Article 116

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Ditches or Biological Filters? Classifying Pollutant Removal in Open Channels

Archaeologists tell us that humans started digging ditches several thousand years ago, beginning with the extensive ditch networks dug by early civilizations to irrigate the "fertile crescent" of the Middle East. Ditch digging hasn't changed that much since then, although stormwater engineers now refer to them by fancier terms such as "open channels" or "grass swales." In reality, these terms are rather broad and imprecise, and fail to distinguish the potential differences in pollutant removal potential that various channel designs can have during small storms. In this sense, open channels can be classified into one of four possible categories, based on their hydrologic design. They are the drainage channel, grass channel, dry swale and wet swale (Figure 1).

The open channel design in most common use is termed a *drainage channel*, and is designed to have enough capacity to safely convey runoff during large storm events without erosion. Typically, a drainage channel has a cross-section with hydraulic capacity to handle the peak discharge rate for the ten year storm event, and channel dimensions (i.e., slope and bottom width) that will not exceed a critical erosive velocity during the peak discharge associated with the two-year storm event. Consequently, most drainage channels provide very limited pollutant removal, unless soils are extremely sandy or slopes are very gentle.

To achieve greater pollutant removal, stormwater engineers have recently employed *grass channels* to achieve greater pollutant removal. A grass channel is designed to meet runoff velocity targets for two very different storm conditions: a water quality design storm and the two-year design storm. During the "water quality storm," runoff velocity typically cannot exceed 1.5 fps during the peak discharge associated with the six month rainfall event, and the total length of the channel must provide at least 10 minutes residence time. In some regions of the country, grass channels are termed "biofilters" (Seattle METRO, 1992). To meet the water quality criteria, grass channels must have broader bottoms, lower slopes and denser vegetation than most drainage channels.

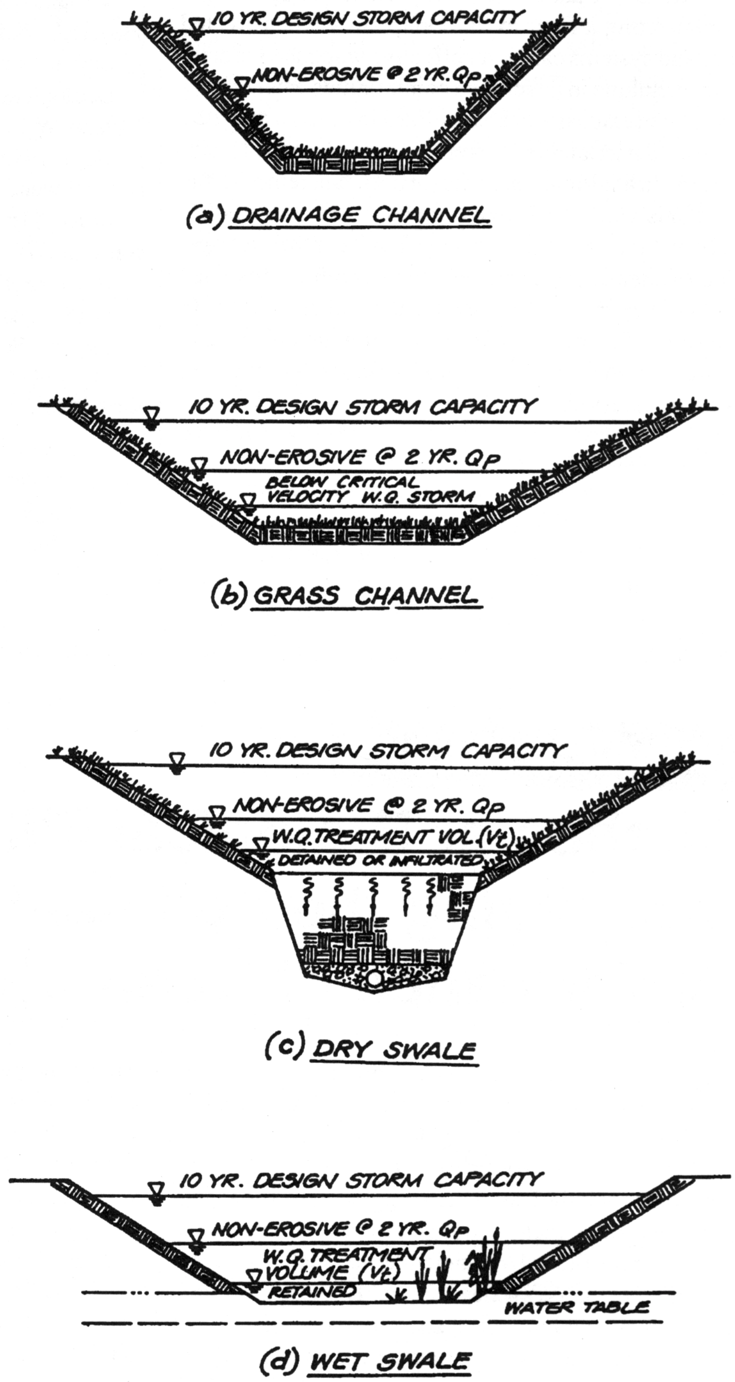
A third open channel is termed the *dry swale*. In a dry swale, the entire water quality volume is temporarily retained within the swale during each storm, allowing time for it to filter through 30 inches of prepared soil before it is collected by an underdrain pipe (see Figure 2). A dry swale is often the preferred open channel option in residential settings since it is designed to prevent standing water that makes mowing difficult and generates complaints. The swale is designed to rapidly dewater, thereby allowing front yards to be more easily mowed. Design methods for the dry swale can be found in Claytor and Schueler (1995).

