National Phosphorus Runoff Project: Hydrologic Evaluation of Runoff Boxes

M.S. Srinivasan, P.J.A. Kleinman, and W.J. Gburek

USDA-ARS, Pasture Systems and Watershed Management Research Unit

University Park, PA 16802

Background

The National Phosphorus Runoff Project (NPRP) was implemented in response to concerns over non-point P losses, with a primary objective of coordinating environmental P research. As a part of this project, the benchmark soils component seeks to quantify soil P-runoff P relationships. To achieve this, rainfall-runoff simulations are being conducted, using runoff boxes, at various locations across the country.

This study examines the hydrology component of rainfall-runoff simulations. The goals of the study are to characterize the hydrology observed at the scale of the runoff simulations (1.5 - 2 m^2 plots) and explore approaches to scale up the results from the plot scale to landscape- and watershed-scales. The following specific objectives are being addressed:

1. Identify and characterize the dominant hydrologic variables controlling runoff and P transport from the runoff boxes.
2. Assess the importance of hydrologic variability to runoff P concentrations in runoff boxes under infiltration excess and saturation excess runoff conditions.
3. Evaluate runoff box hydrology;
    a) within individual runoff boxes (temporal differences in soil moisture and spatial and temporal differences in soil infiltration properties),
    b) between runoff boxes in the same soil (spatial variability in soil moisture and soil physical properties affecting rain infiltration; variations in landscape positions for the same soil), and
    c) between runoff boxes across different soils (at various spatial and temporal scales).
4. Investigate and establish the significance of "time to runoff" in P availability for transport from the runoff boxes.
5. Recommend changes in the benchmark soils protocol to improve the strength of project conclusions and reduce the resources/time required to conduct rainfall simulations.

Research approach

During storm events, surface runoff transports sediment and sediment-bound pollutants to water bodies. Rainfall intensity and depth, soil infiltration capacity, depth to the water table, and landscape position are some of the factors that influence the occurrence and dynamics of runoff generation. Surface runoff can be either infiltration excess or saturation excess (Figure 1). Infiltration excess runoff occurs when the incoming rainfall intensity exceeds the soil's infiltration capacity. Saturation excess runoff occurs when the water table rises up to the surface and the soil's storage capacity is exceeded. Saturation excess runoff includes both rainfall and soil water, while infiltration excess runoff is predominantly rainfall water. Saturation excess runoff is commonly observed in the near-stream locations, because of the proximity to the water table. In general, however, NPRP runoff simulations are conducted under infiltration excess conditions because of the high intensity rainfall applied and location of experiments (away from streams).

