CONTAMINANTS IN RAINWATER AND THEIR REMOVAL

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ABSTRACT

As rainwater harvesting and reuse becomes more common, concern about potential contaminants has increased. A discussion of contaminants expected to be present in rainwater is provided, for roof runoff rainwater and roadway and parking lot runoff water, as well as a discussion of some methods and designs for removing these contaminants.

Keywords: Stormwater, rainwater,

INTRODUCTION

Rainwater harvesting is an important way to preserve groundwater and surface water resources, especially in dry areas such as Texas and the Pacific Southwest. Each gallon of rainwater that can be saved from runoff and diverted to domestic or industrial use is a gallon that does not have to be pumped out of the ground. Aquifers in many parts of the United States and other parts of the world have been severely depleted by overuse. Some areas of the United States, such as San Antonio, Texas, depend almost exclusively on groundwater for potable water and as these areas grow in population, the strain on the aquifers increases.

Rainwater from various sources may be contaminated with solid particles, floating oil droplets, and some dissolved components.

TYPES OF RAINWATER HARVESTING

Rainwater harvesting has been known since at least ancient times; catchment cisterns can be seen in the citadel at Masada in Israel and also at Anasazi Indian sites in the southwestern US.

Rainwater runoff may be harvested from roofs or paved areas in cities and from pastures and other grassy areas in rural parts of the country. Water harvested in rural areas is usually directed to ponds, where it is used for livestock watering and to some extent for irrigation. This water may contain pesticide and fertilizer residue, but because it is widespread and there is no way to contain and treat the runoff, little can be done about it except to try to minimize the use of pesticides and fertilizers.

Rainwater runoff harvested from roofs in urban areas is generally used for landscape irrigation, although it may also be used (generally as non-potable water) for restrooms. Portland State University, in Oregon, has a rainwater harvesting system that services two public restrooms. This system is provided with chlorination equipment which is set automatically using an amperometric sensor. It is believed that this system tends to stay solids free due to the height of the building (no leaves) in combination with the fact that there is an eco-roof in the catchment area, which acts as a filter. The photo below shows the rainwater harvesting system from a metal roof at a building in Denton County, Texas

Rainwater Harvesting System in Denton County, Texas

Stormwater harvesting may also be done from parking lots, roadways, or bridges because these are usually provided with storm sewers to carry the water away.

Parking lot and roadway water presents a different situation than roof water because of contaminants that may be present which would not be expected in roof runoff water.

CONTAMINANTS THAT MAY BE PRESENT IN ROOF RUNOFF WATER

The contaminants that are to be expected in roof water runoff are limited in both quantity and constituents because (with the possible exception of contaminants from the roof itself) there is little traffic on the roof and the only way that contaminants can be there is if they are blown on the wind or deposited by birds.

In general, metal roofs do not present a contaminant problem because they are either made of powder coated materials or galvanized and the coating is sturdy and does not slough off.

Commonly, roofs are used as catchment areas and roofing material includes metal, clay/concrete tile, composite or asphalt shingle, wood shingle and slate. The quality of rainwater collected is a function of the roof texture: the smoother, the better (Brown, Jan, Stephen, & Krishnia). Certain catchment surface types, such as composite or asphalt shingle roofs, are not suitable for potable reuse systems because toxins can leach into runoff. Additionally, a roof can collect dust, leaves, blossoms, twigs, animal feces, pesticides and other airborne residues (Brown et al). These are still suitable for landscape reuse.

CONTAMINANTS THAT MAY BE PRESENT IN PARKING LOT AND ROADWAY RUNOFF WATER

Hydrocarbons:

Whereas roof runoff is of generally good quality, parking lot and roadway runoff water is likely to be much greater in quantity because of the larger areas concerned.

Contaminants in urban runoff water are primarily derived from rainwater from streets, parking lots and highways. Hydrocarbons in this water include primarily gasoline fractions, diesel fuel, and automotive and truck crankcase oil leaks. Of these, crankcase lubricating oil and diesel fuel predominate in runoff water (Romano).

