CHAPTER 2

LITERATURE REVIEW

Researchers have been studying the effect of watershed subdivision on runoff for many decades. A variety of models have been applied for estimating surface runoff from watersheds, such as Soil and Water Analysis Tool (SWAT), Kinematic Runoff and Erosion Model (KINEROS), HEC-1, HEC-HMS, SWMM, NRCS TR20, and other codes written by researchers. Some of the studies used a synthetic approach, in which no data were used to evaluate model parameters, similar to the general use of models in a design setting. Other researchers used measurements of rainfall and runoff to evaluate some of the model parameters.

2.1. Literature Review

Hromadka (1986) developed an application manual for hydrologic design for San Bernardino County. In that manual, mechanics were developed based on the Los Angeles hydrograph method. In Hromadka's notes on application of the methods presented in the manual, it states "Arbitrary subdivision of the watershed into subareas should generally be avoided." The fact is that an increase in watershed subdivision does not necessarily increase the modelling "accuracy" but rather transfers the model's reliability from the valiated unit hydrograph and lag relationships to the unknown reliability of the subsequent flow routing submodels used to link together the divided subareas.

Wood et al. (1988) examined the relation between watershed scale and watershed runoff on the 6.5 mi^2 Coweeta River experimental watershed located in North Carolina.

Wood et al. divided the Coweeta River watershed into 3, 19, 39, and 87 subwatersheds. TOPMODEL (Beven and Kirkby, 1979) was used as the simulation engine, with watershed topography from a 30-meter digital elevation model and other model parameters and variables randomly sampled from distributions. Wood et al. (1988) reported that for a drainage area less than 0.4 mi^2, subwatershed response was highly variable. However, at scales greater than about 0.4 mi^2, further aggregation of subwatersheds had little impact of simulated results. It is important to observe, however, that the interest of Wood et al.'s (1988) study was to determine what they termed the representative elemental area (REA) for the Coweeta River watershed (if such a concept exists) but not to evaluate the impact of watershed subdivision on runoff hydrographs directly. Therefore, whereas the Wood et al.'s (1988) study is interesting, it does not directly apply to the current research problem.

Norris and Haan (1993) used a synthetic method to study the impact of watershed subdivision on hydrographs estimated using the Natural Resources Conservation Service (NRCS, then SCS) unit hydrograph procedure, as implemented in HEC-1. The Little Washita watershed near Chickasha, Oklahoma, which has a drainage area of about 59 mi^2, was used as the study watershed. The watershed was subdivided into 2, 5, 10, and 15 sub-watersheds, as well as treating the watershed as a whole. A balanced hyetograph was used to drive hydrograph computations, with duration of 24 hours and a return period of 50 years. Results from Norris and Haan (1993) were that watershed subdivision had a pronounced impact on the estimate of peak flow from the watershed. The change from a single watershed to 5 sub-basins resulted in a net increase in peak discharge of about 30 percent. Use of 15 sub-basins increased the difference from a single watershed to about

40 percent. However, the impact of subdivision diminished with further increase of sub-basins. Based on their synthetic study (no observed hydrographs were used to assess model performance), Norris and Haan (1993) concluded that the number of sub-basins for simulating watershed response should not vary through the course of a hydrologic study. If the watershed discretization scheme is changed during a hydrologic study, then the impact of changes in land-use (or other changes) may easily be masked by differences arising from the subdivision scheme. It was not clear from the report whether any assessment was made concerning which level of subdivision, if any, was most appropriate for reproduction of watershed hydrographs.

