

Establishing Riparian Vegetation Through Use of a Self-Cleaning Siphon System

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Abstract—Storm water or overland flow can be captured and injected into a soil trench or infiltration gallery attached to a siphon and emplaced adjacent to a stream or arroyo bank. This injected soil water can be used by stream side vegetation for wildlife habitat, bank stabilization or other purposes. The siphon system has three hydrologically-distinct flow regimes: (1) infiltrating flow, (2) cycling outflow, and (3) constant outflow. These flow regimes are dependent upon infiltration gallery design, soil hydraulic conductivity, and rainfall intensity. The design is low-cost and is predicted to be self-cleaning and low maintenance.

Soil functions as a plant growth medium, a regulator and partitioner of water flow, and as a buffer of environmental change. A National Research Council report (1993) reviews soil's role in the hydrologic cycle. Rainfall in terrestrial ecosystems falls on the soil surface where it either infiltrates the soil or moves across the soil surface into streams or lakes. The condition of the soil surface determines whether rainfall infiltrates or runs off. If it infiltrates the soil, it may be stored and later taken up by plants, move into ground waters, or move laterally through the earth, appearing later in springs or seeps. This partitioning of rainfall between infiltration and run-off determines whether a storm results in a replenishing rain or a damaging flood. The movement of water through soils to streams, lakes, and ground water is an essential component of recharge and base flow in the hydrological cycle (Stephens, 1995).

Current engineering practices in the Southwest often reduce infiltration and increase runoff by collecting and conveying storm water quickly and efficiently for ultimate discharge to an existing surface water course. The goals of this management strategy are to reduce hazards to the public and minimize property damage. Although this strategy maximizes the objectives in terms of safety and risk reduction, it prevents the beneficial use of storm waters through recharge. Conveyance times are minimized while flow rates are maximized to remove it from highways, streets and public areas. With concern growing over the availability of water supplies for public and industrial use, alternative uses of storm water must be considered, and if practical, implemented. One such strategy is to recharge

vadose zone aquifers through the use of a sub-surface siphon system to increase recharge and storage (Ankeny and Sumrall, 1998).

The operational objective is to maximize long term water recharge in an infiltration gallery while minimizing long term maintenance requirements. The objectives of the analysis for this structure is multi-fold and includes: (1) determination of hydraulic parameters governing system operation, (2) quantification of water velocities within the system needed to entrain sediment carried into the system, and (3) quantification of the recharge potential of the system through various storm events.

Physical Design

The siphon system is schematically illustrated in figure 1. The siphon behaves as a standard siphon and cycles (drains) as the water level exceeds the *critical head* in the siphon. After the drainage cycle, the siphon breaks and the siphon reservoir refills. The siphon reservoir consists of the *drainage pipe*, the large air-filled pores in the *gravel backfill*, and the air-filled pore space in the surrounding soil (fig. 2). As the siphon refills, water infiltrates into and is redistributed by the soil.

The siphon system consists of a perforated pipe buried in a gravel-filled trench (fig. 2). The perforated pipe is bedded at a nominal slope toward the discharge with an ascending limb angled upward at the terminal end. This upward angled non-perforated portion is formed into a radius of approximately 180 degrees forming an inverted P-trap. This radius is directed downward for discharge. The system operates passively by capturing a point source flow such as a storm drain inlet or other concentrated flow source.

When the siphon cycles, water velocity in the drainage pipe increases, silt in the overlying gravel is back flushed, and water in the drainage pipe reaches entrainment velocity for silt and clay deposited during the infiltration phase of the cycle. Thus, a siphon can take a linear input of water, sediment, and potential energy and turn it into a nonlinear system that retains a large fraction of the water and potential energy while discharging the sediment and part of the water.

Water Flow

TOUGH-2, a multiphase, multidimensional flow and transport code (Pruess 1991) was used to model trench infiltration across a range of soil types and hydraulic heads. Output from this model was used as input for a spreadsheet application to model the infiltration gallery/siphon system.

