

FLASH FLOOD POTENTIAL: DETERMINING THE HYDROLOGIC RESPONSE OF FFMP BASINS TO HEAVY RAIN BY ANALYZING THEIR PHYSIOGRAPHIC CHARACTERISTICS.

Greg Smith – November 2003

This paper is intended to be a brief overview of a project underway at the CBRFC

INTRODUCTION:

Several physiographic factors contribute to the possibility a flash flood will occur in any particular drainage area. Soil texture and structure are important in determining water holding and infiltration characteristics. Slope and basin geometry determine such behavior as the speed and concentration of runoff. Vegetation and forest canopy affect precipitation interception. Land use practices, particularly urbanization, can play a significant role in water infiltration, concentration, and runoff behavior. Together these somewhat static characteristics yield information about the hydrologic response and flash flood potential inherent to a specific area. As these features change this flash flood potential will take on a more dynamic nature. Changes in vegetation or seasonal changes in a deciduous forest may decrease or increase the hydrologic response associated with similar rainfall events. Perhaps the greatest affect is that of forest fire where a hydrophobic soil layer, impervious to water infiltration, may result due to the burning of organic material. In this case the flash flood potential changes dramatically on an event-by-event basis.

While the desire for this kind of flash flood potential information has existed previously, the incorporation of the Flash Flood Monitoring and Prediction System (FFMP) into Weather Forecast Office (WFO) operations has accelerated a need for such information. The FFMP software takes advantage of the ability of the WSR-88D NEXRAD Doppler Radar Digital Hybrid Scan Reflectivity precipitation algorithm to sample rainfall amounts and rate at a fine resolution (1⁰ X 1 KM polar grid resolution). This gridded precipitation is then converted to an Average Basin Rainfall (ABR) for a predefined set of watershed boundaries. These watershed boundaries exist on a scale generally from about 2 to 10 square miles in area.

Providing flash flood guidance values at this scale has proved quite challenging. Methods for populating FFMP with flash flood guidance values include pre-existing rules of thumb, the modernized Threshold Runoff/FFG system, and other local applications. These methods, however have proved to have serious limitations when applied in the Colorado Basin River Forecast Center area of responsibility. Many of these limitations have to do with both the temporal and spatial scale of the datasets utilized. Most data were simply too coarse or generated from original datasets that were on a spatial scale much more vast than that of flash floods. Additionally, while methods such as the Threshold Runoff/FFG attempted to account for some basin geometry, there were scale limitations associated with the Sacramento Soil Moisture Accounting (SAC-SMA) model. Lumped, conceptual models such as the SAC-SMA contain parameters and variables that represent an average over an entire catchment. Therefore the hydrologic process descriptions are not based directly on equations and model parameters must be obtained through a calibration process. This requires time series of

hydrologic data with a historical record long enough for model calibration. Typically this data is only available for gaged sites that usually represent watersheds up to several hundred square miles in area, unrepresentative of basins at the flash flood scale.

Despite how flash flood guidance is obtained it is questionable whether in the near future a level of accuracy can be obtained for it to be utilized in a widespread, purely deterministic, fashion in FFMP. This project endeavors to supplement FFMP by providing information about the relative flash flood potential of the FFMP basins.