Sasowsky and Gardner (1991) applied the SPUR model to a 56 mi^2 sub-watershed of the Walnut Gulch experimental watershed in Arizona. The SPUR model operates on a daily time step and was designed for rangeland watersheds. A GIS procedure was used for watershed subdivision based on stream order, an approach not used by other researchers. The study watershed was divided into 3, 37, and 66 contributing sub-areas for modeling purposes. The model was calibrated against measured rainfall-runoff sequences. Sasowsky and Gardner (1991) used the "efficiency" statistic (Nash and Sutcliffe, 1970) to assess model performance on a monthly basis, that is, monthly runoff volumes were used to measure model accuracy. An efficiency greater than zero indicates that the model is a better predictor of observed runoff volumes than the mean runoff. In their study, Sasowsky and Gardner calibrated each "model" (instance of subdivision) to measured rainfall-runoff events, and then noticed that the curve number, in particular, decreased with increasing subdivision. Sasowsky and Gardner (1991) reported that simulations were sensitive to the degree of watershed subdivision. Lower curve numbers yield better results for coarser subdivision, and higher curves number yield better results for finer subdivision.

Michaud and Sorooshian (1994) applied three different model formulations to simulate the rainfall-runoff process for Walnut Creek Gulch in Arizona. The models used KINEROS-complex, KINEROS-simple, and the curve-number approaches to simulate the rainfall-runoff process. The authors reported that KINEROS was not able to produce reasonable solutions comparable to observations. In addition, the results from application of the curve number approach also did not compare well with observations. An earlier study by Loague and Freeze (1985) also report mixed results from their hydrological simulations for a set of watersheds with three very different modeling approaches. In fact, their recommendation was that simpler models appear to perform better than more complex approaches.

Mamillapalli et al. (1996) conducted a study of the impact of watershed scale on hydrologic output. As other studies reported in the journal literature, the NRCS Soil and Water Analysis Tool (SWAT) model was used with a use of Geographic Information Systems procedure to develop the required input streams. Mamillapalli et al. (1996) concluded that, in general, increase of the level of discretization and the number of soil and land use combinations resulted in an increase of the level of accuracy. There is a level of discretization beyond which the accuracy cannot be further improved. It suggests that more detailed simulation may not always lead to better results.

Bingner et al. (1997) applied the SWAT to the Goodwin Creek watershed in northern Mississippi. SWAT uses the uniform soil-loss equation and its variants to predict sediment yield from the study watershed. Their objective was to determine the degree of watershed subdivision required to achieve reasonable results in predicting watershed runoff and sediment yield. Watershed drainage area of the Goodwin Creek Watershed was about 8.2 mi^2. A suite of subdivisions was generated with elemental areas that ranged from a maximum of 60 acres to a minimum of 4 acres was used to model runoff and sediment yield. The authors concluded that model predicted runoff volume was not heavily dependent on the degree of watershed subdivision, however, the model predicted sediment yield did depend on the degree of watershed subdivision.

FitzHugh and Mackay (2000) conducted a study similar to Bingner et al. (1997) for the Pheasant Branch watershed in Dane County, Wisconsin. FitzHugh and Mackay (2000) also reported that model predicted watershed runoff was not heavily dependent on the degree of subdivision (also using the SWAT model), but the predicted sediment yield dependened on the degree of subdivision.

Hernandez et al. (2002) presented results from use of the Automated Geospatial Watershed Assessment (AGWA) tool. The purpose of the software tool is to assist the development of input parameter sets for the KINEROS and SWAT watershed models. The authors did not specifically test the impact of watershed subdivision on model performance. However, the authors reported that results from the SWAT model differed substantially from observations for the two watersheds tested.

Jha (2002) examined the relation between watershed subdivision and water-quality model results. He applied the SWAT model to four Iowa watersheds. Jha (2002) reported that streamflow was not significantly affected by a decrease in sub-watershed scale, where model predicted results stabilized with about ten subdivisions. However, model predicted sediment yields were more dependent on sub-watershed scale, requiring 40-50 divisions to stabilize model predicted sediment yield.

Tripathi et al. (2006) applied the SWAT model to the 35 mi^2 Nagwan watershed in eastern India. The watershed was subdivided into 12 and 22 sub-watersheds, as well as treating the entire watershed as a whole. Four years of record were used to carry out the model simulations. The model was calibrated to produce best estimates of model parameters. Tripathi et al. (2006) reported little difference in watershed runoff for different number of sub-watersheds used. However, they observed variations in other components of the hydrologic cycle. Estimates of evapotransipiration increased with increase of numbers of sub-watersheds.

