Article 58

Technical Note #84 from Watershed Protection Techniques. 2(3): 434-439

Improving the Trapping Efficiency of Sediment Basins

Sediment basins that are designed to settle out suspended sediments in stormwater runoff are typically the last line of defense at construction sites. Many communities employ the same basic and fairly simple design specification for sediment basins (see Table 1). While most specifications refer to optional design features such as de-watering devices, baffles or perforated risers, these "extras" are seldom installed in the field for cost reasons. In practice, the criteria are often used to tell the contractor how much dirt needs to be scooped out to provide the requisite storage.

Consequently, in many regions, sediment basins are really no more than an engineered hole in the ground (HIG). HIGs can be seen at almost any construction site around the country: steep-sided rectangular holes, that may or may not have standing water, with a ring of bright orange safety fencing, a reusable corrugated metal pipe (CMP) riser and perhaps a truckload of rip-rap dumped near the outlet.

It is not surprising, then, that most HIGs are a poor settling environment, and few are probably capable of consistently removing 70% of incoming sediment, much less the 95 to 99% removal needed to achieve a relatively clear water discharge. A large number of factors work to reduce the trapping efficiency of a basin in the field (Table 2), some of which could conceivably be "engineered away" through better design. Thus, the key question is how much improvement in performance can be expected if the basic design of sediment basins is modified?

A steady stream of sediment basin design improvements have been advocated over the years, including perforated risers, perforated risers with gravel or filter fabric jackets, filter fence baffles, floating skimmers, "dual basins in series," greater storage volumes and various combinations thereof (see Figure 1). Until recently, however, these design improvements were seldom subjected to experimental testing or field monitoring to determine if they actually improved trapping efficiency. Lacking proven performance data, many local and state erosion programs have been reluctant to adopt these improvements, given the potential cost and maintenance ramifications.