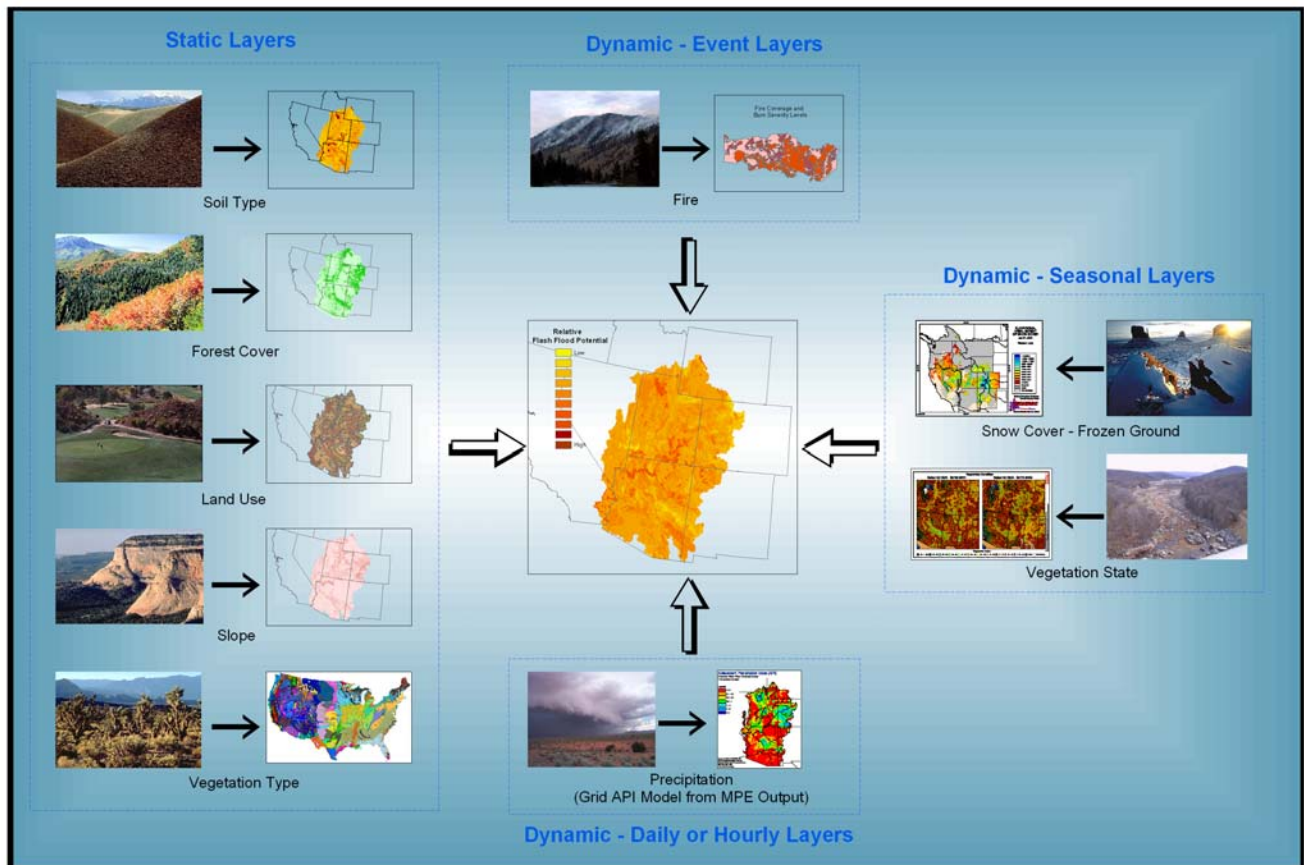
METHOD:

The concept is fairly simple. The process involved acquiring or developing raster (gridded) datasets that represent the type of physiographic characteristics that influence the hydrologic response and flash flood potential. These datasets were then geo-registered and re-sampled to a consistent resolution using a bilinear or nearest neighbor method. A relative flash flood potential index ranging from 1 to 10 was assigned to each data layer based on the layer attributes associated with the hydrologic response. For the initial analysis a simple equal interval classification scheme was used. These values simply represent a grid cells susceptibility to flash flooding relative to neighboring cells. The values are unit-less. The layers were then averaged together and a single gridded output of relative flash flood potential was generated. Without observed event information it is difficult to know how to weigh each layer. Until these observed data layers are generated the input layers were weighed equally with the exception of the slope layer. This layer was weighed slightly more than the others due to the significant influence slope has in flash flood development. A more robust weighting scheme is anticipated when observed flash flood event data is included in the analysis.

The initial analysis has been completed using four readily available datasets that included slope, land use, forest density, and soil texture. The intent of this first attempt at developing a grid of flash flood potential was to test the process and gain some initial feedback from a weather forecast office regarding the value of such a product. The gridded output was interpolated to the basin coverages used in the FFMP so it could be displayed concurrently with FFMP for testing during a flash flood situation. Due to the spatial nature of this project and need for geo-referencing data all work was carried out in a GIS.

DATA

As with many GIS analysis limitations are frequently encountered due to varying resolution between datasets. Resolution of the datasets acquired for this initial analysis ranged from 90 meter to 1-kilometer grid cells. Perhaps the most important dataset in the CBRFC area is slope, which was derived from a Digital Elevation Model (DEM) dataset. The DEM data available was 3-arc second resolution, or approximately 90-meter grid cell, obtained from the USGS. This dataset was re-sampled to 400 meters, an arbitrary mid-point between the datasets used. This resolution is not the most desirable as the minimum basin that can accurately be defined is approximately 60 km². While in the final analysis an attempt will be made to utilize finer resolution data, it will depend upon what datasets can be obtained.



The concept is to collect rasterized datasets representing physiographic characteristics and relate them to a hydrologic response to heavy rainfall in order to produce a “static” relative flash flood potential grid

The dominant soil texture (or soil type) dataset used in this preliminary analysis was from the State Soil Geographic (STATSGO) soils data that was compiled by the Natural Resources Conservation Service (NRCS). STATSGO soil maps are compiled by generalizing more detailed soil maps where available. Where detailed maps are unavailable geological, topographical, vegetation, and climate information have been combined with Land Remote Sensing Satellite (LANDSAT) images to determine probable classification and extent of soils. For the dominant soil texture class there are 11 standard soil layers in the vertical soil profile. This analysis only took into consideration the two surface layers representing a depth of 10 centimeters. No variation was observed in soil texture class between the first several surface layers. Twelve soil texture classes are defined, ranging from sand on one end to clay on the other. Organic material, water, bedrock, and undefined or no data classes are included for a total of 16 texture classes. Although STATSGO data intended use includes the mention of river basin in the official USDA NRCS description it is pushing the limits of being too coarse in resolution for application at the flash flood scale. Data from the Soil Survey Geographic (SSURGO) NRCS database that exists at a finer resolution would be more applicable. When

this project was initiated the SSURGO data was not available for the entire area of study, therefore the decision was made to use the STATSGO data, realizing the limitations due to the data resolution. Attempts will be made to obtain finer resolution soil texture data in the final analysis.