In: Finch, Deborah M.; Whitney, Jeffrey C.; Kelly, Jeffrey F.; Loftin, Samuel R. 1999. Rio Grande ecosystems: linking land, water, and people. Toward a sustainable future for the Middle Rio Grande Basin. 1998 June 2-5; Albuquerque, NM. Proc. RMRS-P-7. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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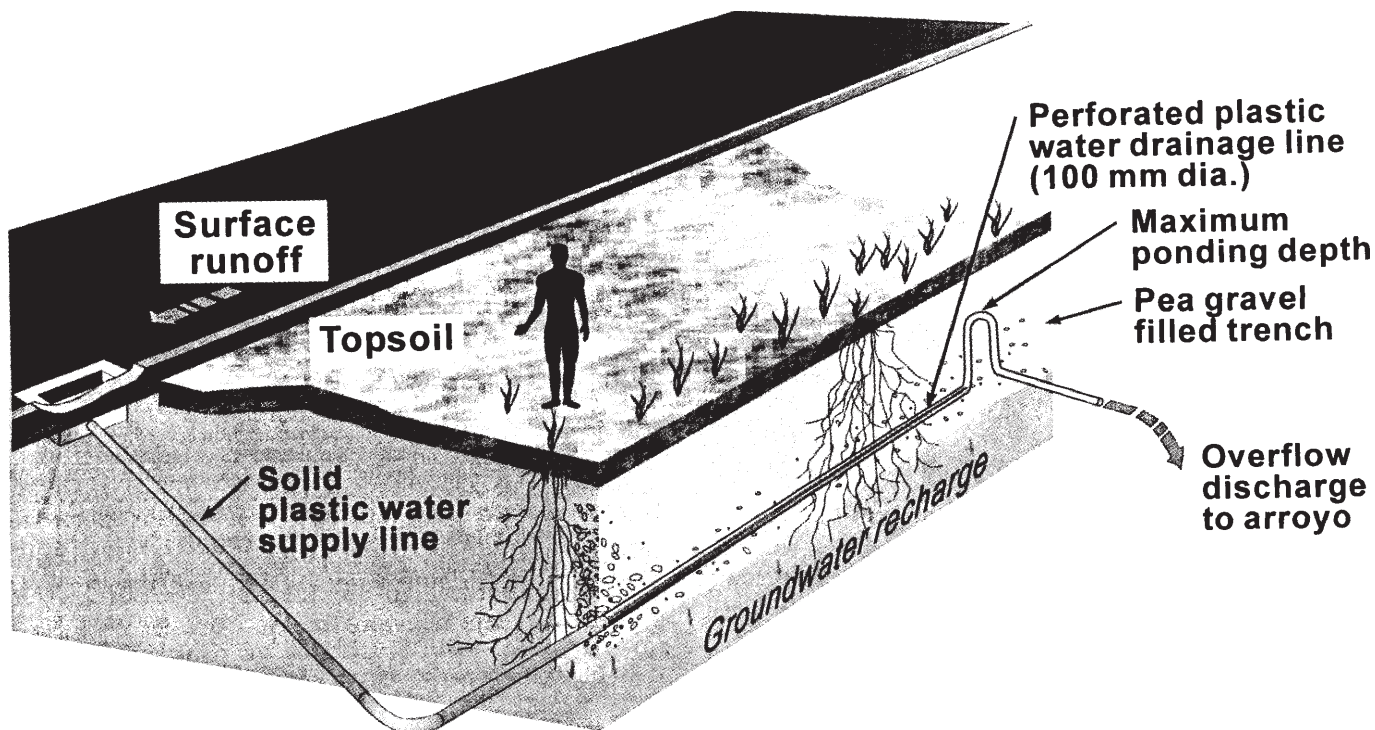
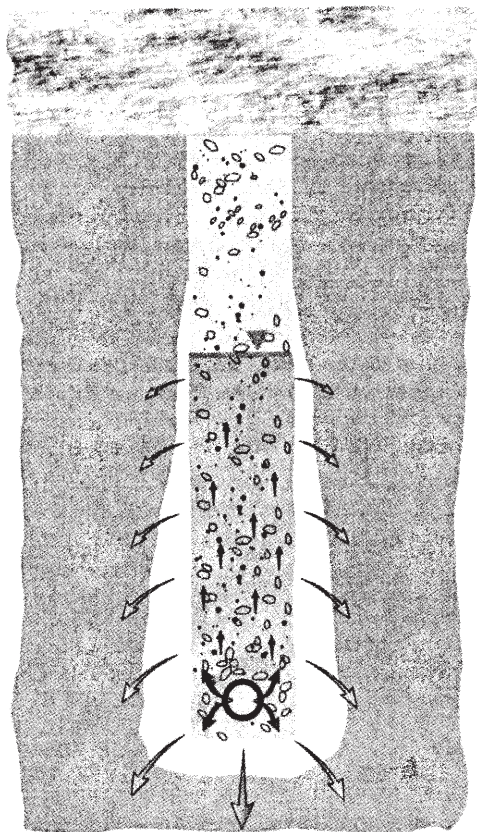


Figure 1—Siphon/infiltration gallery schematic.