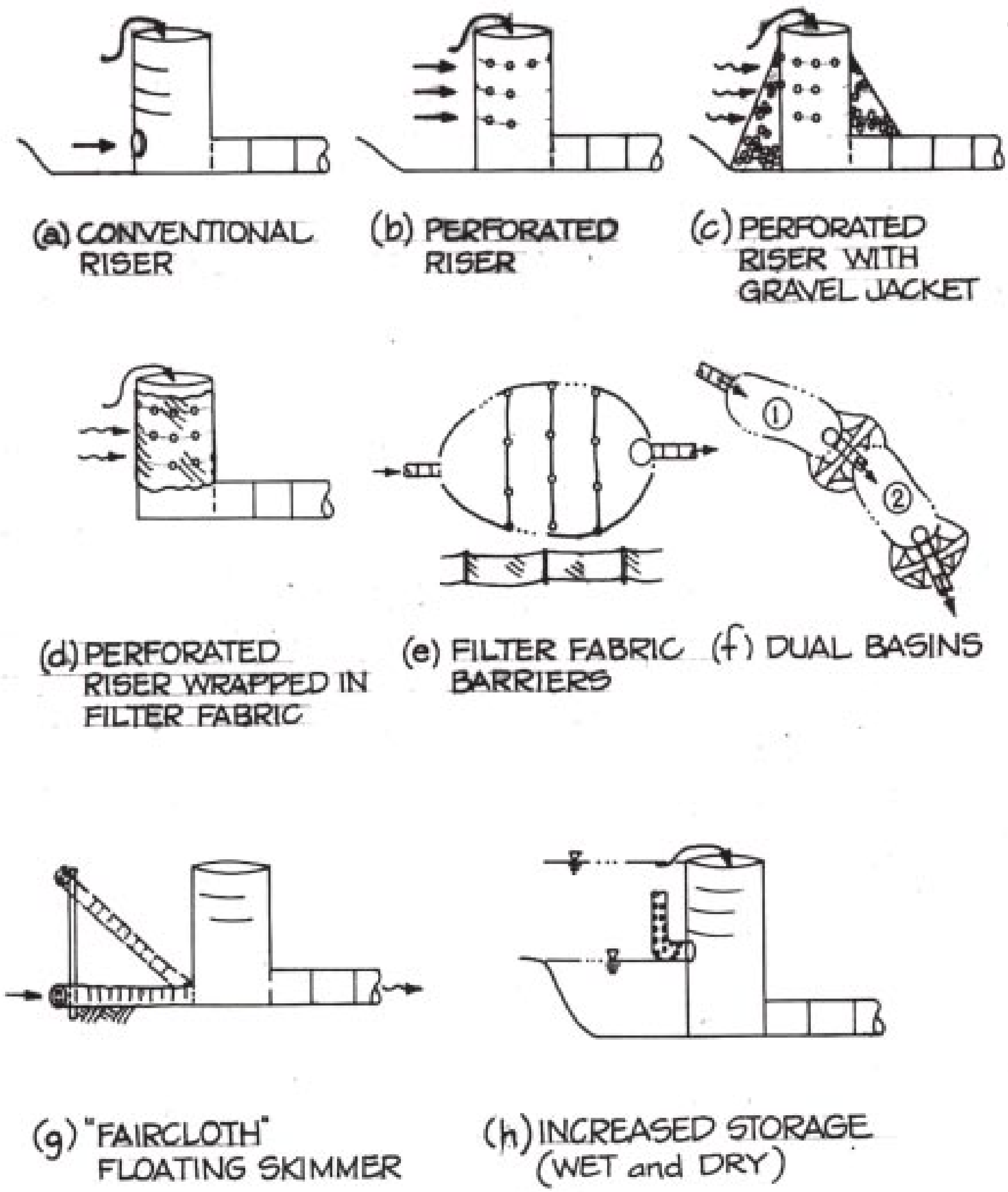
Sediment Basin Re-Design

Our understanding about the performance of innovative sediment basin designs has recently been increased by a series of laboratory experiments, field monitoring and modeling studies conducted by A. R. Jarrett and his colleagues at Pennsylvania State University and Rich Horner of the University of Washington. While it is difficult to make direct comparisons between studies because of differences in soils, rainfall, design storage and experimental techniques, the research does offer some insight into these innovative techniques.

Table 1: "Standard" Sediment Basin Design Criteria Compiled from Various State and Local ESC Manuals

- Provide 1,800 cubic feet of storage per contributing acre *
- Surface area equivalent to one percent of drainage area **
- Riser w/ spillway capacity of 0.2 cfs/acre of drainage area (peak discharge for two-year storm, undeveloped condition)
- Spillway capacity to handle 10-year storm with one-foot freeboard
- Length-to-width ratio of two or greater **
- Basin sideslopes no steeper than 2:1 (h:v)
- Safety fencing, perforated riser, de-watering **

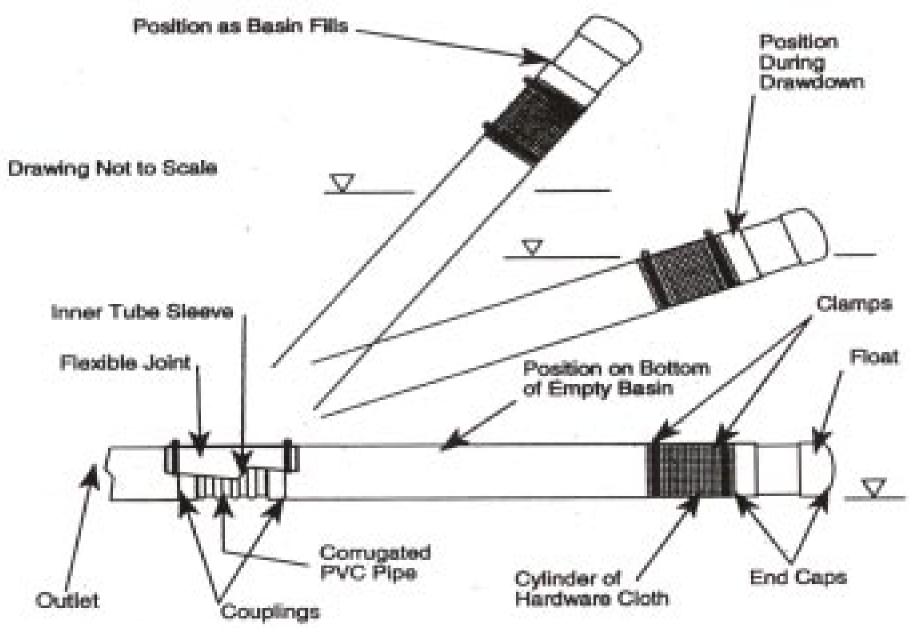
* A number of states (MD, PA, GA and DE) recently increased storage requirement to 3600 ft^3 or more.
** Optional technique, but seldom actually required during plan review.