A study has shown (Hunter, et al), that runoff water from highways can contain an order of magnitude more hydrocarbons than runoff from other urban areas. Some of the hydrocarbons in runoff are associated with particulate matter. This indicates that systems designed to deal with rainwater should also be designed to handle the associated solids.

Solid Particles and Dissolved Materials:

It is recognized that floating trash and dissolved materials (such pesticides, nutrients, and benzene) are also contaminants, but these subjects have been extensively discussed elsewhere. For these reasons, the scope of the following discussion has been limited to discussions of sediments, metals, and hydrocarbons in rainwater.

When rainwater comes in contact with solids, such as rotting leaves, it picks up natural organic matter (NOM), which causes taste and odor problems (Hill, n.d.). *If harvested water is intended for potable use, it should be kept in mind that chlorination of water containing NOM can cause formation of carcinogenic disinfection byproducts.* Additionally, fine particles in rainwater runoff have been shown to carry heavy metals, PCBs, PAHs and other pollutants (Leisenring, Clary, Lawler, & Hobson). While the water quality of runoff from roads and parking lots is different due to different usage than that of rainwater harvested from roofs, precautions should be taken to remove solids before harvested rainwater is stored; removing solids lowers the cost of maintenance and increases water quality.

TOXIC EFFECTS OF CONTAMINANTS: Various contaminants have been shown to have adverse effects on human beings as well as to aquatic life. Concentration levels as low as 10 to 100 micrograms per liter have been shown to adversely affect aquatic organisms by altering processes such as feeding or reproduction (Romano). Table 1 below shows some possible adverse effects and recommended criteria.

TABLE 1: COMPARISON OF TYPICAL STORMWATER POLLUTANT CONCENTRATIONS TO WATER QUALITY CRITERIA

Concentrations, µg/l or ppb					Particulate Fraction	USEPA/Washington Dept of Ecology Standards, Freshwater	
Pollutant	**Commercial**	**Industrial**	**Residential**	**Highway**		**Acute**	**Chronic**
Cadmium	5	5	<3	<3	60%	0.60	0.32
Copper	245	105	20	100	60%	3.9	3.0
Lead	380	245	210	1780	90%	10.5	0.41
Zinc	275	275	120	400	60%	30.0	27.0
Oil/Grease	15 ppm	480(5)	<5(5)	90(5)		10 ppm	

Notes: ***1) Particulate fraction values apply to concentration date for commercial and industrial uses only***
2) Acute Criteria for freshwater at a hardness of 20 ppm
3) Standards are receiving eater standards except oil and grease
4) Oil and grease standards Washington State Department of Ecology
5) Source: City of Seattle Engineering Dept. (Paston)

Source: Stormwater Management Manual for Puget Sound Basin, 1992

Sediments:

Buchholz (1994) notes that in many rainwater monitoring programs: "Sediments were the most critical and frequently observed pollutant in rainwater flows."

In a study done in Philadelphia, PA, Hunter, et al reported suspended solids content from 26 to 118 mg/L, with an average of 87 mg/L. It is likely that in many areas, sediment contents are greater than this. Snowfall is not as important a source of solids because suspended solids loading for snowfall precipitation are approximately one half those for rainfall (Bennett, et al).

Since researchers have found that hydrocarbons tend to partition to the solids in a rainwater stream, and many of the particles are automotive exhaust particles (Eaganhouse), removal of sediments should also tend to help reduce the hydrocarbon content of the rainwater. Conversely, failure to remove the particles from the rainwater should allow some of the hydrocarbons to pass through a separator. Sediments can also contain heavy metals.

Sediments in water can contain nutrients and provide substrate for bacterial growth, which are unwanted in Rainwater Harvesting Systems.