Filling



Emptying

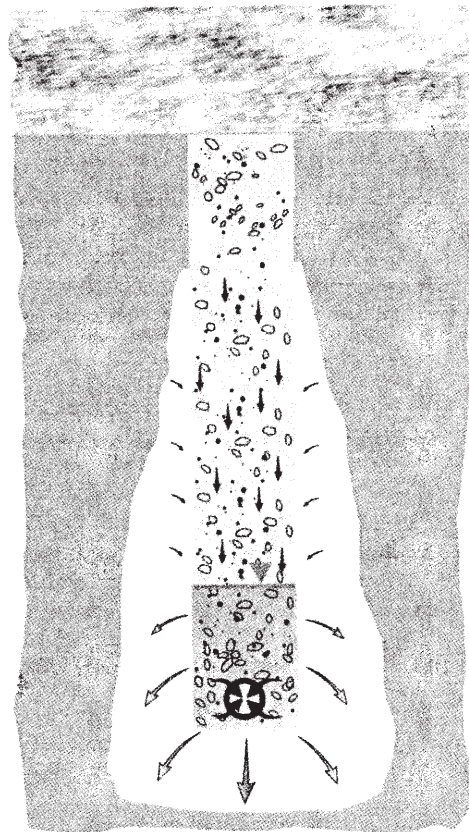


Figure 2—Siphon/infiltration gallery cross section.

The equation governing siphon operation is the energy equation developed by Bernoulli.

$$\frac{P_i}{\gamma} + \frac{V_i^2}{2g} + Z_i = \frac{P_o}{\gamma} + \frac{V_o^2}{2g} + Z_o + h_f$$

where Z = elevation of the pipe (m) subscripts: P is pressure (N/m^2), γ is fluid density (kg/m^3), V is fluid velocity (m/sec), g is the gravitational constant (m/sec^2), and h_f is the head loss within the system (m). Head loss is system dependent and includes friction losses and pipe bends. The subscripts "i" and "o" refer to inlet and outlet values, respectively. This governing equation is used to calculate flow within the spreadsheet model.

In addition to standard hydrologic modeling, the siphon is governed by logical statements embedded within the spreadsheet code to start and stop the siphon based upon water level in the system and upon the previous status of the siphon.

Three flow regimes exist for an infiltrating siphon system: (1) infiltrating inflow, (2) cycling outflow, and (3) continuous outflow, figure 3 shows siphon behavior under the three flow regimes.

The results shown in figure 3 are for a 50 meter long by 0.2 meter wide by 1.75 meter deep soil trench backfilled with

coarse gravel placed over a 0.10 meter diameter perforated pipe. Porosity of the gravel is 35 percent. The siphon empties into an arroyo 1.5 meters below the bottom of the trench. The soil used for calculations is a loamy sand with a permeability of 4.1×10^{-5} m/s. The rational method is used to estimate runoff and a runoff coefficient of 0.90 is used. Rainfall intensity is varied from a drizzle (1 mm/hr) in figure 3a to a light rain (5 mm/hr) in figure 3b and to a downpour (50 mm/hr) in figure 3c. Each rainfall intensity results in a different flow regime.

In infiltrating inflow (fig. 3a), infiltration into the trench bottom and walls exceeds inflow. All water infiltrates, and trench water level is less than the water level needed to activate the siphon (critical head).

In cycling outflow (fig. 3b), when inflow exceeds trench infiltration capacity, the water head in the trench exceeds the critical head, and the siphon is activated. For flow to stop, the rate of outflow must exceed the sum of inflow and infiltration up until the point at which the trench is emptied of water. At this point, air entering the pipe through the inlet or through the perforations is able to break the water column and stop the siphon.

In continuous outflow, an equilibrium is reached between inflow and outflow (fig. 3c). Water level in the trench and infiltration from the trench are constant.