The standard riser configuration in a sediment trap may not provide enough detention time or the proper conditions for settling. Some alternative design options include a perforated riser (panel b), and wrapping the riser in filter fabric or gravel (panels c and d). To prevent short circuiting, some designers use filter fabric or a dual pond in series (panel e and f). Floating skimmers (panel g) and increased wet/dry storage volume (panel h) show the greatest promise.

Figure 1: Options for Design Improvements

Table 2: Factors that Impair Trapping Efficiency of Sediment Basins and Traps
Factors that Impair Trapping Efficiency
Large storm events (greater than two-year storm)
Moderate to low incoming TSS concentrations
Sediment deposits on bottom are re-suspended, or sides erode
Fine particle sizes in incoming runoff (silt and clay particles 40 microns or less)
Advanced stage of construction, with storm drains and paved roadways increasing runoff volume/velocity
Low intensity, long duration rainfall events
Length-to-width ratio of 1:1 or less
Multiple inlets, particularly if not stabilized or if their invert is more than a foot above basin floor
Steep side-slopes, particularly in non-growing season or poor vegetative cover
Turbulent energy in runoff
Cold water temperatures (below 40 degrees F)
Absence of standing water in basin
Upland soils are in C and D hydrologic soil groups, or highly erodible soils



Comments:
Barrel pipe is 10.2 cm (4 in) schedule 40; float is lightweight drainage pipe.
Barrel pipe length should be slightly longer than the depth of basin to crest of principle outlet.
Corrugated PVC pipe in flexible joint prevents inner tube sleeve collapsing under water pressure.
Outlet pipe is fitted with an end cap with a small hole (size varies with volume of basin) to restrict outflow and maximize sedimentation, typically .5 to .75 inch diameter.
Fence posts are placed on both sides of skimmer as guides; wire across the top limits floating and can be used to stop and sink skimmer when water level reaches desired elevation.

The floating skimmer rests on the floor of a sediment basin in between storms. The float causes the skimmer to rise during a storm, thereby increasing detention time and withdrawing from the less turbid surface waters.

Figure 2: Floating Skimmer Design (Faircloth, 1995)

Perforated Riser. A simple means of achieving greater detention times is to replace the standard riser (with its large flow orifice) with a perforated riser (see Figure 1). The perforations should slightly increase detention times in the basin for smaller storms, and therefore increase trap efficiency. In practice, the effect of a perforated riser on detention time and basin hydraulics is poorly understood, although an excellent design methodology has been proposed by Jarrett (1993). Test tank research has shown that the perforated riser, by itself, only results in sediment removal on the order of 60 to 70%, depending on the de-watering time achieved (Table 3; Engle and Jarrett, 1995). The perforated riser was generally unable to settle out fine-grained silt and clay particles, which accounted for the mediocre removal rate.

Perforated Riser with Gravel Jacket. The use of a "jacket" of gravel around the perforated riser has been used in some communities to provide more filtering, further increase detention times, and promote greater settling. The experimental work of Engle and Jarrett generally supports this notion (Table 3). Sediment removal increased by 15 to 18% compared to a perforated riser alone. The same authors found that encasing the riser with expanded polystyrene chips (EPS), similar to those used in packing, had the same effect on trapping efficiency, as well.

Perforated Riser with Filter Fabric Lining. The use of gravel jackets can be fairly expensive, can lead to clogging, and may make maintenance operations more difficult. As an alternative, several communities allow a layer of permeable filter fabric to be wrapped around the outside of the perforated riser. Based on experimental tests of Fisher and Jarrett (1984), however, this approach is not likely to increase trapping efficiency much. Of six fabrics tested, none performed well in trapping silt and clay particles, although most fabrics did prevent sand from passing through. Also, field experience has shown that the pores of filter fabric clog very rapidly, transforming the fabric from a filter to a barrier. When filter fabric clogs, basins tend to fill up with water to the crest of the riser, thereby losing valuable storage capacity.

Recent experiments by Brown (1997) using two types of filter fabric on a perforated riser, where the uncovered perforated riser, basin and storms had a 48-hour de-watering time, showed that the filter fabric clogged quickly, greatly extending the de-watering time. In addition, the particle size distribution of suspended sediment passing through the filter fabric was essentially the same as measured for the influent.

