Automated Geospatial Watershed Assessment (AGWA) Tool:
A GIS-based Hydrologic Modeling Tool for Watershed Assessment and Futures Analysis

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Overview

- AGWA Background & Basics
- Watershed Assessments with AGWA
- AGWA use by BAER Teams
- Modeling Expectations
- Rainfall Representation Impacts
- Lessons Learned

Major Groups Involved in AGWA Development

USDA-ARS    US-EPA    USGS
University of Arizona  University of Wyoming
AGWA – Background - Basics

- An automated GIS interface for watershed modeling (hydrology, erosion, WQ) designed for resource managers
- Applicable to ungauged / gauged watersheds
- Operates with nationally available data (DEM, Soils, Land Cover)
- Investigate the impacts of land cover change
  - Identify sensitive, “at-risk” areas
  - Assess impacts of management (e.g. growth, fire, mulch)
- Provide repeatable results for relative change assessments
- Must have good rainfall-runoff observations for quantitative predictions
- Three established watershed/hillslope models for multiple scales
  - KINEROS2
  - SWAT
  - RHEM/WEPP (hillslope runoff and erosion within KINEROS2)
  - 4000+ Reg. users; 10,500+ downloads in 170 countries; >250 citations
Two distributed hydrologic models to address multiple scales

- **SWAT** for large basins, daily time steps (HRU – Hydrologic Response Units, CN-Curve Numbers)
- **KINEROS2** small/med. basins, sub-hour time steps, dynamic routing and physically-based infiltration, runoff-runon, cascade of elements, allows explicit treatment of different cover and management

Endpoints: runoff, erosion, sediment, plus N and P in SWAT
Conceptual Design of AGWA

**PROCESS**

1. Build GIS Database
2. Discretize Watershed $f$ (topography)
3. Characterize Model Elements $f$ (land cover, topography, soils)
5. Build Input Files & Run Model
6. View Model Results *link model to GIS*

**INPUTS & OUTPUTS**

<table>
<thead>
<tr>
<th>KINEROS Outputs</th>
<th>SWAT Outputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel Infiltration (m$^3$/km)</td>
<td>Precipitation (mm)</td>
</tr>
<tr>
<td>Plane Infiltration (mm)</td>
<td>ET (mm)</td>
</tr>
<tr>
<td>Runoff (mm or m$^3$)</td>
<td>Percovation (mm)</td>
</tr>
<tr>
<td>Sediment Yield (kg)</td>
<td>Surface Runoff (mm)</td>
</tr>
<tr>
<td>Peak Flow (m$^3$/s or mm/hr)</td>
<td>Transmission Losses (mm)</td>
</tr>
<tr>
<td>Channel Scour (mm)</td>
<td>Water Yield (mm)</td>
</tr>
<tr>
<td>Sediment Discharge (kg/s)</td>
<td>Sediment Yield (t/ha)</td>
</tr>
<tr>
<td>Nitrate in Surface Runoff (kg N/ha)</td>
<td></td>
</tr>
<tr>
<td>Phosphorous in Surface Runoff (kg P/ha)</td>
<td></td>
</tr>
</tbody>
</table>
Data for AGWA Parameterization

- **Digital Elevation Model**
  - Usually USGS 10m – 30m DEM will work fine in western terrains in large watersheds
  - LIDAR can be used

- **Soils**
  - USDA STATSGO – nationally available; SSURGO where available
  - FAO soils globally

- **Land Use - Land Cover (NLCD, ReGAP)**

- **Weather**
  - If not using design storms - “good” rainfall data is essential in time/space (more later)

- **Management Information**
  - Where and what
  - Information must be provided by user (i.e. burn severity map)

*(Examples and more detail in training tutorials)*
Visualization of Results

- Color-ramping of results for each element to show spatial variability
- Multiple simulation runs for a given watershed
- Calculate and view differences between model runs
- Channel simulation differences also displayed
- Hydrograph/Sedigraph for overland and channel elements
How AGWA tools Fits into Comprehensive Watershed Assessments and Analysis

Impact of Historical Landscape Change (e.g. San Pedro/New York City)

Alternative Futures (e.g. San Pedro, Willamette River, South Platte)

AGWA (Runoff, Peak Discharge, Sedimentation, Nitrogen, Phosphorous)

Sub-catchments/Stream Segments at Risk to Increased Sedimentation and Run-off (e.g. 404q, post-fire)

Decision Support Tool for Watershed Assessment and Watershed-based Planning (e.g. GI, BMPs, Border 2020)
Spatial and Temporal Scaling of Results

- Using SWAT and KINEROS for integrated watershed assessment
- Land cover change analysis and impact on hydrologic response