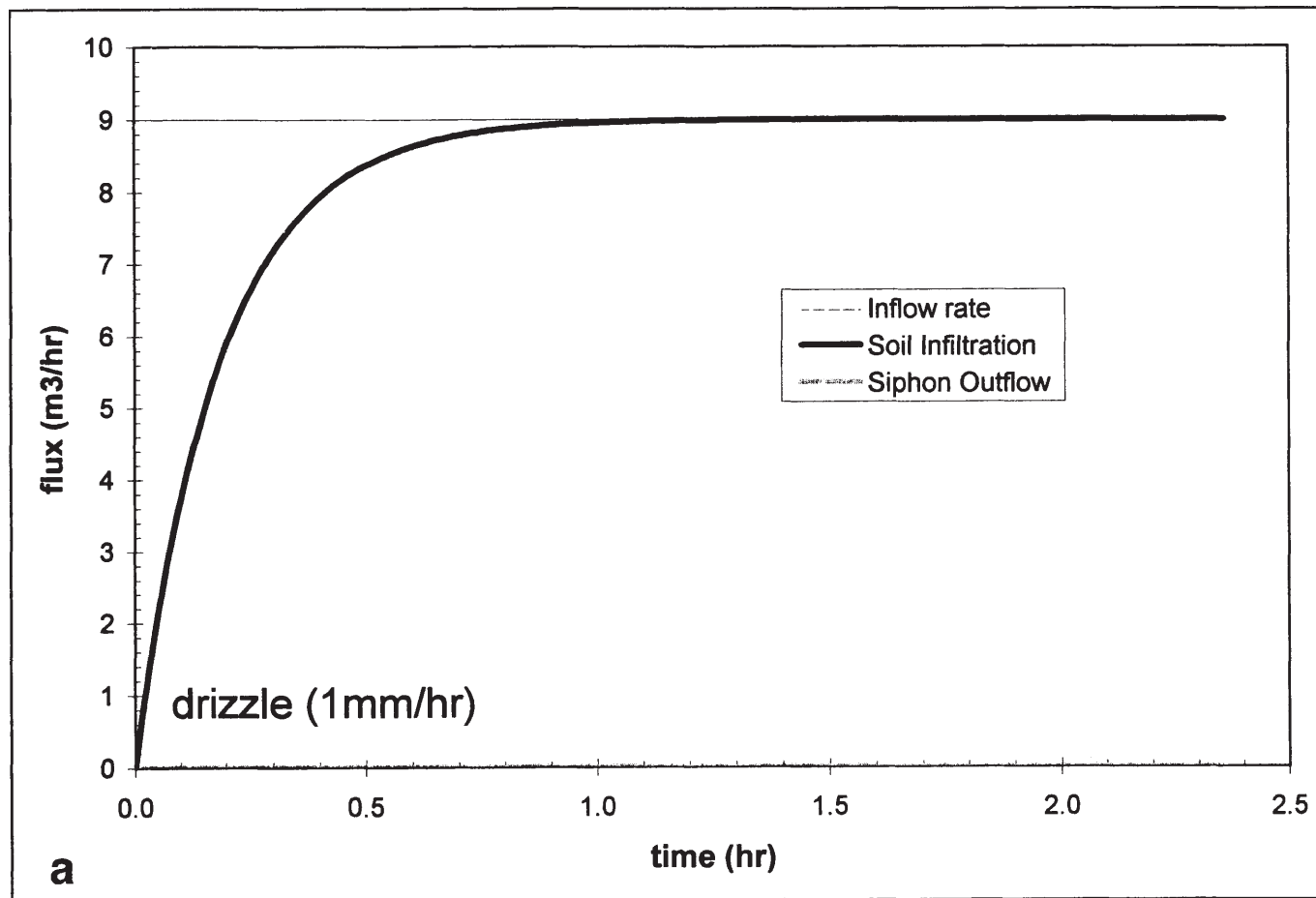


Figure 3—Flow regimes: infiltrating inflow is shown in 3a; cycling outflow is shown in 3b (next page), and continuous outflow is shown in 3c (next page).