Silt Fence Barriers. To achieve the desired length-to-width ratio of 2:1 or 5:1, some communities require that baffles or silt fence barriers be placed perpendicular to the flow path within a sediment basin. Experiments by both Millen and Jarrett (1996) and Horner *et al.* (1990) found silt fence barriers to be of relatively little value in improving sediment removal in test basins, primarily because they had little or no influence on detention time (see Table 4). Dye tests reported by Jarrett (1996) did show that the barriers reduced short-circuiting to near zero, but tended to increase the volume of dead storage in the basin. Poorly-mixed dead storage zones provide less detention time for incoming sediments as they move from inlet to the riser. The research implies that while baffles are important in basins with multiple inlets or poor geometry, they provide only a marginal sediment removal benefit for a well-designed basin.

Faircloth "Floating Skimmer." The floating skimmer was developed by William Faircloth of Orange County, North Carolina (Faircloth 1995). The simple, inexpensive device consists of a straight section of PVC pipe attached via a flexible coupling to the low-flow outlet situated at the base of a riser (see Figure 2). Equipped with a float, the skimmer pipe will rise and fall along with water levels in the sediment basin. The inlet to the skimmer pipe is a small hole located at the end-cap (this small hole, often only 1/2 to one-inch in diameter, restricts flow, and therefore increases detention time). Fence posts are driven in on both sides of the skimmer pipe, guiding it up and down.

Table 3: Effect of Riser Configuration on Sediment Basin Removal Efficiency (Engle and Jarrett, 1995)

Riser Configuration	TSS Removal 1.5 hour dewatering time	TSS Removal 3.0 hour dewatering time
Perforated riser (PR)	59.8%	71.0%
PR w/ Gravel Filter	78.3%	85.6%
PR w/ EPS Chips Filter	78.3%	89.0%

***Test Conditions**: experimental settling tank, 18 trials, initial TSS concentration of 5880 mg/l; particle size distribution 24% clay, 35% silt, and 41% sand.*

Table 4: Effect of Design Features on Sediment Basin Trapping Efficiency (Jarrett, 1996)

Basin Design Feature	Sediment Removal
Perforated Riser	94.2%
Perforated Riser w/ Barriers	95.4%
Skimmer on PR	96.9%
Skimmer on PR, w/ Barriers	96.6%

***Test Conditions**: full-scale sedimentation basin, one-acre construction site, 6250 ft^3 capacity, two-year, 24-hour rainfall event, peak inflow Q_p of 0.83 cfs, 12 trials, 2000 to 5000 mg/l average TSS inflow; particle size distribution: 6% clay, 21% silt, 51% sand, 22% gravel.*

Prior to the storm, the skimmer pipe rests on the floor of the sediment basin. During the first part of a storm, the inlet hole restricts flow, backing water up in the basin, and causing the skimmer pipe to rise. Sediment-laden runoff encounters a permanent pool which promotes greater settling. After the storm, the basin gradually de-waters, and the skimmer slowly descends back to the floor of the basin. This de-watering allows full recovery of storage capacity in the sediment basin for the next storm. In addition, the skimmer is always drawing cleaner runoff near the top of the pool, rather than the dirtier bottom sediments.

Several prototypes have been tested in the Chapel Hill, North Carolina region, and Faircloth reports that they appear to perform well and are very durable. In addition, the cost of the skimmer is less than $100, and is comprised of readily available materials. The performance of the floating skimmer was recently tested under simulated field conditions by Jarrett (1996). Nearly 97% of sediment removal was achieved by the test basin during a simulated two-year, 24-hour design storm event (Table 4), the highest trapping efficiency observed for any of basin designs tested. The trapping efficiency of the floating skimmer appears to be ultimately limited by turbulent energy of incoming runoff. According to Jarrett (1996), fine-grained particles (smaller than 45 microns) are not subject to effective settling when turbulent energy exceeds 0.3 feet per second, which is quite common in many basins.

Dual Basins. A promising, if not always practical, means of improving sediment basin efficiency is to split the total storage volume into two basins in series rather than one. Laboratory experiments by Horner *et al.* (1990) suggested that a dual basin arrangement was the single most effective design strategy to increase detention time, and therefore, settling potential (i.e., greater than baffles or increasing basin length). While this option is certainly more expensive than others, it may be appropriate for highway and other development sites that have long and narrow areas available for treatment.