2.2. Implications

The literature reviews described above have contributed to the understanding of how basin scale affects the hydrologic response of a watershed. An important note is that a number of papers referred to the insensitivity of runoff volume to the degree of watershed subdivision. It is important to realize that the principal input to the watershed, precipitation, is typically measured at point gages, which measure the rainfall field over an eight-inch diameter (if a standard rain gauge is used). In contrast, measurements from a stream gage reflect the integrated response of the watershed to the rainfall field and all of the processes that act as rainfall become runoff. The two phenomena and their measurements are inherently different.

Furthermore, it is not clear from the literatures how sets of parameters should be assigned to sub-watershed units. It seems reasonable to assume that each sub-watershed should have a unique parameter set, but even with data for calibration, it is nearly impossible to determine a unique parameter set for each sub-watershed as there is not enough information contained in a rainfall-runoff series. This was the message of Gupta and Sorooshian (1983) and others. It seems overly optimistic to believe that assigning a parameter set to a sub-watershed without specific data concerning watershed response characteristics will result in better estimates than using a lumped approach with fewer parameters. An important note is in all of the previous studies, the simulated runoff hydrograph of a single watershed (with no subdivision) was compared to that from modeling all sub-watersheds.

Synthesis of these and other references suggests the following approaches to model watershed subdivision (in the absence of obvious natural features and flow regulation structures):

1. An iso-characteristic approach, where each sub-basin has about the same physical characteristic (area, length, etc.). Drainage area ratios would fall into this approach. The characteristics may be subtle—one paper presented at the 2006 American Geophysical Union used contiguous areas of similar slope to define watershed subareas (McGuire, 2006). Although watershed subdivision was not the focus of the particular paper, nevertheless the idea appeared sound. The San Bernardino (1986) manual seems to imply a range of area ratios that are acceptable for preserving sufficient model believability, again a spatial characteristic based concept.

2. An iso-temporal approach, where each sub-watershed is selected to have about the same characteristic response time, that is, t_c. This particular approach may have great value in concurrent flooding (concurrent arrival times of flood waves). A challenge of

this conceptualization is that lumped systems will necessarily be replaced by routed systems and any gain in certainty by using smaller sub-basins may be more than offset by increased uncertainty caused by routing. Despite this important criticism, TxDOT researchers still feel this is a line of investigation that needs consideration. At some scales of high subdivision, the entire runoff process that is currently explained using unit hydrographs becomes entirely replaced by hydraulic elements; interestingly the hydrographs "look" like convolved unit hydrographs so the accepted connection between the physical processes in a distributed hydraulic model and the lumped hydrologic model are well manifest in this sense.

3. A scoring approach: Scoring is similar to the above concepts, except a set of characteristicsis assigned a score; similar scores that are geographically connected are selected as watersheds. The scoring approach could admit descriptors not easily quantified numerically. For example the use of binary variables in TXDOT Research Projects 0–4193 and 0–4696 to account for the effect of developed/undeveloped and rocky/non-rocky are arguably scoring approaches.

4. A gage-defined approach where the locations of existing gages are used to subdivide a watershed — not necessarily a modeling tool, but a good comparative tool. An extension would be to locate good gage locations based on measuring requirements and use these locations to divide a watershed.

5. Stream-order/bifurcation approach. Watersheds are subdivided based on branches in the dendritic drainage network. Several papers at 2006 American Geophysical Union used this approach to divide research watersheds for water quality and nutrient transport studies.

6. The ad hoc approach is a research-only approach where basins would be defined at random subareas, perhaps preserving some minimum measure. These random subareas would then be used to simulate runoff and these results compared to observations on the same watershed. Patterns that best agree with observations would be saved and analyzed to determine what physical features are common to “good” subdivisions (i.e. iso-temporal, iso-characteristic, etc.)

This research examines an iso-characteristic approach based on sub-basin areas. Area is the principal scale measure common in all hydrologic studies; it is usually available. The report by Rousel and others (2006) illustrated that different analysts, and diferrent methods (manual, automated) compute areas to within 10%; thus, area represents a reasonably consistent metric.