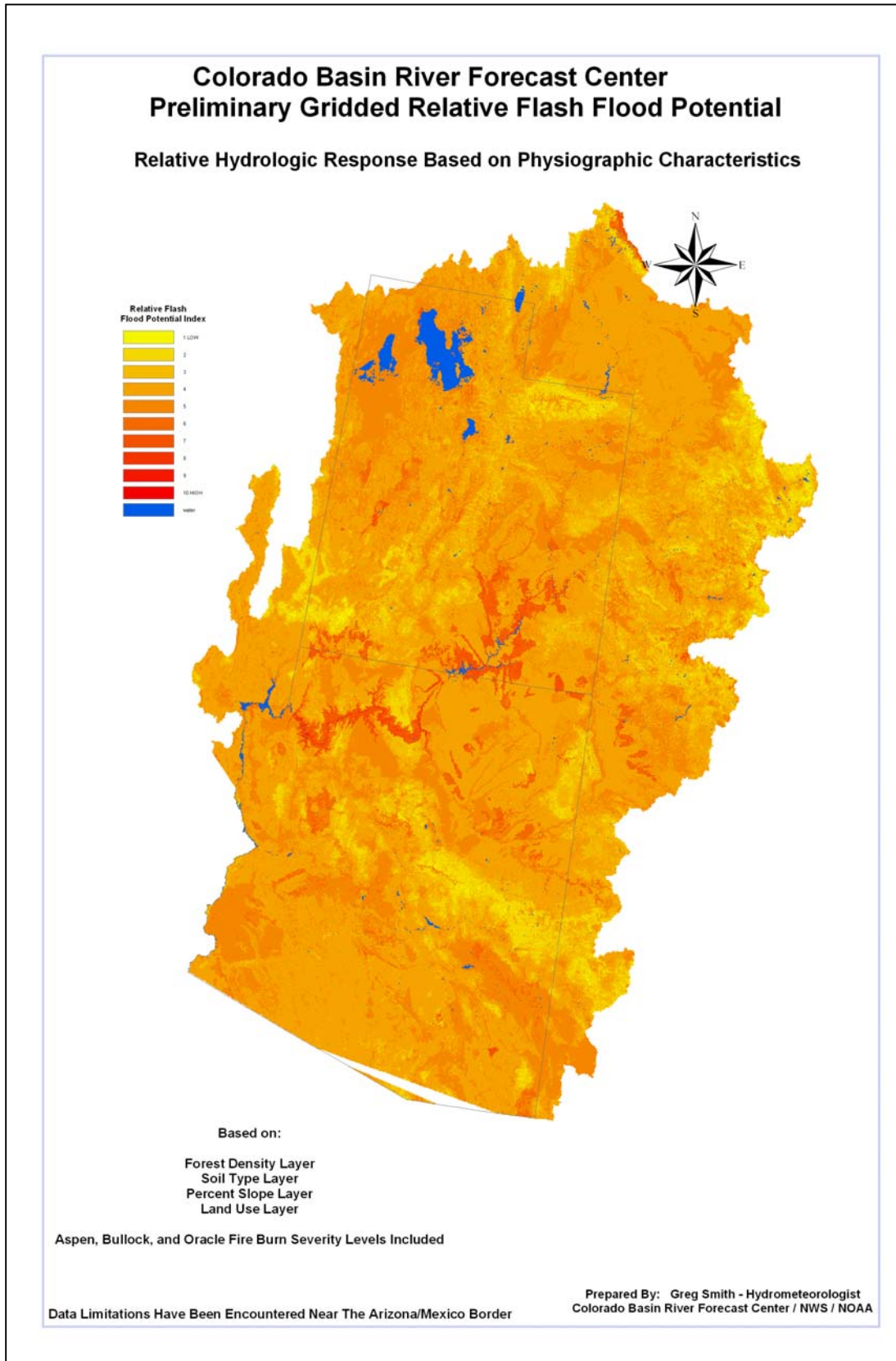
The land use dataset was developed from 30 – meter early 1990's Landsat Thematic Mapper data purchased by the Multi – Resolution Land Characterization (MRLC) Consortium. The MRLC consortium is a group of several federal agencies sharing the cost of acquiring satellite images for use in various environmental monitoring programs. Although the data may be used for a variety of purposes, only a small number of aerial photographs were used for ground truth in the analysis and interpretation of the satellite imagery, which at times consisted of multi-state mosaics (source: MRLC Documentation). Therefore caution and careful scrutinizing of the data was recommended by the MRLC when applying it to large scale or local studies. Significant changes in land use practices over the past decade are not represented and this limitation must be recognized.