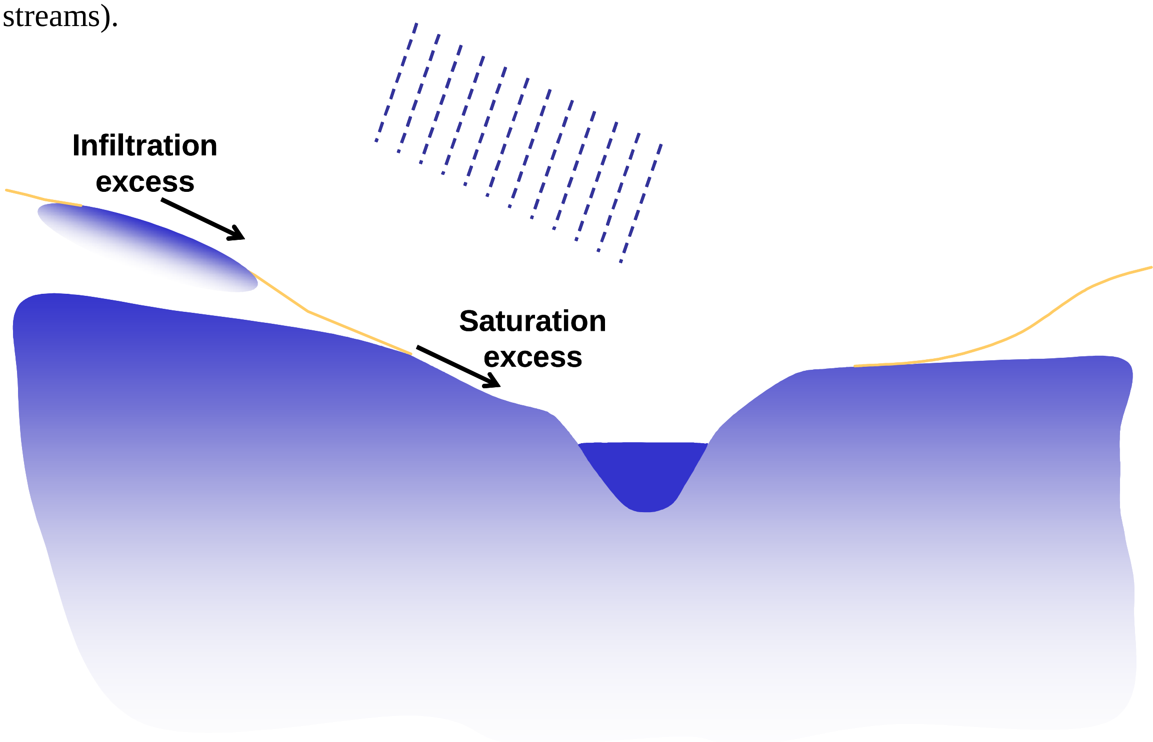

Figure 1. Occurrence of infiltration excess and saturation excess surface runoff.

Research findings

1. Time to runoff:

During the rainfall-runoff experiments, the objective is to collect 30-minute of runoff data from the runoff boxes. Thus, the length of rainfall simulation is the sum of the time it takes to initiate runoff and the 30 minutes of runoff time. Time to runoff changes with soil properties and landscape positions. So, the total depth of rainfall applied changes with soil. Even for a given soil and location, the time to runoff can change with individual experiments, depending on the runoff generation process and soil moisture levels.

Figure 2 illustrates the general relationships between the time to runoff and rainfall depth and return period. For example, a smaller time to runoff would mean a smaller rainfall event that is expected to occur frequently. As the size of the rainfall event simulated becomes larger, the frequency of occurrence of such rainfall event in reality becomes infrequent. Under such conditions, the soil P-runoff P relationships appropriate for frequently occurring events becomes invalid. Relationships developed based on shorter return period rainfall events may reflect the P transport behavior of the watershed for the majority of rainfall events. However, a "rare" event has greater potential to transport P over longer distances because of larger runoff volumes and rates. Thus, the time to runoff is imperative defining and developing the soil P-runoff P relationships.

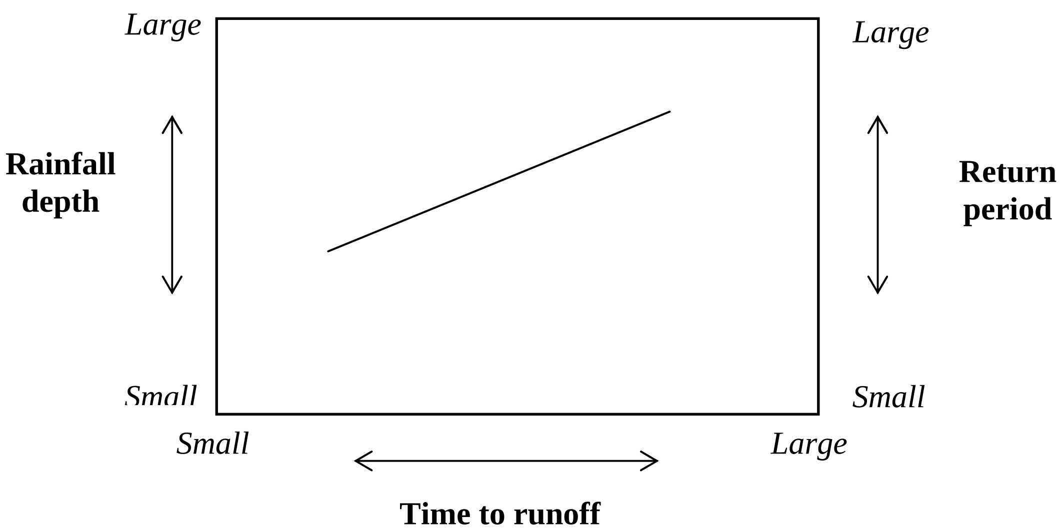

Figure 2. Relationship between time to runoff and rainfall depth and return period.

