Water Quality Benefits

Green Roofs can be very effective as method for improving water quality. A recent study in Charlotte, North Carolina, showed that in addition to heavy metal pollutants, 10-30 percent of nitrogen and phosphorus pollutants contributed to streams and lakes are derived from runoff from urban roofs. These pollutants are the principal culprits in degrading aquatic habitat. Dust containing a range of pollutants accumulates on roofs until it is washed off with next rainfall. Furthermore, the acidity of runoff from roofs is typically higher than already acidic rainfall.

Plants are not necessarily effective in removing nutrient pollutants like nitrogen and phosphorus. However, recent research conducted in Germany has shown that green roofs can be surprisingly effective in improving the quality of roof runoff. These water quality green roofs utilize coarse-grained mineral media and Sedum plant varieties.

The research cited here was prompted by an effort to reduce pollution in the River Spree in Berlin. Zoning requirements for the new Potsdamer Platz district include green roofs for all buildings, including high-rise structures. Fertilization of the green roofs is not permitted. The overall plan for Potsdamer Platz included a combination of water quality green roofs, water treatment reflecting pools, settling basins, and created wetlands. All these features are integrated into the landscape design for this ultra-urban architectural space.

The experience at Potsdamer Platz provides encouragement that green roofs can become an important tool in improving water quality in critical watersheds here in the United States

Study of extensive “Green Roofs” in Berlin

By Manfred Köhler and Marco Schmidt
Part III Retention of Contaminants
(*translated by Saskia Cacanindin*)

Summary:

The ability of Green Roofs to bind and retain contaminants is not sufficiently recognized at this time. The two studies discussed here show initial results regarding this topic. Two contradictory processes are apparent in green roofs. On one hand, green roofs retain and bind contaminants which are introduced either as dry dust particles or suspended and dissolved in rain water. On the other hand, contaminants can be leached out of the substrate used in the green roof’s construction, which can complicate the reuse of the runoff water. This is particularly noticeable immediately after installation. When specifying substrates for use in green roofs that are intended to achieve water quality objectives, more attention should be paid to the nature and quantity of contaminants that a certain substrate is able to bind and retain. However, with the appropriate choice of substrate, mature green roofs can contribute to a significant reduction in the pollution of

the receiving waters. The results discussed here are compared to a conventional, unplanted bituminous roof and to two green roofs that were installed 15 years ago. The substrate depth utilized in these two green roofs was 5 cm and 12 cm.

Every year in late summer the same picture presents itself in Berlin: The algae bloom abruptly terminates the enjoyment of playing and swimming in the lakes and rivers. Even though laws were passed in the past decades that put a significant financial burden on polluters and large sums were invested in the expansion of water treatment plants, no real qualitative improvement of the water can be identified (1). The true extent of indirect 'non-point source' contributions to runoff contamination has only recently been addressed (1). The two main indirect contributors of contaminants are agriculture and urbanized areas. While pollution from agriculture is diminishing in recent years, the impact from urbanized areas is increasing with a daily expansion of 120 hectare. The amount of settled land and land used for traffic infrastructure has doubled within the last 40 years. In Berlin alone the daily loss of open space is more than one hectare (2).

Because of the ever-increasing amount of impervious surfaces, significant quantities of nutrients and pollutants find their way into surface waters. Bodies of water are also hydraulically impaired by high runoff rates, especially during heavy rain events. There are two major ways that contaminants enter surface waters:

- In areas with separate storm and sanitary sewage systems, nutrients and pollutants that accumulate on impervious services become entrained in rainfall runoff and directly enter surface waters with every rain event.

- In areas with combined storm and sanitary sewage systems, heavy rain events frequently cause an overload of the system and untreated sewage enters surface waters directly.

One tool for combating the negative impact of impervious surfaces is the establishment of decentralized compensatory mitigation areas, as specified by the "Interference Regulation" of the German Environmental Protection Act. Here green roofs play a central role. Also, the introduction of fees for the treatment of rainfall runoff by municipalities or public utility services further increases the importance of green roofs.

The positive ecological impact of planted roofs on urban hydrology must be viewed in context. In areas with separate sewage systems the retention of contaminants is crucial. However, in areas with combined sewage systems, control of storm water runoff rates is paramount. In this third part of the Berlin Study the retention of contaminants is discussed. Storm water retention will be discussed in a later publication.

Illustration 1 shows the net amount of nutrients and heavy metals retained as a percentage of the influx from precipitation. The data was collected in the experimental plots of the Technical University of Berlin in Charlottenburg (Study Englische Strasse, s.(3)). A recycled soil substrate was utilized. The soil type was a loamy sand with rock fragments. The illustration shows the median results derived from three years of measurements.

Illustration 2 shows the increase of phosphate retention efficiency after establishment of the vegetation.

The amount of discharge from the system is, on one hand, dependent on the successful establishment of the vegetation and, on the other hand, on the substrate and its potential to leach stored substances. The quantity of contaminants discharged, depends on the origin of the substrate and the percentage of organic matter. The influence of the substrate on performance is especially noticeable immediately after installation, with a potential for net additions of contaminants. In this experiment chemical soil analyses that were performed on the substrate did not show any significant changes over time. The discharge and/or retention of the systems were mostly explainable as a function of the amount of the influx through precipitation and/or the retention by the vegetation.