Upper San Pedro River Basin

Water Yield change between 1973 and 1997

High urban growth 1973-1997

ARIZONA
SONORA

Phoenix
Tucson

SWAT Results
Spatial and Temporal Scaling of Results

- Using SWAT and KINEROS for integrated watershed assessment
- Land cover change analysis and impact on hydrologic response

Upper San Pedro River Basin

High urban growth 1973-1997

Water Yield change between 1973 and 1997

<<WY     >>WY

Sierra Vista Subwatershed

KINEROS Results

SWAT Results
Spatial and Temporal Scaling of Results

- Using SWAT and KINEROS for integrated watershed assessment
- Land cover change analysis and impact on hydrologic response

Upper San Pedro River Basin

Sierra Vista Subwatershed

Water Yield change between 1973 and 1997

1997 Land Cover

- Concentrated urbanization

- High urban growth 1973-1997

- SWAT Results
- KINEROS Results

- Forest
- Oak Woodland
- Mesquite
- Desertsrub
- Grassland
- Urban
**Rapid Post-Fire Watershed Assessment using AGWA**

- 2011 – Wallow Fire, AZ – AGWA was the only model that produced results for the entire burned area; ’12-15 – used in over 21 large fires
- Adopted by DOI National BAER teams
- Model Parameterization for post-fire
  - Define look-up table for pre- and post-fire model parameters as a function (land cover & burn severity) from well gaged basins
  - SWAT (CN, roughness)
  - KINEROS2 (roughness, Interc., cover, Sat. Hydraulic Cond.)
  - Assume a reduction in cover of:
    - 15% - low severity
    - 32% - moderate severity
    - 50% - high severity
  - Note: In K2 a cover reduction also decreases infiltration rates
  - For K2 fix the roughness factor for overland flow to equal bare soil (n = 0.011) => more than an order of magnitude change in extremely rough environments, such as conifer forests.
**Typical AGWA Application by DOI BAER**

- **Time sensitive**: BAER process must be completed in 14 days to acquire Federal emergency response funds
- I.D. Values at Risk (VAR)
- Discretize watersheds to these points
- Simulate watershed response for pre-fire conditions with design storms
- Import initial BARC burn severity map
- Simulate post-fire (same storm) to stratify field work and produce field verified burn severity map (BSM)
- Re-run AGWA with BSM
- Difference pre- and post-fire simulations
- Allows limited $$ for fire mitigation to be applied to highest at-risk areas (Elk fire complex saved ~$7M)
KINEROS2 Modeling Expectations

- Recent study compares pre- and post-fire modeling results for Rule of Thumb (ROT), Modified Rational Method (MODRAT), HEC-HMS Curve Number, and KINEROS2 in San Dimas Exp. Forest (Chen et al. 2013)
  - ROT & MODRAT – OK with careful local calibration
  - HEC-HMS CN better for pre-fire prediction
  - KINEROS2 better for post-fire prediction
  - Evidence that pre-fire runoff is Sat. Excess or Subsurface and post-fire is Inf. Excess
  - KINEROS2 (as currently setup in AGWA) only does Inf. Excess (can do Sat. Excess from shallow soils over rock) – tutorials will get into more complex model setups
Basics of Runoff Generation

**Interflow – Shallow Subsurface Flow**
Infiltrated rain hits restrictive layer and flows laterally to stream (slow response, attenuated peak)
Typical in unburned areas with shallow soils and heavy litter

**Infiltration Excess**
Rainfall Int. > Soil Infil. Rate
Typical in burned areas – high Int. rain

**Saturation Excess**
Soil pores saturated
Wet areas – shallow water table or shallow soil over rock

KINEROS2 – as set up in AGWA
CN better represents this mechanism
Marshall Gulch

Pre - Fire Hydrograph
8/16/57 – 8/26/57

Post - Fire Hydrograph
7/24/03
(Aspen Fire – 6/17/03 ~ 7/10/03)

Runoff / rainfall ratio similar; timing & peak runoff rate are profoundly different (also noted by Springer & Hawkins 2005; McLin et al. 2001).
- Drainage Area: 149 km²
- Ave. annual Precipitation: 312 mm
  - 60% from N. American Monsoon
  - 35% frontal winter
  - ~5% from tropical depressions
- 54 years record
- 88 weighing recording rain gauges, 1 min.
- 29 gaged watersheds (8 with sediment)
Model Limitations – Poor Predictions for Small Runoff Events

- Small errors and uncertainties in rainfallObs. can result in large uncertainties in runoff
  - Typical rain gauge measurement error ~ 3mm
  - Wind induced gauge errors ~ 5 to 15% of total