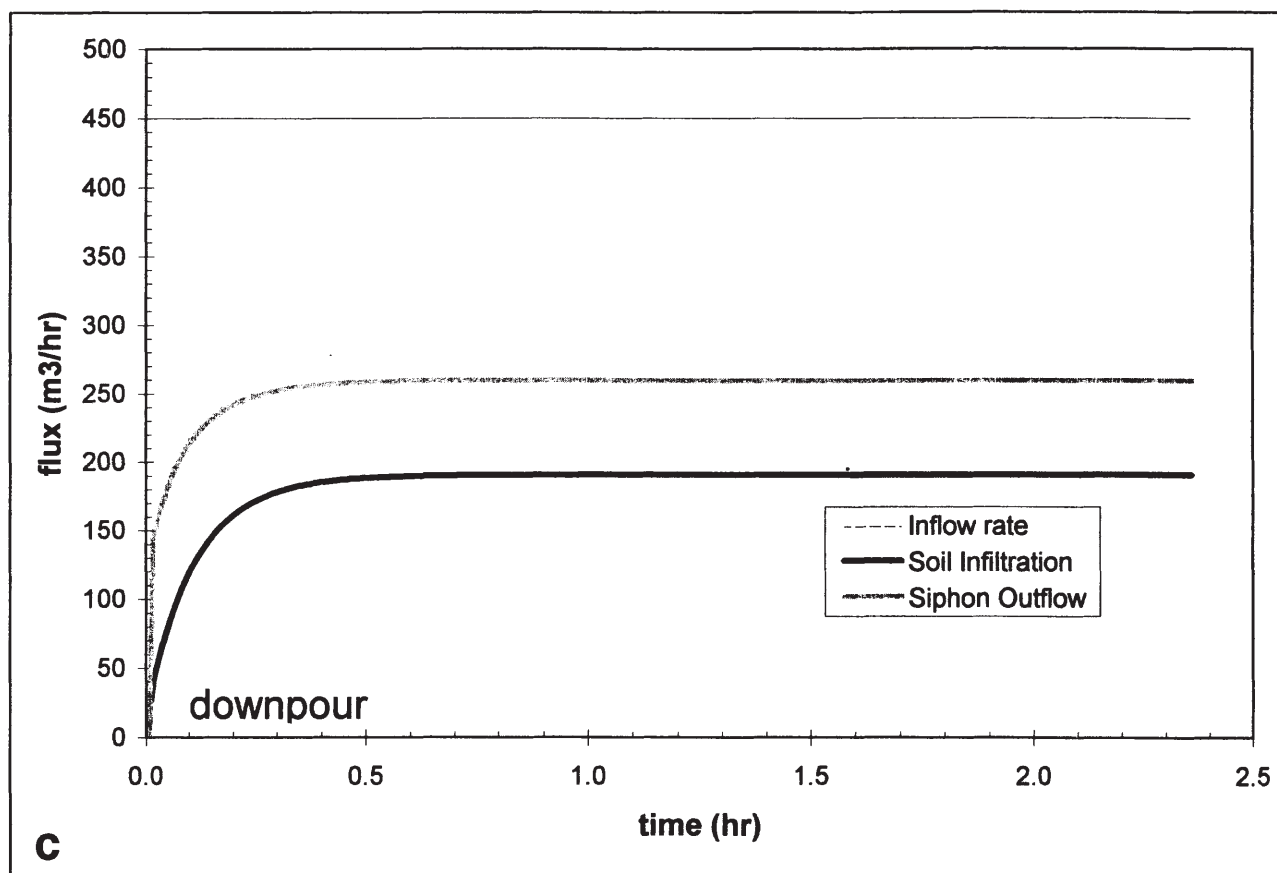
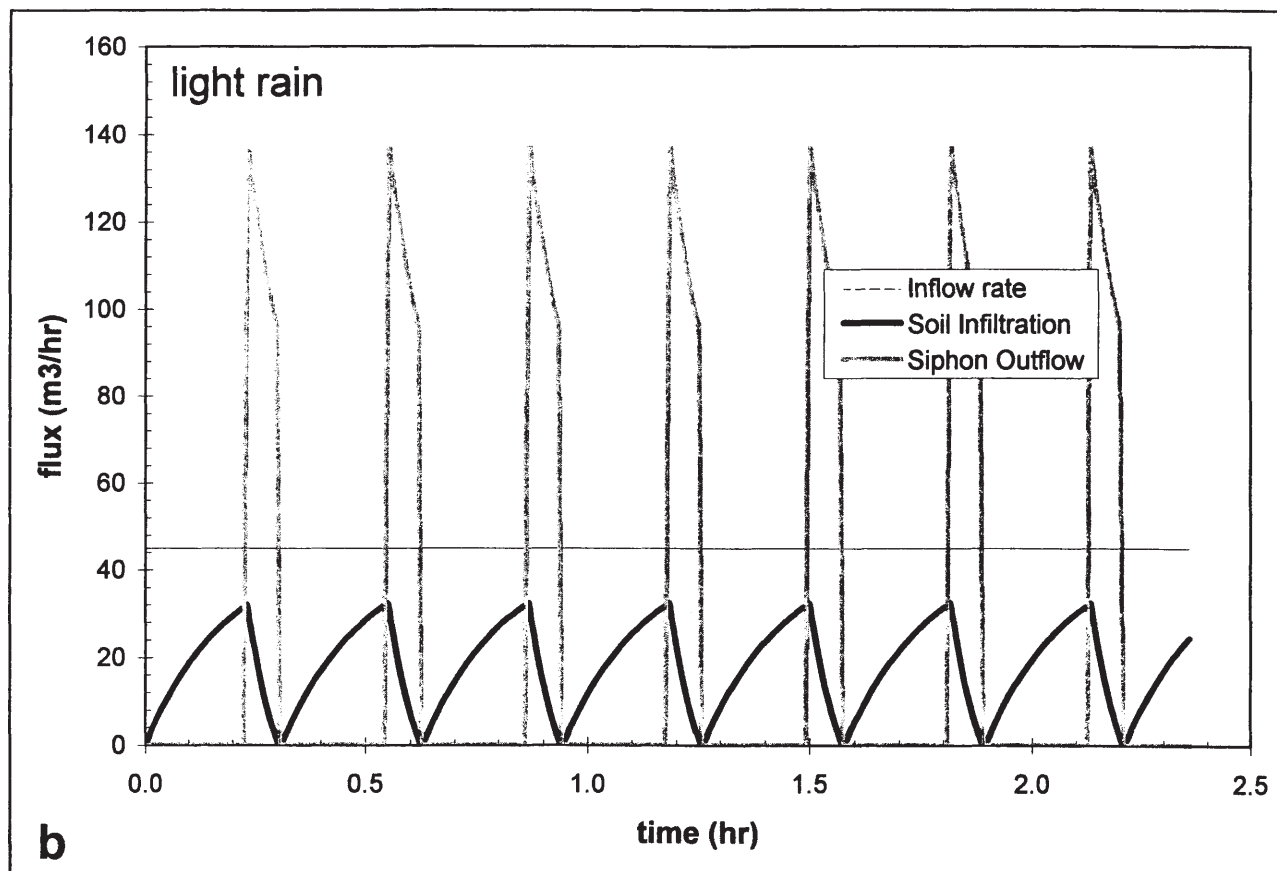


