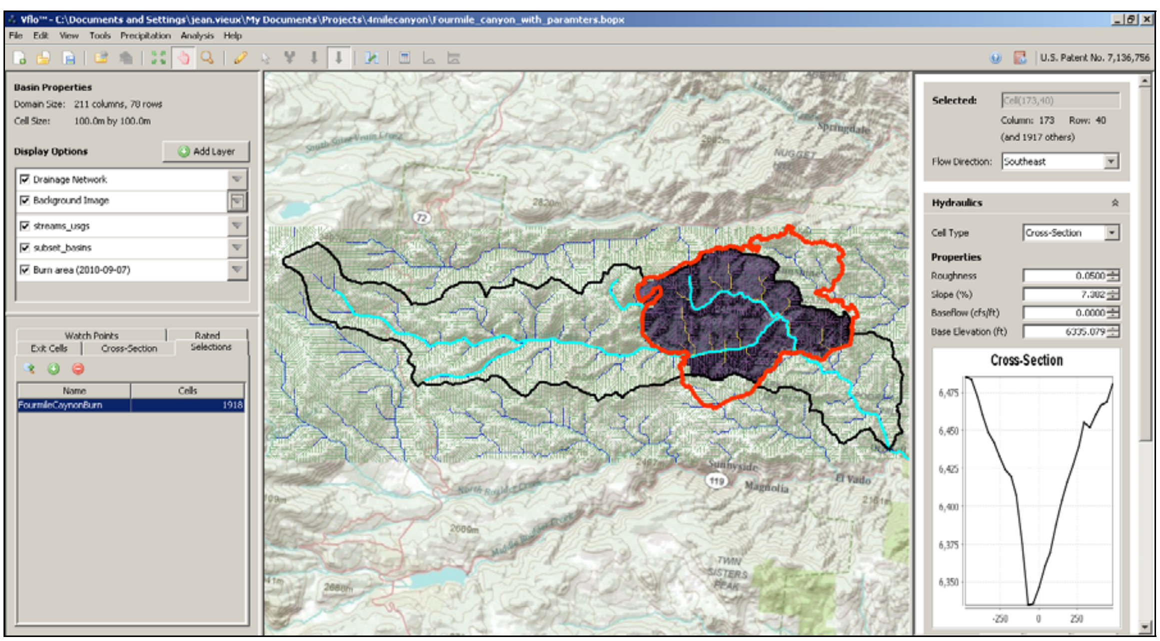

Figure 2 Desktop V*flo*™ interface displays a basin with drainage network and shapefiles.

The Storm Builder tool displayed in Figure 3 is useful for generating realistic moving (dynamic) storms over the entire watershed or selected areas such as the burn area to evaluate the increase in runoff due to the change in land cover affecting infiltration, hydraulic roughness, and resulting runoff potential in burn areas. Figure 4 presents a sample event shown here moving down the basin toward the burn area. Various scenarios can be examined by placing the center and movement of the storm to coincide with critical parts of the watershed. Further, towards understanding the consequences of wildfires on subsequent storms over a burn area, increases to rainfall intensity can be modeled using the Calibration Panel to adjust rainfall intensity, e.g. increasing rainfall rates by 25% over the burn area.

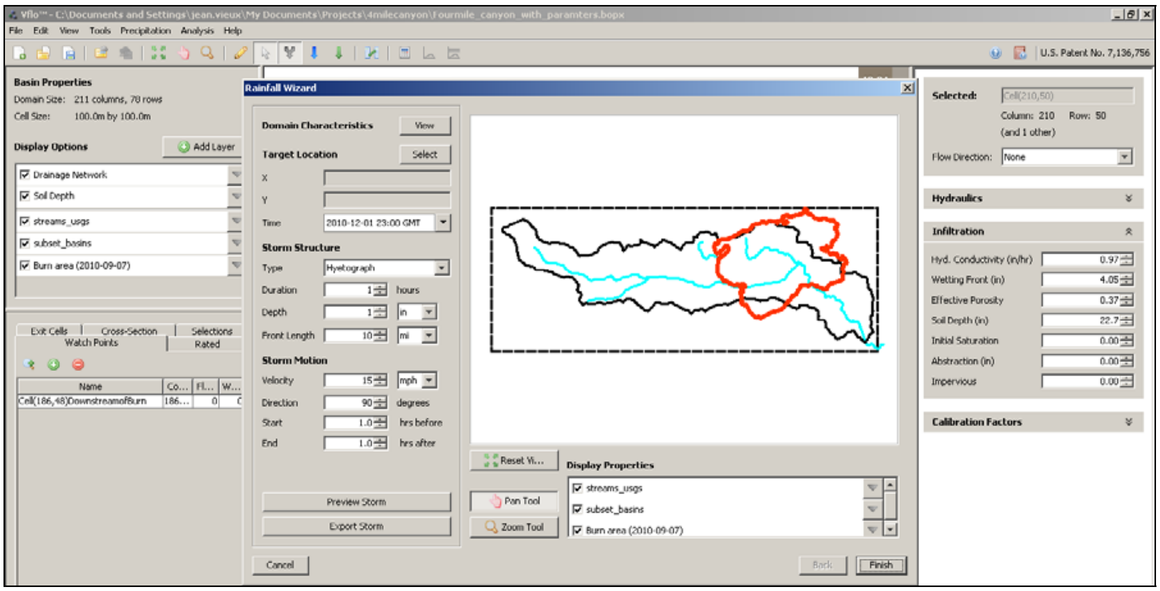

Figure 3 Storm Builder for generation of dynamic storms as input for modeling of the burn area