Walnut Gulch (148 km²)
Average Annual Water Balance

<table>
<thead>
<tr>
<th>Component</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPT</td>
<td>350 mm</td>
</tr>
<tr>
<td>ET</td>
<td>327 mm</td>
</tr>
<tr>
<td>Infil.</td>
<td>327 mm</td>
</tr>
<tr>
<td>Hill-slope Runoff</td>
<td>23 mm</td>
</tr>
<tr>
<td>Chan. Losses</td>
<td>20 mm</td>
</tr>
<tr>
<td>Runoff</td>
<td>2 mm</td>
</tr>
</tbody>
</table>
Model Limitations – Poor Predictions for Small Runoff Events

- Small errors and uncertainties in rainfall Obs. can result in large uncertainties in runoff
  - Typical rain gauge measurement error ~ 3mm
  - Wind induced gauge errors ~ 5 to 15% of total

Walnut Gulch (148 km²)
Average Annual Water Balance

- PPT 350 mm

Model Limitation

In arid in semiarid regions where runoff / rainfall ratios are small, we are between a rock and hard place.

We can’t expect any watershed model to make good predictions for small runoff events – especially without very good rainfall observations.
High & Low Runoff to Rainfall Ratio

~27 fold increase in runoff due to urbanization

Ft. Huachuca (grassland)
La Terreza (urban)

Runoff

4 Gages

Precipitation
Urban Runoff
Grassland runoff

Percent of Total

4 Gages

Total Rainfall (mm)
Event Ppt. Depth (mm)

Urban R/R = 0.35
Grassland R/R = 1.3

~27 fold increase in runoff due to urbanization
Bands indicate level of modeling uncertainty (shaded)
Simulated runoff using calibrated parameters (solid line)

**Point:** Any model will make poor predictions when runoff is a small % of rainfall due to uncertainties in rainfall and other model parameters

Kennedy et al. 2013
SCS 24-hour Rainfall Distributions with NOAA Design Storm Depths

Type I and IA – Pacific maritime climate with wet winters and dry summers. Long duration, low intensity events.

Type III – Gulf of Mexico and Atlantic coastal areas where tropical storms bring large 24-hour rainfall amounts

Type II – Everywhere else, intense short duration rainfall, smaller extents.
How should rainfall be input into the model?

Typical goals when modeling post-fire runoff

1) Accurately predict or reproduce magnitude of an event

2) Predict which stream reaches and hillslopes are at risk (values at-risk)

How does rainfall representation affect our ability to meet these goals?
August 1, 2007 storm
>1 year after the fire

August 21, 2011 storm
Reproducing Post-fire Flood Magnitude

What rainfall representation gives us the best estimate of peak discharge?

Rainfall representations input into the model:

1. **Uniform** rainfall intensity over the entire watershed
2. SCS Type II storm over the entire watershed
3. SCS Type II storm centered over the burned area
4. Observed Digital Hybrid Reflectivity (DHR) radar data from post-fire event
North Creek
Storm Totals
Aug. 1, 2007 Event

• Average rainfall depth 
  over watershed: 
  30.22mm (1.19”)
• Approximate duration 
  of event: 1.5 hours
• Correlates to ~10-year 
  rainfall event

Storm Totals
Rainfall Depth (mm)

<table>
<thead>
<tr>
<th>Depth Range</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.000000</td>
<td>Green</td>
</tr>
<tr>
<td>0.01 - 25.4</td>
<td>Light Green</td>
</tr>
<tr>
<td>25.41 - 50.8</td>
<td>Yellow</td>
</tr>
<tr>
<td>50.81 - 76.2</td>
<td>Orange</td>
</tr>
<tr>
<td>76.21 - 82.3</td>
<td>Red</td>
</tr>
</tbody>
</table>
### Post-fire Magnitude: Results

<table>
<thead>
<tr>
<th>Rainfall Representation</th>
<th>Peak Discharge (m³/s)</th>
<th>Time to Peak (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uniform</td>
<td>2.53</td>
<td>355</td>
</tr>
<tr>
<td>Type II</td>
<td>64.69</td>
<td>215</td>
</tr>
<tr>
<td>Type II Burned Area</td>
<td>261.23</td>
<td>189</td>
</tr>
<tr>
<td>DHR Radar</td>
<td>312.91</td>
<td>184</td>
</tr>
<tr>
<td>USGS Estimate</td>
<td>382.33</td>
<td>~180-240</td>
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#### North Creek
- **Uniform**
  - Discharge: 2.53 m³/s
  - Time to Peak: 355 min
- **Type II**
  - Discharge: 64.69 m³/s
  - Time to Peak: 215 min
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  - Time to Peak: 184 min
- **USGS Estimate**
  - Discharge: 382.33 m³/s
  - Time to Peak: ~180-240 min

#### Frijoles Canyon
- **Uniform**
  - Discharge: 2.53 m³/s
  - Time to Peak: 355 min
- **Type II**
  - Discharge: 64.69 m³/s
  - Time to Peak: 215 min
- **Type II Burned Area**
  - Discharge: 261.23 m³/s
  - Time to Peak: 189 min
- **DHR Radar**
  - Discharge: 312.91 m³/s
  - Time to Peak: 184 min
- **USGS Estimate**
  - Discharge: 382.33 m³/s
  - Time to Peak: ~180-240 min