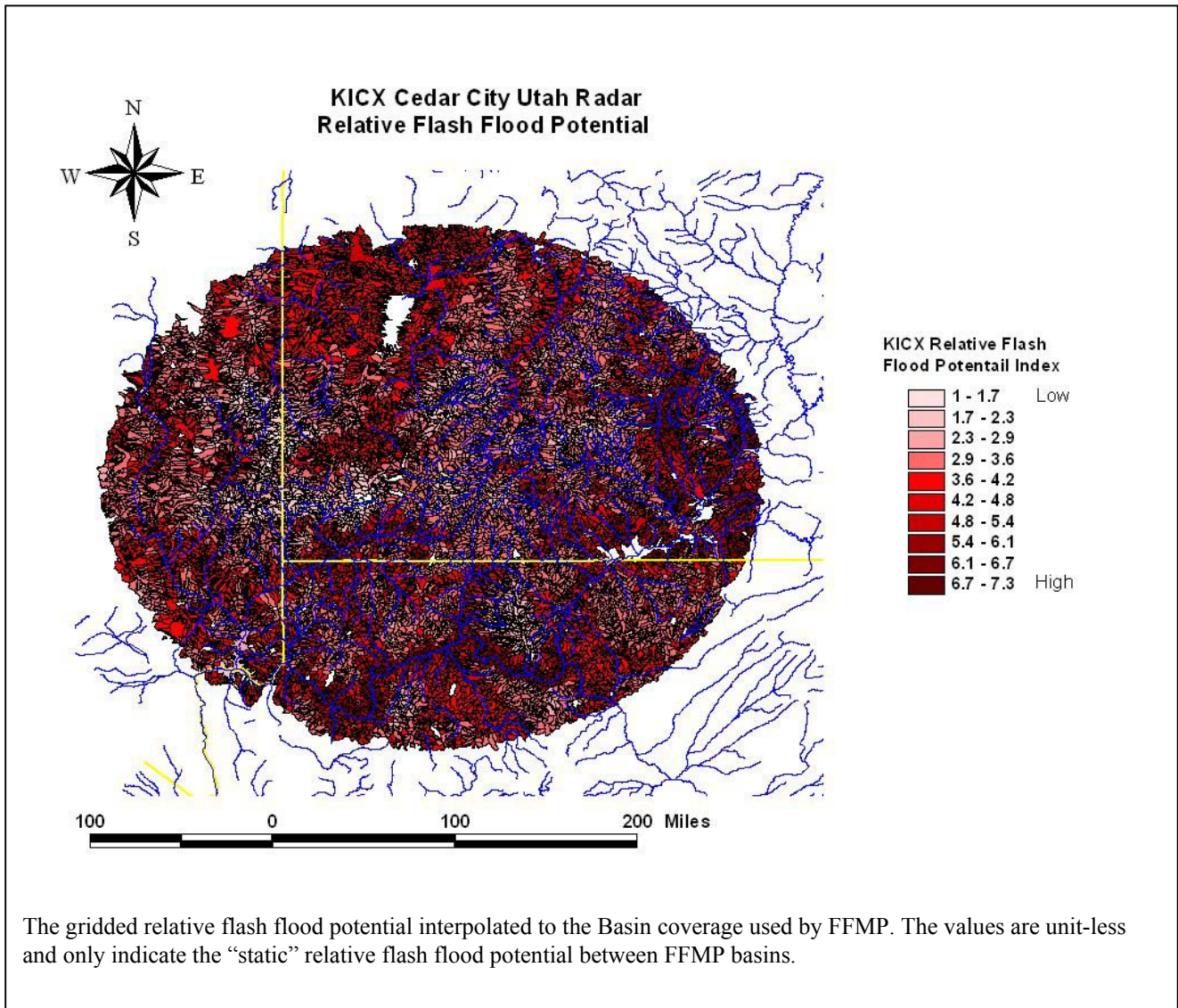
The U.S. Department of Agriculture (USDA), Forest Service, Southern Forest Experiment Station, Forest Inventory and Analysis (SO-FIA) unit prepared a forest density dataset using NOAA's Advanced Very High Resolution Radiometer (AVHRR) satellite data. The dataset expresses forest density as a percent of forest cover at a 1-kilometer resolution. The data does not differentiate between forest types, an important consideration for future analysis, but just provides a generalized look at forest density over the conterminous United States. Forest density is considered an important factor in determining hydrologic response due to the interception of precipitation by the canopy. A dense canopy would tend to reduce the flash flood threat. In the final analysis an attempt will be made to utilize a finer resolution forest cover dataset and one that differentiates between coniferous and deciduous forests where seasonal changes may play a factor.