The hydrological processes occurring during time to runoff are very important in relating the P transport to runoff volumes from the runoff boxes. A longer time to runoff means more water infiltrating and a higher probability of the available P leaching to the subsurface zones, leaving less P available at the surface for runoff. Thus, a rainfall event that has a shorter time to runoff has a higher probability of moving more P by surface runoff.

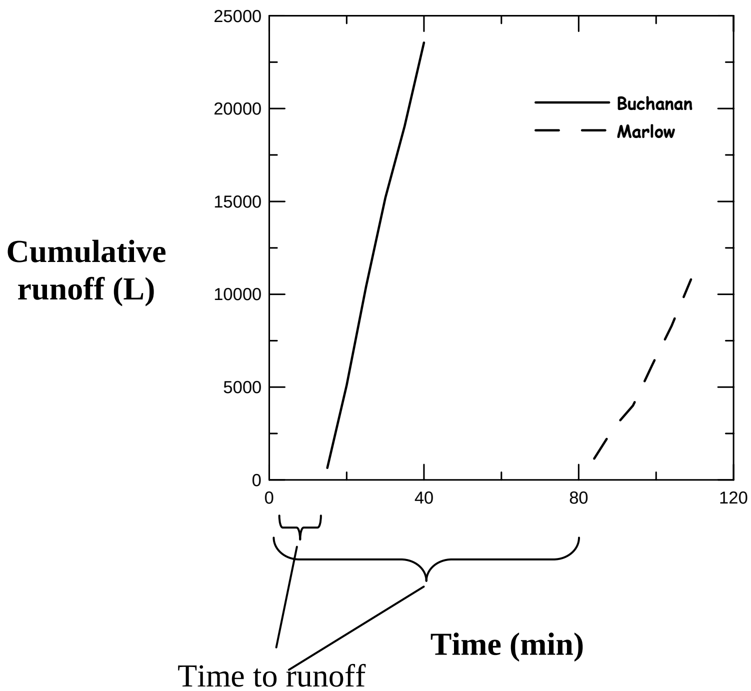

Figure 3. Time to runoff vs. volume of runoff for two soils with different infiltration capacities.

Figure 3 shows the relationship between the time and cumulative runoff volumes for two soils, Buchanan (silty) and Marlow (sandy), with diverse infiltration properties during a simulation. Times to runoff for these two soils were 18 and 81 minutes, respectively. A total of 2.7 (2-yr rainfall return period) and 12.4 cm (> 10-yr rainfall return period) of rainfall were applied on these two soils to generate 30-minutes of runoff. Buchanan produced 24,000 L of surface runoff, while Marlow produced 10,200 L during that same time. It should also be noted that these two soils were infiltrating, even as they were producing runoff at the outlet of the box.

<u>2. Effect of seasons:</u>

Simulations were conducted at the same locations during two different seasons, spring and summer, on Buchanan soil. Figure 4 shows the runoff volumes and P concentrations recorded during these simulations. Data from two different sites, 1 and 2, within the same locations are shown to validate the seasonal trends. The following specific observations were made:

- runoff volumes increased on consecutive days due to increasing initial soil moisture
- runoff P and particulate P were negatively correlated with runoff volumes for both seasons
- runoff P concentrations were lower in the spring, and, generally appeared to decline with increased flow
- particulate P concentrations did not vary seasonally, but did exhibit the same pattern as runoff P concentrations
- though P concentrations in runoff were greater in summer than spring, P loads in runoff were greater in spring
- greater proportion of PP loss occurred in spring than in summer

Ongoing research

Based on field observations and rainfall-runoff data analyses from the National P project, we identified the following for further investigation:

- Cumulative runoff volumes in spring were 2.5 to 4 times larger than that of summer.
    - Do seasonal variations in soil moisture affect NPRP results?
    - Are the mechanisms of runoff generation same in spring and summer?
- Times to runoff were comparable for both wet (spring) and dry (summer) seasons.
    - Do initial soil moisture conditions have any influence on times to runoff?
    - Does each soil have a “characteristic” time to runoff value that is unaffected by seasons and initial moisture conditions?
- During rainfall-runoff simulations, the rainfall to runoff conversion is not 100 percent even during the periods of runoff at the outlet.
    - How does the continued infiltration during the periods of surface runoff influence P-availability for surface transport?