Increase Storage Volume. Several states such as Maryland, Georgia and Delaware have increased the storage capacity of sediment basins from the traditional 1800 ft^3 per acre (i.e., one-half inch over contributing watershed area) to 3600 ft^3 /acre. The extra storage and changes to the basin's outlet should increase the detention times for many storms, particularly those less than one-inch deep. For smaller storms, it may be possible to achieve "zero discharge" during a storm event if it is smaller than the capacity of the basin. It is important to note that the expected improvement in efficiency will not occur unless the principal spillway is also modified to increase detention at the same time. This is done by raising or constraining the low-flow orifice, creating a partial permanent pool with a riser elbow modification, or using the floating skimmer or perforated riser (Jarrett, 1996; McBurnie *et al.*, 1990; Schueler and Lugbill, 1990). Further, it should be noted that the effect of increasing storage volume on basin efficiency has not yet been documented experimentally in the lab or the field, although anecdotal evidence suggests that it produces more zero discharge events than the old criteria.

Summary: Recommended Basin Design Specifications

While a large number of sediment basin design refinements are being promoted, current research suggests that some may not substantially improve performance. In addition, more field research is needed under a wider range of construction site conditions to accurately assess which design refinements are worth adopting. In particular, the value of the basin design improvements in capturing extremely-fine grained sediments needs more assessment. Further, new design refinements must be carefully assessed from the standpoint of future maintenance and contractor expertise—an overly complex design refine-

Table 5: Recommended Sediment Basin Design Criteria	
1	Provide a minimum storage of at least 3,600 ft^3 per acre.
2	Provide storage in wet and dry stages.
3	Silt fence barriers required if length to width ratio is less than two.
4	Evaluate all proposed inlets for stability.
5	Employ a floating skimmer, or at least a perforated riser w/ gravel jacket.
6	Incorporate storage in multiple cells, where possible.
7	Limit side-slopes to no greater than 3:1.
8	Check water table to determine if basin can/should fully de-water.
9	Paint depth markers on principal spillway to measure sediment deposition to better trigger cleanouts.
10	Stabilize side-slopes and basin bottom with mulch or hydroseeding within one week.

ment that works great in the lab may be difficult to construct or maintain in the field. Lastly, if the design refinements greatly increase the cost of sediment basins, it is probable that many designers will shift to cheaper (and presumably less effective) sediment controls that are available in the local ESC handbooks. With these considerations in mind, some possible refinements to traditional sediment basin design criteria are proposed in Table 5.

—TRS

References

Brown, E.R. 1997. *Filtering Efficiency and Water Transmissibility of Geotextiles Utilized in the Design of Sedimentation Discharge Riser Pipes.* Unpublished MS Thesis. Civil Engineering. Pennsylvania State University. University Park, PA.

Engle, B.W and A.R. Jarrett. 1995. "Sedimentation Retention Efficiencies of Sedimentation Basin Filtered Outlets." *Transactions of ASAE* 38(2): 435-439.

Faircloth, W. 1995. *Experimental De-watering Device to Improve Sedimentation Basin Efficiency.* Unpublished manuscript. Orange County Planning and Inspections Dept. Hillsborough, NC. 12 pp.

Fisher, L., and A.R. Jarrett. 1984. "Sediment Retention Efficiency of Synthetic Filter Fabrics." *Transactions of ASAE* 27(2): 429-436.

Horner, R., J. Guedry, and M. Kortenhoff. 1990. *Improving Cost-Effectiveness of Construction Site Erosion and Pollution Control.* Washington State Dept. of Transportation. WA-RD-200.1 Seattle, WA. 64 pp.

Jarrett, A.R. 1993. "Design of Perforated Risers to Control De-watering of Sedimentation Basins." *Transactions of ASAE. Applied Engineering in Agriculture* 9(1):37-42.

Jarrett, A.R. 1996. *Sedimentation Basins: Evaluation and Design Improvements.* Final Report. Orange County Planning Commission. Pennsylvania State University. 77 pp.

McBurnie, J., B. Barfield, M. Clar, and E. Shaver. 1990. Maryland Sediment Detention Pond Design Criteria and Performance. *Applied Engineering in Agriculture* 6(2): 167-172.

Millen, J.A., and A.R. Jarrett. 1996. *Improved Sedimentation Basin Performance with Barriers and a Skimmer.* ASAE Microfiche No. 96-2056.

Schueler, T., and J. Lugbill. 1990. *Performance of Current Sediment Control Measures at Maryland Construction Sites.* Metropolitan Washington Council of Governments. Washington, D.C. 90 pp.