Figure 3— Continued from previous page.

All of these flow regimes potentially can be seen in a single rainfall event. Figure 4 schematically shows rainfall intensity over the course of a typical southwestern thunderstorm. Rainfall starts, quickly builds to maximum intensity, and then slowly tails off. Runoff and erosion intensity follow a similar qualitative pattern. At low rainfall intensities with low sediment inputs, all water infiltrates. As the rainfall intensity increases, sediment input increases, the cycling threshold is reached, and the system starts to cycle. If rainfall intensity increases sufficiently, sediment concentrations may increase, and a continuous outflow flow regime can be established. As rainfall decreases, the system will then revert to cycling outflow, and finally, to infiltrating inflow regimes.

Sediment

Sediment accumulation varies with flow regime. Under infiltrating flow, all water infiltrates and sediment accumulates in the system. However, because infiltrating flow generally occurs during low rainfall intensity events, little sediment enters the system.

During cycling flow, sediment accumulates during the infiltration phase of the cycle and is flushed during the siphon phase. Design parameters must be set to ensure an adequate velocity to entrain sediment in the perforated pipe and to back flush the overlying gravel backfill. The water

velocity obtainable in the system defines the particle size that can be entrained and removed. This velocity sets the upper limit on particle size that can be accommodated by the system.

During constant outflow, little sediment is likely to accumulate in the pipe. However, sustained unidirectional flow into soil is likely to result in some soil plugging and permeability decline. The time frame is likely to be empirically dependent upon soil properties, sediment flux, and particle size distribution.