Heavy Metal Contaminants:

A report by the EPA on the San Francisco Estuary Project indicated that most pollutants in the estuary were due to agricultural and forest management activities, but that urban runoff was the most significant contributor for lead and hydrocarbons. Buchholz agrees that lead in rainwater is most significantly contributed by urban environments. A private study made of samples of street gutter sediment, collected at sites in the city of Coral Gables, Florida, showed copper contents from 40-350 mg/kg, lead contents of 60-500 mg/kg, and zinc contents from 500-1600 mg/kg (Gamble). This indicates that street sediment may be a significant contributor of metals.

Hunter, et al. reported: "The storm-sewer loading from an area representing 0.83% of the total Philadelphia urban area represented three quarters of one of the seven refineries in the same area." Their calculated hydrocarbon pollutant loading for the study area was 22.9 lb/year/acre. This data would tend to support the assertion made above that rainwater is a very important source of hydrocarbons in the environment. It is also recognized that hydrocarbons exist in snowmelt runoff, but not to as great an extent as are found in rainwater (Bennett, et al).

Solids Removal from Rainwater:

To remove solid pollutants, a number of treatment processes may be used. Screens may be placed on gutters and downspouts, which prevent larger solids from entering storage tanks. Settling devices, which remove solids and non-aqueous liquid pollutants, may also be used before rainwater enters storage. Settling devices are convenient as they do not require filter replacements and can remove quite small particles. Manufactured filtering devices, activated charcoal filters and slow sand filters provide excellent solids removal down to very small particle sizes, but must be maintained. Such maintenance is often not completed as required for good performance and may be very expensive. The California Department of Transportation (CALTRANS) installed many filtration type systems along a major southern California freeway and subsequently abandoned them because of the cost of maintenance (Hanley).

In a recent study by Gorski & Fish, at Portland State University, the solids removal capability of an MSR coalescing plate separator was tested according to regulatory standards established by the Washington Department of Ecology. Sil-Co-Sil 106, a ground silica product manufactured by U.S. Silica Company, was used to simulate stormwater solids of concern, typically found in developed stormwater catchment areas (roadways, industrial areas and in parking lots).

Solids used in this experiment have a density similar to that of sand; approximately 30% of solids of the test solids are smaller than 10 µm, and 96% of the particles are smaller than 100 µm, which is about 0.004 inches. Further detail of the particle size distribution of test solids may be seen below in Figure 1. While the solids used in this study are not necessarily representative of solids found in rainwater harvesting catchment areas (this readily available solid mixture has often been used for rainwater processing equipment testing in New Jersey and other jurisdictions), the study shows the MSR unit to be very effective at removing fine solids.

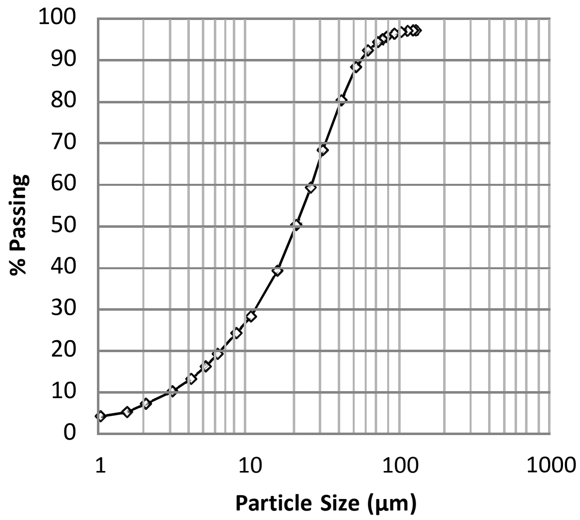


Figure 1: Particle Size Distribution of Test Solids Used in Assessing Solids Removal Capacity of the MSR Coalescing Plate Separator (U.S. Silica Company)