INITIAL RESULTS:

While there is currently no quantitative measure regarding the performance of this product encouraging response was received from the Salt Lake City WFO when it was utilized during flash flood events in August 2003. According to forecasters at the WFO the product aided in successful decision making about disseminating warnings: “ During active thunderstorm and heightened flash flooding activity, forecasters utilized the FFP after analyzing radar data indicating rainfall intensities were great enough for flash flood genesis in certain areas. When deciding to issue a flash flood warning for a specific location, forecasters at the office referenced the FFP shape file to determine the flash flood potential of a specific geographic location. In the past, inferences had to be made regarding the area's terrain features and how they would affect the flash flood potential. The absence of detailed geographic information was a definite gap in the decision-making process for issuance of a flash flood warning. The Salt Lake City CWA encompasses areas with varied terrain and flash flood potential. This potential is based on multiple features such as slope, vegetation, soils, and land use. These variables are static and are little influenced by soil moisture conditions. The detailed geographic information was generally not widely known to the forecasters prior

to the flash flood potential GIS layer. The FFP has been a great success and further enhancement to the method will only assist the flash flood program.”





The results indicate the project should continue forward with a more robust analysis and further enhancements, including development of a process for producing and updating such a product. An acceptable static data layer of flash flood potential is viewed as a good starting point for the generation of finer resolution flash flood guidance that can be utilized by the FFMP software. The layers of observed flash flood event data could be most useful at this level, as it is important to ground in truth any flash flood guidance that is developed.

Additionally, the move from a somewhat static output to a more dynamic one is anticipated by including events such as forest fires, seasonal information such as vegetative state or existence of frozen ground, and daily or hourly precipitation to account for soil moisture. Output from the Multi-Precipitation Estimator (MPE) is currently being looked at as

a possible index of the soil moisture state at a finer resolution than existing hydrologic models can provide.

An approximate project timetable is laid out below:

PROJECT STATUS / TIMETABLE:

August 2003: Completed

- Initial static geophysical datasets acquired
- Initial analysis utilizing limited geophysical datasets complete
- Initial testing at Salt Lake City Weather Forecast Office

Autumn 2003 - Spring 2004:

- Collect and database observed flash flood event data
- Generate themes from observed flash flood event data
- Incorporate additional and finer resolution geophysical datasets
- Statistical analysis and layer weighting results
- Develop process for incorporating MPE (soil moisture & precipitation) output into analysis
- Develop process to obtain / include fire coverages into analysis

Spring 2004 – Summer 2004

- Testing of output at additional WFO's.
- Initial flash flood guidance values generated
- Process for updating, issuing, displaying product for WFO use.

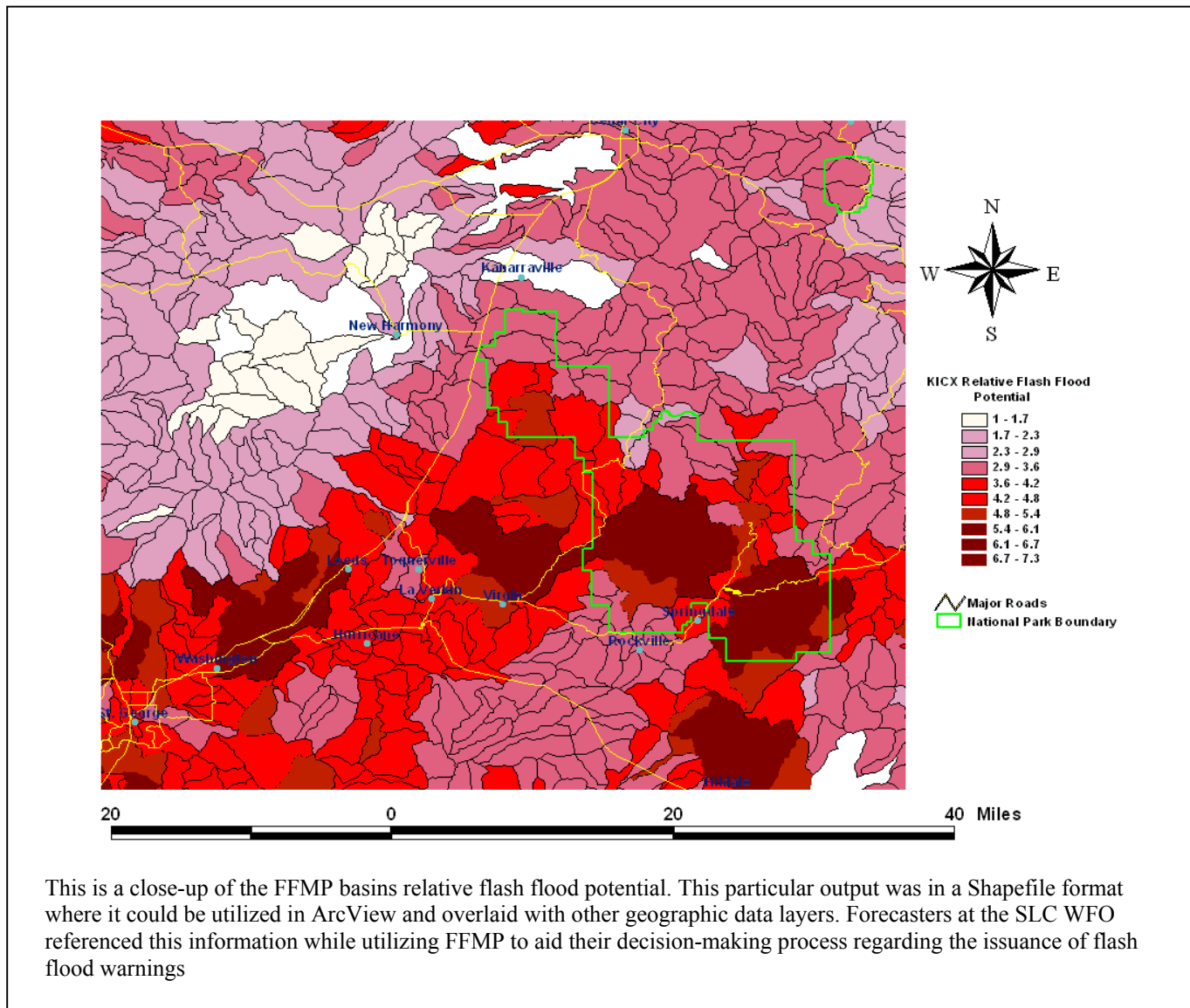
Summer 2004:

- Incorporation of dynamic layers (soil moisture, precipitation) completed
- Operational testing results analyzed
- Fine resolution southwest Utah study area completed
- Assess results and define future project path

The anticipated primary benefits include

- Dynamic flash flood potential tool for briefing as well as operational use
- Improved quality and increased spatial and temporal resolution flash flood guidance values
- Better input to the Flash Flood Monitoring and Prediction system
- Improved operational use of the FFMP due to improved FFG values
- Database design and procedure for documenting flash flood related events
- Recommendations for improvement of the NWS flash flood warning program
- Possible interface for viewing / manipulating flash flood potential information
- Demonstration of the value of incorporating GIS functionality into NWS programs

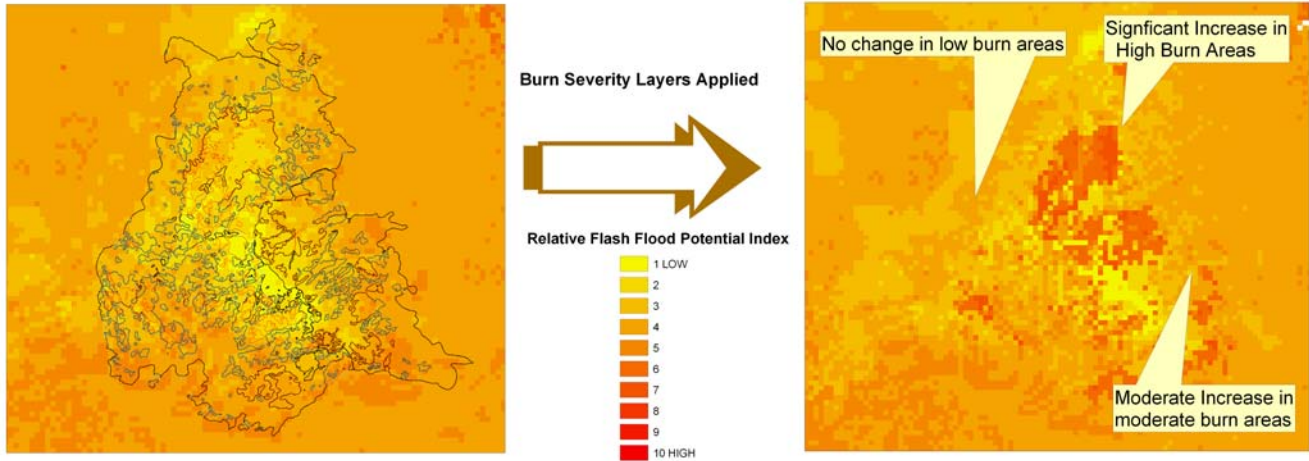
Additional graphics and discussion relating to this project are included in the next few pages:



This is a close-up of the FFMP basins relative flash flood potential. This particular output was in a Shapefile format where it could be utilized in ArcView and overlaid with other geographic data layers. Forecasters at the SLC WFO referenced this information while utilizing FFMP to aid their decision-making process regarding the issuance of flash flood warnings

Affect of Fire on Hydrologic Response and Gridded Relative Flash Flood Potential

* Preliminary Results *



Prepared by: Greg Smith - Colorado Basin River Forecast Center - NWS/NOAA

The occurrence of fire can have a significant affect on the flash flood potential of an area. In this example near Tucson Arizona fire burn severity information was obtained for the Oracle, Aspen, and Bullock fires. Burn severity categories of “High”, “Moderate”, and “Low” are associated with fire affects on vegetation and soil “baking”. These affects were applied to the forest density and soil type layers used in the analysis. For example “High” burn areas are defined as areas where all vegetation is blackened and deep soil heating has occurred, killing seeds, roots, and thus “baking” the soil. In these “High” burn areas the affect on the forest density layer was to reduce the forest density to zero percent. This in turn increased the hydrologic response and thus flash flood potential in these locations of the forest density layer since no forest canopy now exists to intercept rainfall. Similar applications were made to the soil type layer, rendering it impermeable in the “High” burn areas. A reduction in forest density was applied in “Moderate” burn areas and minor adjustment to the soil type to increase the hydrologic response. No change was made in “Low” burn areas.