The last open channel design is termed a *wet swale*, and occurs when the water table is located very close to surface. As a result, swale soils often become fully saturated, or have standing water all or part of the year once the channel has been excavated. This "wet swale" essentially acts as a very long and linear shallow wetland treatment system. Like the dry swale, the entire water quality treatment volume is stored and retained within a series of cells in the channel, formed by berms or checkdams. In some cases, the cells may be planted with emergent wetland plant species to improve removal rates.

Few stormwater treatment practices exhibit such a great variability in pollutant removal performance as open channels. In this article, 16 historical performance monitoring studies of "grass swales" were reanalyzed based on the open channel classification presented earlier to try to explain this variability. Ten of the open channels could be classified as "drainage channels" based on two criteria: they were designed only to be non-erosive for the two-year storm, and their particular combination of soil and slope did not allow significant infiltration of runoff into the soil profile. Site data and pollutant removal data are shown in Table 1(a).

The remaining six open channels were either explicitly designed as a grass channel, dry swale or wet swale, or had a combination of soils, slope and water table so that they effectively functioned as one of these three systems (Table1(b)). Given the relatively small number of open channels that met these criteria, they were lumped together as a single group, and are hereafter termed "water quality channels."

As a group, drainage channels provided negligible removal of most pollutants. For example, only four of nine drainage channels had a positive removal rate for suspended sediment, and all but two channels had phosphorus removal rates lower than 15%. Removal rates for all forms of nitrogen were consistently low or nonexistent. The three studies that examined the ability of drainage channels to remove fecal coliform bacteria



Open channels can be designed in one of four ways—as either (a) a drainage channel, (b) a grass channel, (c) a dry swale, (d) a wet swale. All open channels are typically designed to convey the ten year design storm, and prevent critical erosive velocities during the two year design storm. The grass channel is designed to achieve a critical velocity during a water quality design storm. The dry swale is designed to capture and treat the entire water quality volume in the swale. The same is true for the wet swale, except that the storage is provided by a pool of water, due to the presence of a high water table.

Figure 1: Open Channel Options for Treating Urban Stormwater

also found no significant change in the counts of this key indicator of human health. While some channels did exhibit a moderate ability to remove trace metals often found attached to particles (i.e., lead and zinc), an equal number showed no metal removal capability whatsoever.

In contrast, the water quality swales demonstrated a much greater and more consistent capability to remove pollutants conveyed in urban stormwater. In nearly every case, most of the mass removal could be accounted by the infiltration of runoff into the soil profile during storms (i.e., actual pollutant concentration did not change appreciably as they passed through the channel). As a group, water quality channels showed excellent removal of suspended sediment, nitrogen, organic carbon and trace metals. The only study that examined hydrocarbon and bacteria removal indicated high removal rates for hydrocarbons, but poor removal for bacteria. Phosphorus removal for water quality channels was mixed, with two channels reporting phosphorus removal greater than 80%, but the other three reporting removal rates of 30% or less.

The clear implication is that channels that designed to infiltrate, retain or at least achieve a modest contact time during most storm events will perform much better in removing most pollutants than a typical drainage channel. Phosphorus, however, may be exception. Monitoring has shown that open channels have high phosphorus levels stored in the thatch and surface soil layer. Some of the stored phosphorus may recycle back into the water column, or be eroded during larger storms. Indeed, when outflow concentrations of open channels are compared to other stormwater practices, open channels appear to have a higher “irreducible concentration” of sediment, total phosphorus and soluble phosphorus than all other stormwater practices.

This reanalysis of historical performance monitoring studies clearly supports the idea that a drainage channels by itself cannot be considered an effective best management practice, unless soil and slope conditions are exceptionally favorable. To be effective, open channels should be explicitly designed to increase the volume of runoff that is retained or infiltrated within the channel. Suggested design guidelines for the dry swale, which can be used in many residential settings, are detailed in Table 2. The novel aspect of these guidelines is that the channel is no longer designed based on a rate of flow, but rather a defined water quality volume (which makes swale design more consistent with other stormwater practice designs.)

