CRITICAL AREAS AND WATER QUALITY IN AN AGRICULTURAL CATCHMENT LOCATED IN THE CHESAPEAKE BASIN

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One of the main issues facing catchment planners is how land use and its management at the small scale ties to the quality of catchment outflows. In humid-climate, hill-land catchments, relatively small and well-defined areas typically contribute much of the nonpoint source water, sediment, phosphorus (P), and nitrogen (N) exported in outflow. From a prediction, management, and control perspective, it is important that we recognize and develop the concepts, sampling protocols, and modeling tools to delineate and assess the impacts of these critical areas. These are the highest priority areas for treatment and remediation within the catchment.

Based on up to 30 years of experimental and monitoring data, the streamflow, N, and P exported from a typical agricultural hill-land catchment in east-central Pennsylvania and the Chesapeake Basin is examined in terms of critical source areas and their delineation. The 7.4 km^2 WE-38 catchment is 35% deciduous forest (mostly dominating the ridges which define the catchment boundary), and 65% agriculture (mostly dominating the valley as cropland with some livestock production). Geology, topography, and soils typify the unglaciated, intensely folded, and faulted Appalachian highlands. Bedrock is interbedded sandstone, siltstone, and shales underlaying residual, colluvial, and alluvial loam-silt loam soils. The climate is humid and temperate with streamflow dominated by subsurface discharge (80%). The approximate hydrologic budget is: 1200 mm precipitation; 600 mm evapotranspiration; 600 mm streamflow. Snow melt is typically a minor source of surface runoff. The subsurface transit time from land source to stream is very rapid (1-3 years) with most subsurface return flow to streams occurring at subcatchment (km^2) scales.

Variable source area (VSA) hydrology controls surface runoff in this catchment. It depends on the moisture status of the catchment, particularly on the position of the ground water table intersection with the land surface. VSA runoff is dominated by saturation overland flow and a rapidly responding subsurface flow. The VSA is dynamic, expanding and contracting rapidly during a storm. Typically, the VSA is located near streams and occupies a relatively small percentage (<10%) of the catchment. Ironically, VSA soils exhibit high infiltration rates when not saturated. The remainder of the catchment provides little surface runoff, the dominant processes being infiltration and ground water recharge. As a result, the catchment can be predictably divided on a hydrologic basis into surface runoff and ground water recharge source areas. The VSA occurrence, processes, modeling, and validations have been determined implicitly (hydrologic response, electrical conductivity, acid-base neutralization) at the catchment and subcatchment scale, and explicitly at the smaller scale (hydrologic cross-sections, geochemical and stable isotope tracing, surface runoff detectors). Erosion can be major on an incidental basis, but typically is less than 1 mg l^{-1} even during major runoff events. In any case, the critical source area for both erosion and surface runoff is the VSA.

Catchment export of P is determined by hydrologic controls and P content in soil. On several WE-38 subcatchments, we have found soil test P levels (as Bray or Mehlich) to be highly variable spatially (10 to 700 mg kg^{-1}). Levels are generally distributed according to field boundaries within the catchment as a function of land use and fertilizer or animal manure application. In our upland catchments, the export of soil test P and bioavailable P (Fe-resin, NaOH-extractable) is more closely related to the high P soils distributed near the stream than those throughout the whole catchment.

A hydrologically-validated P simulation method applied to a WE-38 subcatchment, using experimental hydrologic and P input, showed nearly all surface runoff to be generated from <15% of the land area, most bioavailable P exported to be generated from about 5-10% of the subcatchment, and about 20-30% of this P originating from about 1% of the subcatchment. The bioavailable P exported was about one-half sediment associated and one-half dissolved P, which corresponds to observed storm-based results. This approach, based on hydrologic simulations developed previously to delineate seep zones and design storm boundaries for flood control and animal waste placement, provides a defensible basis for sampling, prediction, and remediation.

In contrast to P source areas, which are hydrologically concentrated and streamside, the land source of exported N is much more diffuse and distant from the stream. Most N is exported as nitrate (NO_3) in subsurface return flow, originating from the other 90% of the catchment. While hydrologic delineation of ground water recharge source areas remains important, the N-use based delineations are more important, particularly where N applied plus available soil N exceeds crop uptake. Also, the flow pathway and travel times between these N-excess source areas and the stream become more critical in determining export. One major reason is NO_3, unlike P, is very mobile once formed. Another major reason is NO_3 does not behave conservatively as does P, but can be supplied by N fixation or removed by denitrification en route, depending on the environment of the major flow pathway. Thus, delineation of N-excess source areas and the major flow pathways with characterization of flow pathway environment are an important part of the simulation approach. NO_3 sources routed through anoxic ground waters, wetlands, or active riparian zones may be largely diminished en route to the stream.

Experimental work done on WE-38 shows that a simple catchment N budget approach, mostly based on farm N use and budget records, can delineate N excess use areas, and approximate the long-term N export from the catchment. It also showed that N management information obtained directly from farmers is much superior to only using land use information for determining N-excess source areas. N sinks, such as anoxic ground waters and forested riparian zones, were found to be important locally, but not to affect the total N exported from the catchment. One major reason is that most NO_3 discharges to the stream during winter and early spring when biological activity is minimal. Although position of the N-excess source area within the catchment greatly impacted the NO_3 concentration distribution within ground water, it did not change NO_3 export. Based on data from this catchment, a budget approach using surveyed information was shown to reasonably simulate N export in streamflow.

Most of the surface runoff, erosion, and P export from this catchment occurs from areas near the stream. About 90% of the bioavailable P exported in outflow from this catchment was generated in storm flow from stream riparian zones. Annually, most of this export occurred during the largest 5-7 storms. In contrast, nearly all the exported NO_3 originated as subsurface flow entering the soil or ground water some distance from the stream, and is mostly exported in nonstorm flow during winter and spring. By combining a knowledge of land use and management, hydrological processes, and position in the catchment to define critical source areas, the major source areas for P and N are identifiable and predictable.

References

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