The performance of water purification devices that use sedimentation as their primary treatment process, such as the MSR unit, will depend on influent characteristics. Particle size, shape, density, and the rate of flow entering the device, among other variables will determine the solids content exiting the device. Particle sizes exiting the MSR unit from the Gorski & Fish study were measured using light obscuration methods at different flow rates. Results may be seen in figure 2. As expected solids removal decreased with increasing flow rates and smaller particles are less likely to be removed

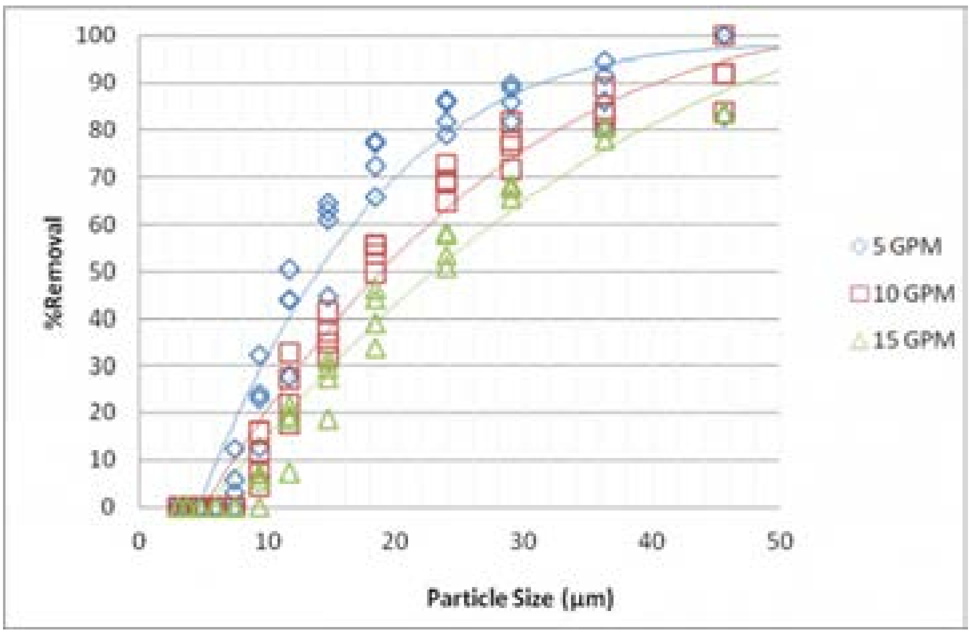


Figure 2: MSR Removal of Particle Size by Percent for Simulated Storm Solids Adapted from Gorski

OIL REMOVAL FROM RAINWATER

Systems for removing oil from water range from very simple holding ponds, with or without skimming arrangements, to very elaborate membrane technology-based systems. For most applications in removing oil and solids in rainwater, the simplest systems are often inadequate (although often used) and the most complicated are either too expensive or too maintenance-intensive. Most of the following discussion, therefore, will concentrate on methods intended to provide high quality separation with minimum cost and maintenance.

Gravity Separation

The simplest possible separator is an empty chamber, but they are not effective at removing small particles.

A somewhat more efficient separation system is the API separator. The American Petroleum Institute (API) provides design criteria for oil-water separators. API separators are gravity type separators, but are generally larger, more sophisticated and more effective than simple separators. API separators are extensively used in oil refineries and chemical processing facilities where waters containing relatively large amounts of oil are present, but the design method is only arranged for removal of droplets down to about 150 mg/L in the effluent – not sufficient for environmental purposes. A diagram of a typical API separator is shown below in Figure 3 (Adapted from API Publication 421, 1990).