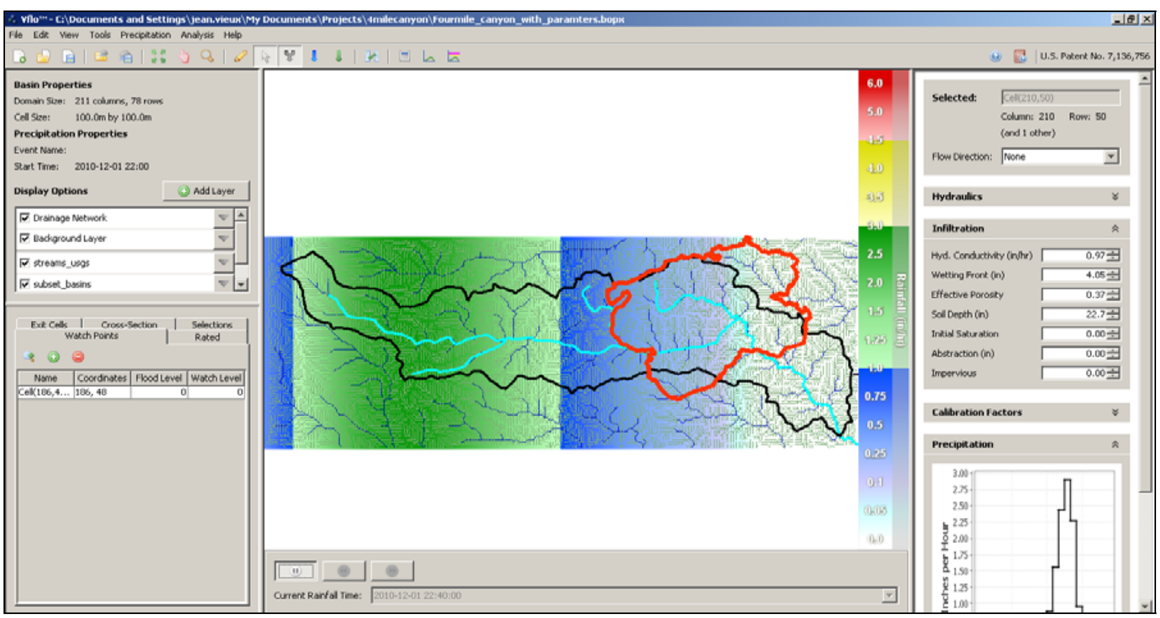

Figure 4 Sample Storm Builder event shown here moving down the watershed from west to east with a maximum intensity of 2.9 in/hr (green band)

Summary

Distributed hydrologic modeling relies on meteorological and hydrologic observation systems for hydrologic input, terrain information, and physics. This approach extends and integrates observations, geospatial data, and sophisticated numerical solutions into software that provides predictive hydrologic information. An integrated approach to hydrologic information and management supports evaluation of flash flood potential and protective measures in burn areas, and for hydrologic monitoring and forecasting needs.

This project is proposed in three phases. Phase I is concerned with model setup and evaluation of the burn area in 4 mile Canyon. Phase II is for expansion to other areas including Boulder Creek in preparation for real-time operational flood forecasting

Phase I Evaluation of Wildfire Burn Areas

Desktop V*flo*™ can be used to setup and adjust the model to evaluate land use change or wildfire burn scenarios. In Phase I, the proposed approach relies on V*flo*™ to model the 4 Mile Canyon burn area. The modeling approach consists of modifying soil properties representing infiltration rates due to surface sealing, and adjustment of hydraulic roughness in the burn areas characteristic of vegetation removal. Storm Builder is used to create synthetic storms for testing hydrologic response before and after the impacts of a wildfire.

Phase II Preparation for Real-time

In preparation for real-time flood forecasting, calibration of the model for multiple storm events helps improve the model and develop understanding of lead-time and achievable forecast accuracy. Continuous radar input should be used for evaluation of soil moisture tracking, and for testing model parameter stability year to year and seasonally. There are distinct advantages that derive from both event-based and continuous model calibration. For Phase II, event and continuous based model calibration is proposed.

Phase III Real-time Flood Forecasting Services

Phase III is for standing up the operational system and supporting real-time flash flood forecasting services. During this phase, preparations will be made for placing the model into operation through continuous rainfall data calibration, and for standing up a real-time system with web support and access.

Proposed Budget

The following pricing for Phase I is offered and is valid for 60 days from Dec. 8th, 2010.

Phase I	**Costs**
I-1. Desktop V*flo*™	
a. Software License[1]	$7,195.50
b. Support	$3,597.75
I-2. Storm Builder	
a. Software License	$7,195.50
b. Support	$1,500.00
I-3. Model Setup	
a. Data preparation	$1,500.00
b. Model setup and support for 4 mile Canyon	$5,000.00
Total Phase I =	$33,793.25

Notes: 1. Vflo Desktop Software license pricing from the General Services Administration (GSA) schedule.

The follow-on Phases, II and III, are planned with the following tasks.

Phase II - Preparation for Real-time
a. Model setup and expansion to Boulder Creek
b. Model setup expanding from 4 mile Canyon to Boulder Cr.
c. Precipitation data review and evaluation
i. Radar event processing (up to 5 events)
ii. Continuous radar data preparation and evaluation (up to 5 years)
d. Streamflow simulation and calibration for multiple events
e. Model evaluation and adjustment for continuous operation
Phase III - Operational Flood Forecasting
a. Preparation of rain and stream gauge data ingest and communication linkages
b. Web site setup and testing for gauge adjusted radar and rain gauge input
c. Continuous operation of model and rainfall display