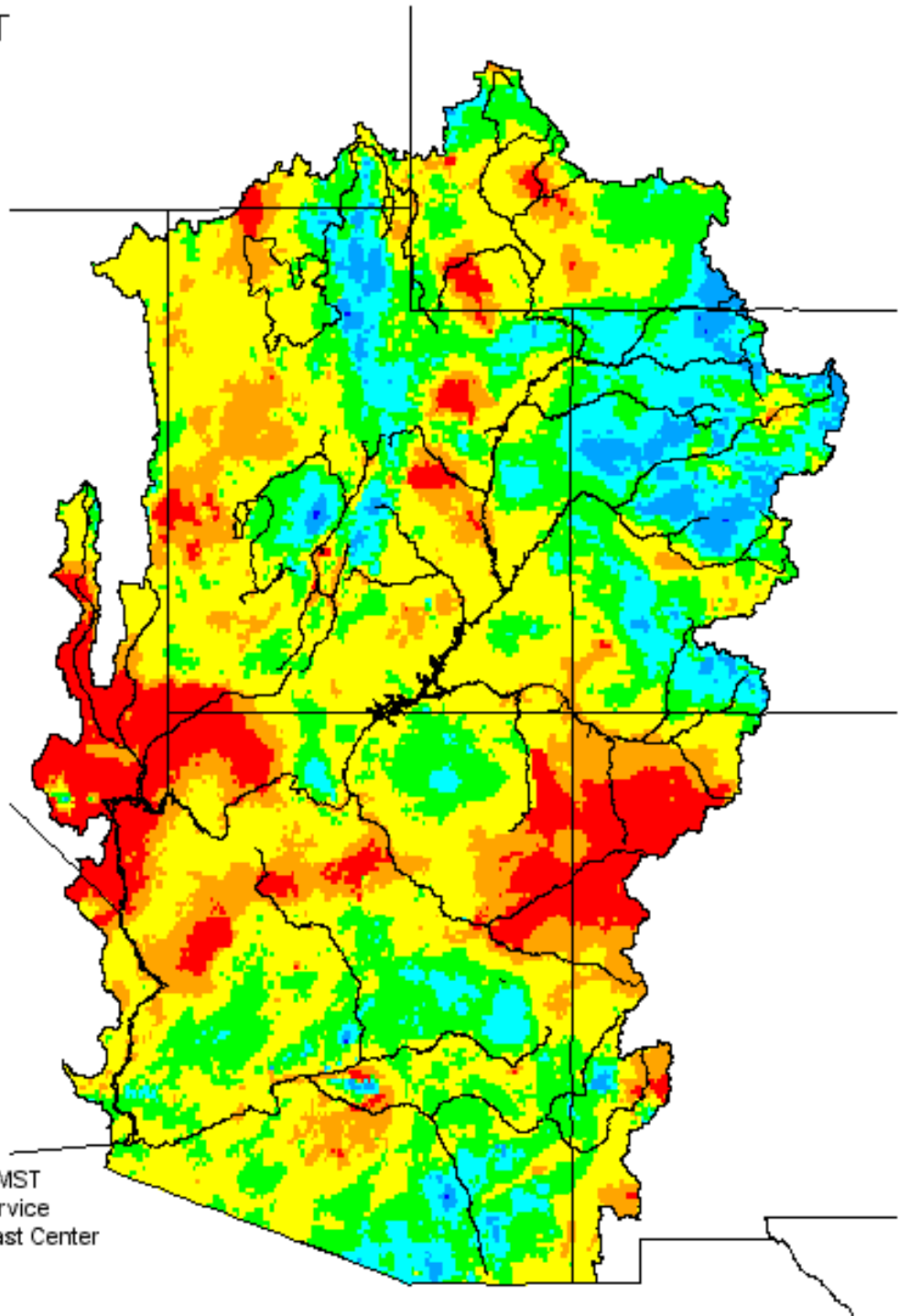
In this graphic the original gridded relative flash flood potential on the left is overlaid with fire burn severity boundaries. The results of ingesting the fire burn severity information into the analysis, as described above, is on the right side. As expected in “High” burn areas there was a significant increase in relative flash flood potential, a mixed increase in “Moderate” areas, and no change to the “Low” and no burn areas.