–TRS

Table 1: Pollutant Removal Capability of (a) Drainage Channels and (b) Water Quality Swales

No.	Ref.	State	Year	No. of Samp.	Mass or conc. method	Slope	Length	Contrib. area (acres)	Soil	TSS	OC	TP	SP	TN	NO_3	Cu	Pb	Zn	Other
(a) Ten drainage channels																			
1	OWML	VA	1983	33	M	1.8	260	9.5	SL	Neg.	Neg.	Neg.	–	Neg.	–	–	Neg.	Neg.	–
2	OWML	MD	1983	50	M	4.1	445	19.0	SL	Neg.	Neg.	Neg.	–	Neg.			Neg.	Neg.	–
3	OWML	MD	1983	8	M	5.1	425	12.0	SL	31	Neg.	Neg.	–	37	–	–	33	Neg.	–
4	Dorman	VA	1989	9	M	4.7	185	1.3	SL	65	76	41	–	–	11	28	48	49	TKN = 17
5	Dorman	MD	1989	4	M	3.2	193	1.3	SL	Neg.	23	12	–	–	Neg.	14	55	9	TKN = 9
6	Yu	VA	1989	4	M	5A	200	1.5	–	68	–	60	–	–	–	–	–	74	–
7	Yousef	FL	1985	6	C	1.0	550	–	Sa	–	–	8	26	13	11	14	27	29	TKN (-20)
8	Oakland	NH	1983	11	C	>2%	100	–	–	33	–	Neg.	Neg.	–	–	48	57	50	Coli = NSD
9	Welborn	TX	1987	19	C	–	200	2.9	–	NSD	Neg.	Neg.	Neg.	Neg.	Neg.	NSD	NSD	NSD	Coli = NSD
10	Pitt	Ont.	1986	50	C	–	–	–	–	NSD	–	–	–	NSD	–	NSD	NSD	NSD	Coli = NSD
(b) Water quality swales																			
1	Dorman	FL	1989	8	M	1.0	185	0.6	Sa	98	64	18	–	–	45	65	81	81	TKN = 48
2	Harper	FL	1988	16	M	1.0	210	0.8	Sa	87	69	83	–	84	80	89	90	90	–
3	Harper	FL	1988	11	M	1.8	210	1.2	WET	81	48	17	–	40	52	56	50	69	–
4	Kercher	FL	1983	13	M	>2.0	–	14.0	Sa	99	99	99	–	99	99	–	99	99	–
5	Metro	WA	1992	6	C	4.0	200	16.0	Till	83	–	29	72	–	Neg.	46	67	73	HC = 75 COLI = Neg.
6	Wang	WA	1981	8	M	–	200	–	–	80	–	–	–	–	–	70	80	60	–

Soil (SL = silt loam, Sa = sandy); Coli = fecal coliforms; Neg. = negative removal efficiency; NSD = no statistically different conc. btw. control (usually pipe flow)
HC = hydrocarbon; M = mass; C = concentrate

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Table 2: Key Design Criteria for the Dry Swale

- Dry swales are designed to retain the full water quality volume over their entire length, allowing for full filtering or infiltration through the bed of the swale, usually by temporary ponding 12 to 18 inches above the swale bottom.
- Pretreatment is required to protect the swale. For pipe inlets, 0.1 inch per contributing acre should be temporarily stored behind a checkdam. For lateral inflows, gentle slopes or a pea gravel diaphragm can be used.
- It is often necessary to modify the parent soils to improve their infiltration rate. Dry swales will have a prepared soil filter bed that is 30 inches deep and composed of 50% sand and 50% silt loam
- Swale filter beds are drained by a longitudinal perforated pipe to keep the swale dry after storm events.
- Swales are parabolic or trapezoidal shapes, with gentle side-slopes (no greater than 3:1 h:v), and bottom widths ranging from two to eight feet.
- Geotechnical tests must be performed to determine the location of the water table. If the water table is within two feet of the planned swale bottom, a dry swale is not feasible.

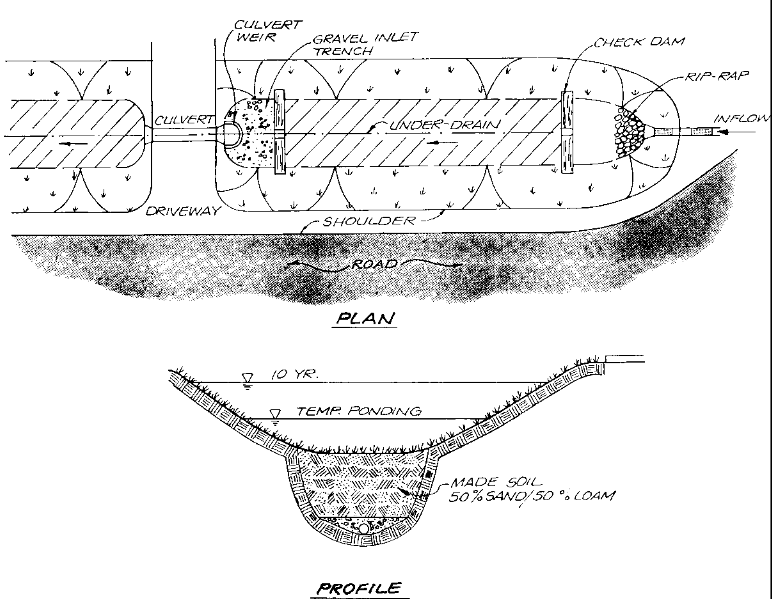

Figure 2: Schematic of the Dry Swale

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