#### Uncertainty
- **USGS Indirect Meas. (15%)**
- **USGS Est.**
- **Uniform.**
- **Type II All Area**
- **Type II Burned Area**
- **DHR Radar**

#### Diagrams
- Graph showing discharge over time for North Creek and Frijoles Canyon.
- Graphs indicate peak discharges and time to peak for different rainfall representations.
Post-fire Magnitude: Results

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Predicting At-Risk Areas

Does rainfall representation change the model’s prediction of high-risk areas?

For rapid assessment of post-fire risk, a design storm is used:
- Monsoon Storm: 2-year 30-minute, 13.18mm (0.52”)
Predicting At-Risk Areas

Which hillslopes and stream reaches have the greatest change in runoff or sediment yield from pre- to post-fire?

Compare peak flow and sediment yield change from 4 storms:
1. Observed Monsoon Storm
2. Uniform Intensity
3. SCS Type II over watershed
4. SCS Type II over burned area
High-Risk Stream Reaches

Map of high risk areas:

To determine if rainfall representation changed the model’s predicted areas of high risk, peak runoff rate of stream reaches and sediment yield of hillslopes were ranked from highest to lowest percent change from pre- to post-fire for each rainfall representation.
Comparing Ranking of Risk Areas

Statistically compare rankings with Spearman’s Coefficients (SC) (SC = 1 implies perfect agreement in ranking, SC = -1 implies an inverse ranking order). **Point:** They are generally high for design storms.

### North Creek (ZION)

<table>
<thead>
<tr>
<th>Peak Flow for Stream Reaches</th>
<th>Type II Burned Area</th>
<th>Type II Watershed</th>
<th>Uniform</th>
<th>Monsoon</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.76</td>
<td>0.66</td>
<td>0.46</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.90</td>
<td>0.84</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.89</td>
<td>0.98</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.89</td>
<td>0.97</td>
<td>0.99</td>
<td></td>
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</tbody>
</table>

### Frijoles Canyon (BAND)

<table>
<thead>
<tr>
<th>Peak Flow for Stream Reaches</th>
<th>Type II Burned Area</th>
<th>Type II Watershed</th>
<th>Uniform</th>
<th>Monsoon</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
<td>0.83</td>
<td>0.83</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.00</td>
<td>0.82</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.80</td>
<td>0.81</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.67</td>
<td>0.68</td>
<td>0.70</td>
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</tr>
</tbody>
</table>

**Sediment Yield for Hillslopes**

- **North Creek (ZION):**
  - Uniform: 0.88
  - Monsoon: 0.99

- **Frijoles Canyon (BAND):**
  - Uniform: 0.62
  - Monsoon: 0.70
Rainfall-Representation Conclusions

• Rainfall representation drastically changes our ability to accurately model post-fire storm magnitude
• Radar is the best method for modeling magnitude
Rainfall-Representation Conclusions

- Rainfall representation drastically changes our ability to accurately model post-fire storm magnitude
- Radar is the best method for modeling magnitude
- High-risk areas do not vary drastically between different rainfall representations
- AGWA/KINEROS2 can reliably be used to predict relative pre- to post fire change to identify these areas
Rainfall-Representation Conclusions

• Rainfall representation drastically changes our ability to accurately model post-fire storm magnitude

• Radar is the best method for modeling magnitude

• High-risk areas do not vary drastically between different rainfall representations

• AGWA/KINEROS2 can reliably be used to predict relative pre- to post fire change to identify these areas

Models are more reliable at predicting relative change than absolute change
Summary

• Changes in roughness can explain much of the post-fire hydrologic and erosion response in non-hydrophobic soils.

• AGWA provides framework to quickly parameterize watershed models and visualize the results.

• AGWA provides watershed scale assessments for both runoff and erosion / sediment transport at multiple points of potential risk and for all model elements.
Lessons Learned from BAER Applications

- Using a design storm with precipitation uniformly distributed over the burn area will accurately identify the ranking of pre- to post-fire percent changes in model outputs for overland and channel model elements.

- The whole BAER Team benefited from initial results.

- Pre- and post-fire % difference maps can be used by BAER team to locate the threat to the downstream values at risk to optimize treatment design – save $$

- Helped other agencies (Army COE, State-wide Hazard Planning Groups) identify site-specific modeling needs and design of emergency warning systems.
Information

AGWA Web Pages:

http://www.tucson.ars.ag.gov/agwa/
http://www.epa.gov/nerlesd1/land-sci/agwa/

Includes:
- Documentation
- Software
- Tutorials
- Pubs / Presentations