Antecedent Precipitation Index (API)

Colorado Basin River Forecast Center

11/12/2003 12 GMT

Legend



Prepared 05:12 11/13/2003 MST
NOAA, National Weather Service
Colorado Basin River Forecast Center
Salt Lake City, Utah
www.cbrfc.noaa.gov

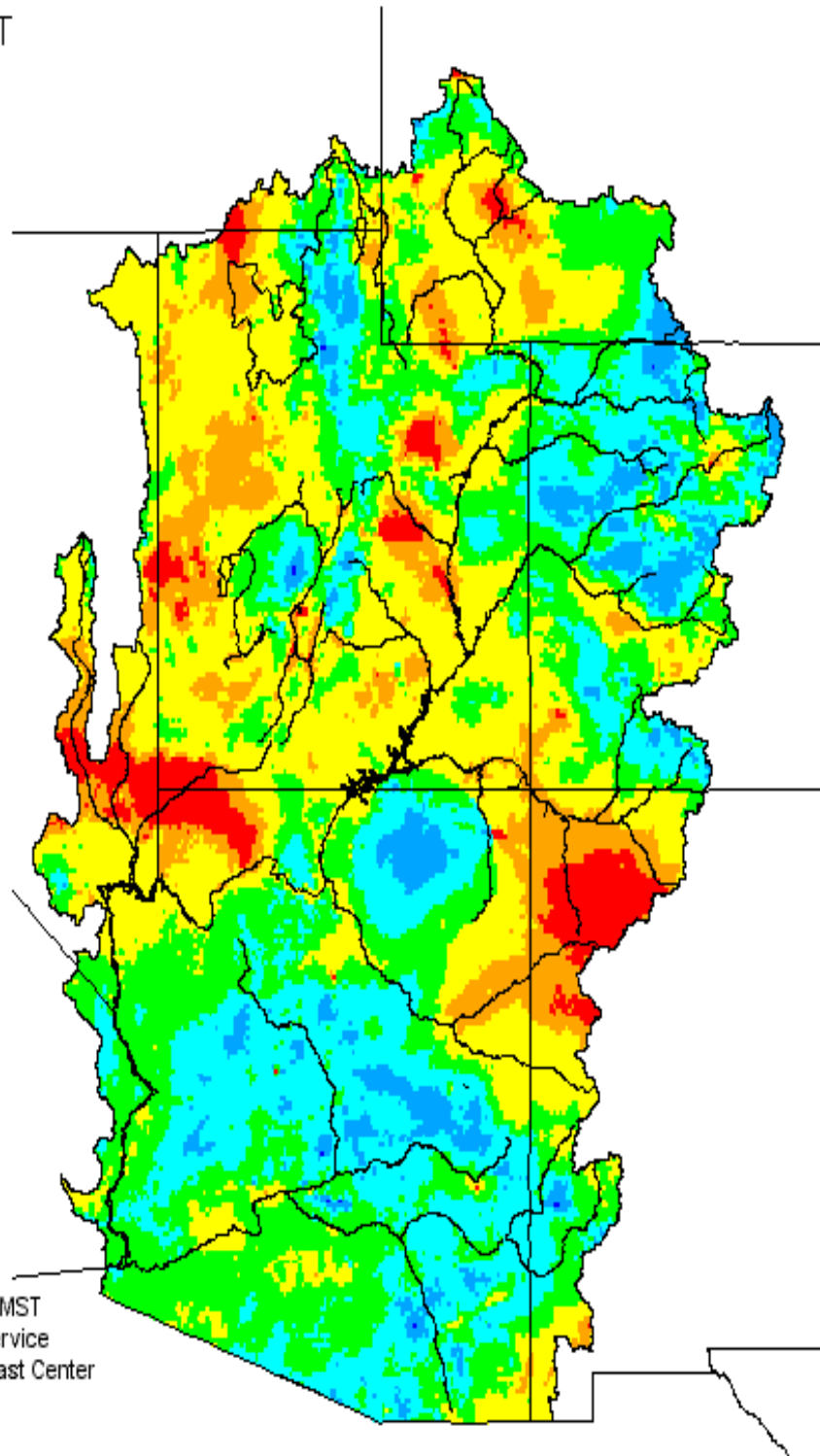
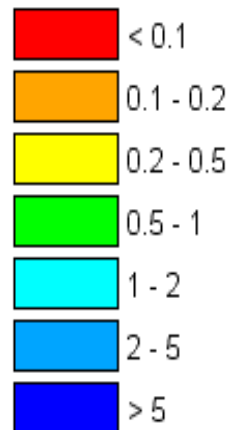
An experimental grid-cell Antecedent Precipitation Index (API) model running on gridded MPE output at the CBRFC may be a possible data layer to represent soil moisture. In this example the higher the index indicates a more recent precipitation episode and wetter soils.

Antecedent Precipitation Index (API)

Colorado Basin River Forecast Center

11/12/2003 20 GMT

Legend



Prepared 05:03 11/13/2003 MST
NOAA, National Weather Service
Colorado Basin River Forecast Center
Salt Lake City, Utah
www.cbrfc.noaa.gov

The gridded API output six hours later. Note the increase in the Index over central and northern Arizona as low pressure system moved into the area from the southwest.