Vegetation/Siphon System Interactions

Root systems can increase soil saturated hydraulic conductivity over an order of magnitude (Prieksat and others 1994). Increased root biomass results in more root channels as well as an associated increase in faunal activity creating wormholes and other channels. These preferential flow paths increase saturated hydraulic conductivity. In arid and semi-arid systems, plant growth is usually limited by water availability. Because plants maintain fairly constant root:shoot ratios, root mass and soil hydraulic conductivity are often directly correlated with water availability. Thus, a potential positive feedback loop exists where increased water availability from the siphon system increases plant and root mass which increases soil hydraulic conductivity which, in turn, increases water recharge and water availability.

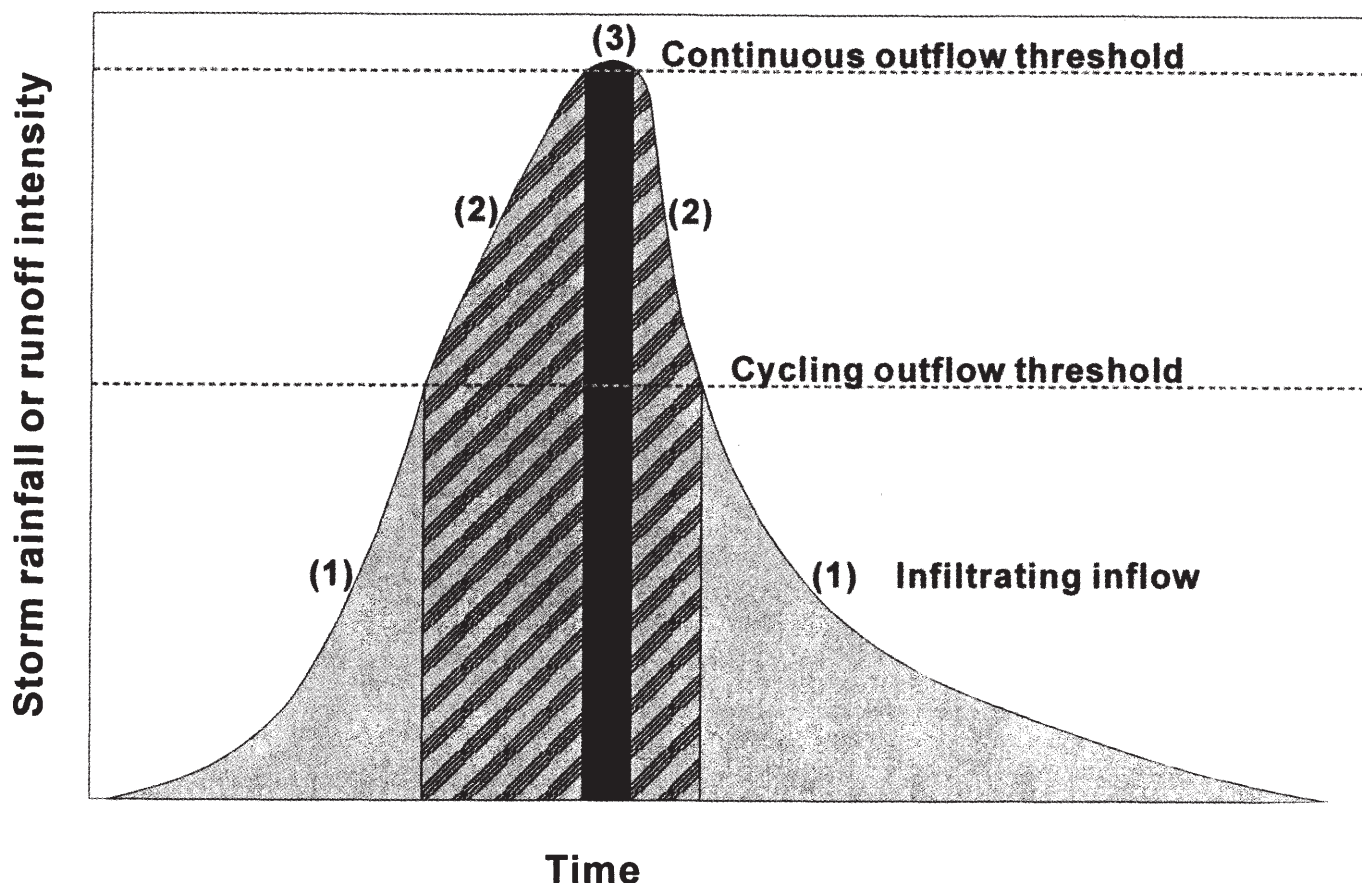


Figure 4—Changes in siphon system behavior over the course of a rainstorm.