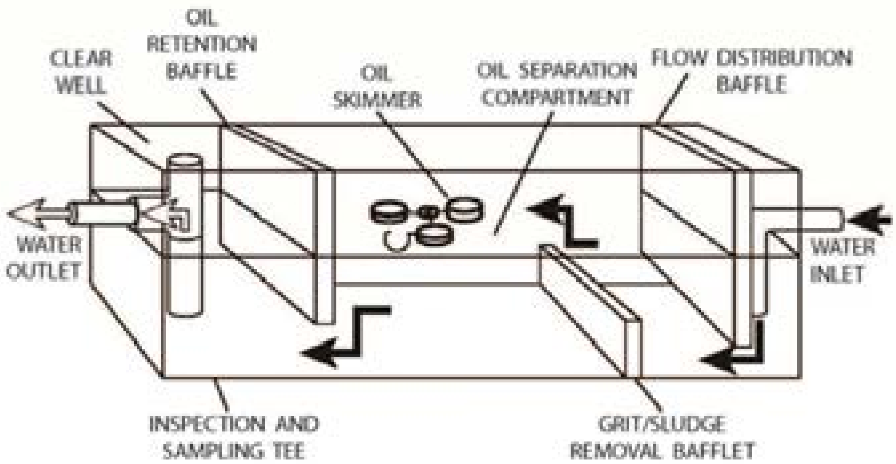


Figure 3: Typical API Separator

The primary disadvantage of these simple gravity separators is the poor quality of separation that they provide.

Coalescing Plate Separators

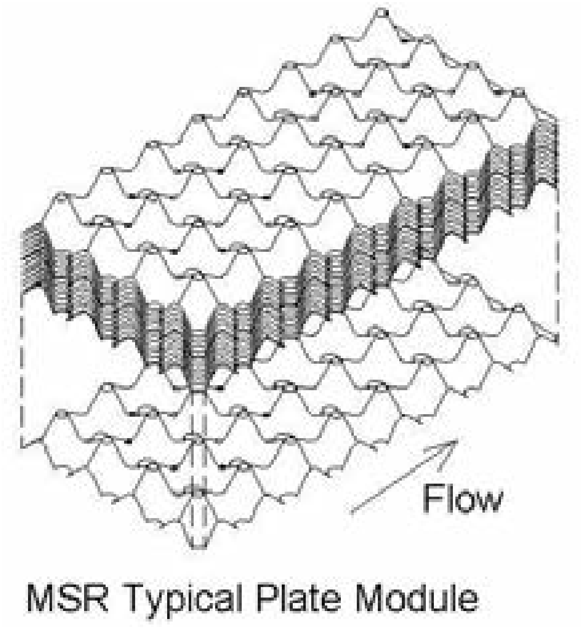
Coalescing plate separators will remove sediments, hydrocarbons and heavy metals in concentrated form, either as separated oil or as sludge. This also means that metallic contaminants may be removed completely from the environment instead of becoming part of the soil matrix in a grassy swale, or perhaps even entering the groundwater through a recharge basin. A typical coalescing separator is shown in the photo below.

Typical Coalescing Separator

MSR Multiple Angle Plate Module Coalescing Separator

Multiple angle plate separators were developed to remove the oil (and incidentally solid particles) in an effective manner and still be resistant to unreasonable plugging by solid particles.

These separator plates are corrugated in both directions, making an "egg-carton" shape. Spacers are built into the plates, constructed so that two spacings (nominal 8 mm and 16 mm) can conveniently be made. Narrower spacings are more efficient and wider spacings are more resistant to plugging by any solids that might be present. A sketch and photo are provided below.



The flow in a module such as this is along the long axis of the module. Oil droplets rise up and meet the undersides of the plates where they are separated and solids particles fall onto the top surfaces of the plates and are directed to the bottom of the separator.

There is a maximum flow rate per volume of media that will still be within the laminar flow requirements of Stokes's Law. To meet this flow limit per module, MSR designs systems using multiple modules with modules placed side by side and stacked as high as necessary to allow for the flow rate and, at the same time, maintain laminar flow. If the process simulation program indicates that a single row of coalescing media will not be sufficient to provide effluent quality that meets the requirements, multiple rows of media can be provided. Systems have been successfully designed up to 20000 US gallons per minute (4550 cubic meters per hour).