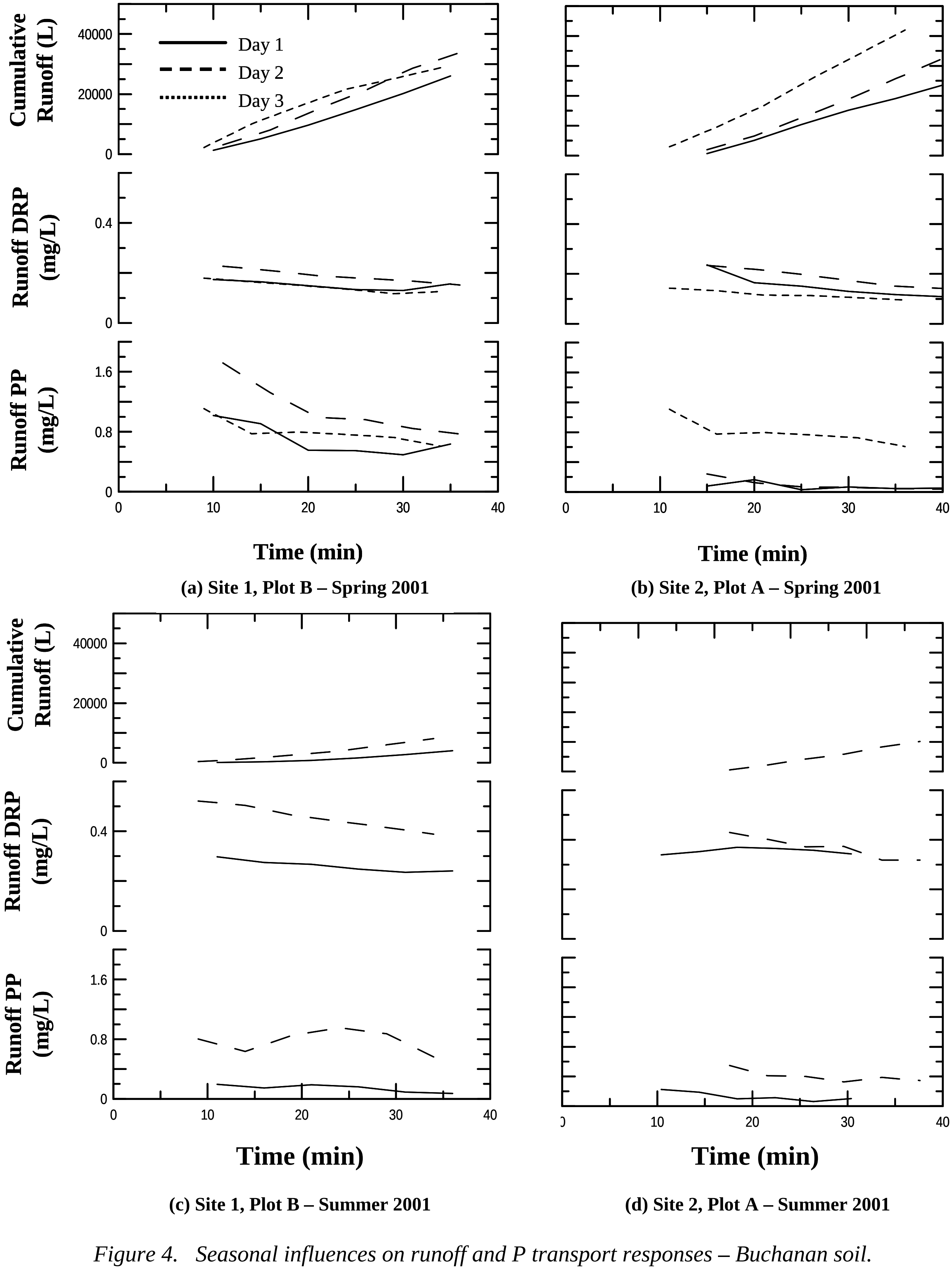

Figure 4. Seasonal influences on runoff and P transport responses – Buchanan soil.

- Based upon hydrology and chemistry, the second and third days of NPRP rainfall-runoff experiments are similar.
    - From a practical perspective, is the third day necessary?
- Soil P-runoff P relationships are derived for individual soils.
    - How do we scale this relationship to represent landscape- and watershed-scale water quality studies?

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References

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