These soil-plant-water relationships can be exploited in a siphon system. By increasing water availability, both root growth and hydraulic conductivity of the infiltration system can improve over time. This is particularly true of finer-textured semi-arid and arid soils where little macroporosity exists. Addition of plant roots and water leads to new macropore channels. The reduced carbon released by these roots ultimately results in soil aggregation. These soil aggregation processes are driven by reduced carbon from plants and can be used to combat the natural tendency of pressurized particulate-containing water to plug infiltration systems.

Siphon/Riparian Zone Interactions

Most previous buffer zone and riparian zone research (primarily from the Northeast and the Midwest) has operated on the premise that vegetation is necessary to establish control of run-off. In the western U.S., establishment of vegetation is often problematic due to intermittent water supply. Thus, contrary to what is typically found in the eastern U.S., runoff must be controlled to (re)establish vegetation in arid and semi-arid areas. Runoff control can provide water for establishment of vegetation. One problem is obvious: to obtain the benefits of vegetated buffer zones in arid and semi-arid areas, we need effective methods to convert transient runoff into a steady water source for establishment of vegetation.

Healthy riparian areas provide numerous benefits when viewed as a component of the basic hydrologic unit, i.e., the watershed. Woody riparian species provide channel and bank stability and thus prevent incisement of the channel. Local ground-water levels are maintained due to slow release of bank storage. Natural fluvial processes create channels which efficiently transport water. Water quality is improved where sources of sediment from destabilized banks are eliminated. Shading reduces extreme fluctuations in temperature and evaporative losses from perennial streams. Additionally, riparian zones can attenuate high flood flows while promoting sediment deposition and ground water recharge. These attributes optimize the hydrologic response of a watershed with regards to the storage and discharge of water.

From a soil science perspective, grazing and cropping practices have often reduced soil water storage capacity and increased run-off. A common result has been lowering of local water tables with permanent stream reaches becoming intermittent. From a hydrological perspective (Munzel 1983), these same agricultural practices lead to an exaggerated seasonal flow regime and increase the frequency, severity, and unpredictability of high-volume flows.

Subsurface flow, including that from recharge galleries, generally provides a more constant source of water than surface flow. Obligate phreatophytes, such as cottonwoods, require a constant source of water for survival. Facultative phreatophytes, such as salt cedar (*Tamarix* sp.), tolerate drier periods. In southwestern riparian zone forests (bosques), replacement of native vegetation (such as willow

and cottonwood) by exotics (such as salt cedar and Russian olive) has occurred with watershed degradation over time. The recharge component of the water balance considered critical for maintaining base flow in streams is therefore important in maintaining desired vegetation.

Surface waters have been diverted and infiltrated for thousands of years in various parts of the world (Bruins and others 1986). Wills (1988) summarizes much of the literature on prehistoric southwestern U.S. agriculture and water harvesting. The primary objective of water harvesting is short-term water storage in the soil profile for crop growth. In the southwest, Native American farmers place fields to optimize water and sediment trapping (Nabhan 1984). These relationships among soil, vegetation, and erosion/deposition are eloquently discussed by Jenny (1980). Soils derived from aeolian deposits, alluvium and colluvium are generally considered unsuitable for agriculture because of their high infiltration rates (Tabor, 1995). This characteristic of rapid infiltration, however, appears to improve the suitability of these soils in siphon systems and in arroyo bank stabilization.

While water erosion processes are complex, as evidenced by an abundant and growing amount of technical literature, the principals of erosion control are often stated as these relatively simple principles: Plant, plant residue, or mulch cover should be increased in intensity or in time to decrease energy and volume of run-off water. In the west, local increase of recharge also may facilitate erosion control. The rationale is this: Increased recharge results in increased bank vegetation, and increased bank vegetation reduces bank erosion. Bank erosion is a major contributor to the sediment load in many western streams. Thus, increased recharge from siphon systems is likely to reduce bank erosion on appropriately selected stream banks.

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