OPERATION OF A SEPARATOR IN RIVER WATER SERVICE

The water flow in a river is simply rainwater downstream of the catchment, and so the experience with a river water separator in removing solids and oil for bacterial growth suppression may be seen to be analogous to treatment of water in a rainwater catchment system. Two separators are installed at a Pacific Northwest hydroelectric plant, and one was refitted with MSR separation media in 2010. The other parallel separator was not refitted (until 2012) and the following discussion of operations before the second refit is therefore pertinent to rainwater systems. The information below is excerpted from Mohr and Sembritzky, 2013:

"The two separators started out with brand new media and an all clean system. One separator had the MSR high efficiency media, the other was filled with the original old media.

Separator with MSR Media Partially Installed

The supply is evenly shared between the two systems. After a year there was a startling difference in the amount of oil collected between the two.

Grab samples taken after several months of operation indicate that there was very little oil in the incoming water and everything was clean. The analysis method used was EPA 1664, which is a hexane extraction/infrared spectrophotometry. There was not a large difference noted between inlet and outlet water oil contents, but this is likely due to the very small droplet size distribution expected because of the very small inlet concentration.

After more than one year of operation, the new high-efficiency media installed in the separator has been shown to be much more efficient than the previous media by comparison of the captured oil and bacterial growth. The photos below illustrate the difference in operations of the separators with the old media and the new high-efficiency media.

Separator with Old Media and Little Oil Collected on top of Water

Separator with New Media and Large Quantities of Oil Collected

In the old media photo, it is difficult to see the collected oil, but in the new media separator, large quantities of oil can be seen.

Old Media Separator Water Overflow with Substantial Bacterial Growth

New Media Separator Water Overflow with Little or No Bacterial Growth

The gray fringes on the water overflow weir photo shown at left above indicate substantial bacterial growth. The bacteria use the oil as a food source (Green and Trett), so when the oil is not removed almost completely, some of the oil will pass into the downstream end of the separator and bacterial growth will occur there.

The water overflow weir in the photo at right above is from the separator with the new high efficiency media. The absence of bacterial growth in this system indicates that the oil has almost completely been removed to the top of the water level, where it cannot be readily accessed by the bacteria for food.

There is a remarkable difference in operations between the two separators with the different media. After one year of head to head service, the original media has managed to collect a small sheen in the oil collection chamber, whereas the MSR high efficiency media has a thick layer of oil that is clean with little biology growing in or on it. It would appear that this oil has collected to a level that is actually overflowing into the oil pocket and oil is being removed. This has not been seen in the ten years that the author has tried to fix the system. It is now worthwhile to put in a proper skimmer.

Old Media after One Year's Operation

Above is an example of the old media after one year’s operation. The amount of growth and solids collected here was an operational problem which was further compounded by the downstream foam packs. These tended to clog and cause more solids to plug the media and the water to overtop all of the separation media.

Further, the overall growth of algae is drastically different. The old media is covered and packed with growth, and the MSR media looks very clean.

This is because the new media is optimized for oil-water separation, whereas the previous media was designed to promote bacterial growth in trickling filters.”

SUMMARY AND CONCLUSIONS

Rainwater is often ***not*** simply pure water, and urban rainwater contains significant impurities in the form of sediments, heavy metals, and hydrocarbons. These can be substantially removed by the use of coalescing plate separators. Removal of sediments and oil will reduce the BOD of the rainwater, and thus, reduce or possibly remove the necessity of treating the water with chlorine or other disinfectants. Reduction of disinfectant use will also reduce the production of chlorinated hydrocarbons, which are known to be carcinogenic. Reduced disinfectant use also results in reduced costs for disinfectant and also reduced maintenance costs. This will also result in the captured/stored water being of higher quality.

Maintenance of any catchment and treatment system is essential to ensure that it will operate as designed and minimize its effects on the environment.

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