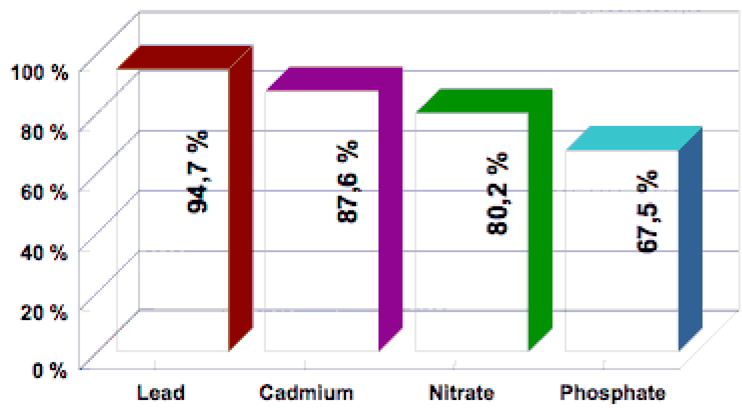

Illustration 1: Retention of contaminants by extensive green roofs (retention as percentage of influx)

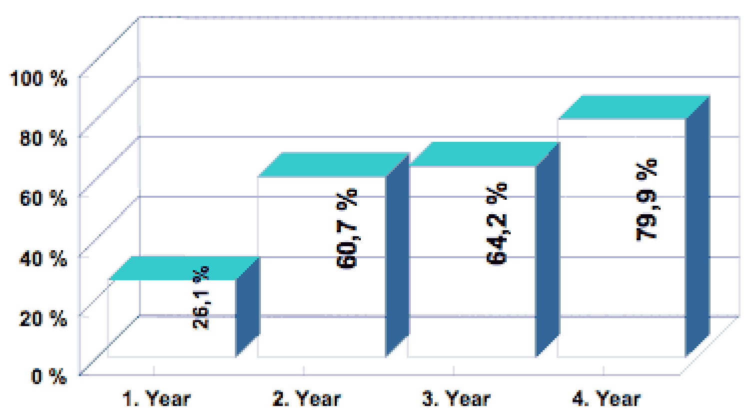

Illustration 2: Development of phosphate retention after installation of green roof (retention as percentage of influx)

Facing the possibility of an initial negative impact from nutrient releases on receiving waters from green roofs a preliminary study was commissioned for the green roof project "DEBIS am Potsdamer Platz." The purpose of the study was to optimize the choice of substrate (4). The goal was to keep the discharge of contaminants as low as possible.

The green roofs in this project are part of an integrated management concept for rainfall runoff that limits the runoff from the development area into the combined municipal sewer system to 1.5% of the precipitation (4,5). Several storm water management tools were combined to handle the 23,000 cubic meters of rain water per year from the 19 buildings of the DEBIS area (6). The discharge factor for the Berlin region is 0.25 with 10 cm extensive green roofs installed (this equals a median yearly evaporation of 75%) (7).

The runoff from the mostly planted roofs is collected in five cisterns with a total capacity of 3,500 cubic meters. This water is used for toilet flushing and irrigation of landscaped areas. The remaining runoff is channeled into an artificial pond system with a surface area of 12,000 square meters (6). The intended uses of the runoff imposed strict requirements for the green roof substrate. On older, mature green roofs the amount of organic matter found is only 2.9-5.1% vol. (8). This was the reason why, after arrangement with the Atelier Dreiseitl and the project landscape architect, Daniel Roehr (office Krüger and Möhrle), only purely mineral substrates were included in this study. A high content of organic matter leads to mineralization processes during cycles of wet and dry periods that can cloud the runoff considerably. The turbidity and nutrient content of this runoff was not compatible with the intended reuse of the rainwater.

Recycled materials also had to be excluded from further analysis after the first chemical and physical laboratory tests. The resulting trials focused on the following commercially available materials: A substrate based on lava rocks (Zeoflor 4/8), an expanded slate (Ulopor 1/11), and a sand/ lava/ pumice mix (Terramineral "Z"). These substrates were installed on test plots measuring 2 square meters each. Subsequently the runoff characteristics and the retention of contaminants were measured. [*Note: The performance of Terramineral was influenced by its origin, which was an unspecified agricultural source*]

Table 1: Water capacity and dry density of the tested substrates

Substrate	Field Capacity [Vol. %]	Dry Density [t/m^3]
Terramineral "Z"	33.80	0.93
Terramineral "E"	24.22	0.94
Zeoflor 4/8	25.60	0.94
Ulopor 1/11	22.29	0.68
Ulopor 0/2	60.43	0.82

By measuring the electrical conductivity of water, the amount of dissolved solids can be determined. Precipitation water usually has a conductivity of 10-100 µS/cm (9). High conductivity signifies contamination of the water with inorganic components. The 'first flush' effect can be recognized in the decreasing conductivity of runoff during a rain event. Compared to the electrical conductivity of precipitation during the study, all runoff from the test plots had an increase in electrical conductivity. The conductivity was 200 and 250 µS/cm for Zeoflor and Ulopor and 320 µS/cm for Terramineral "Z".

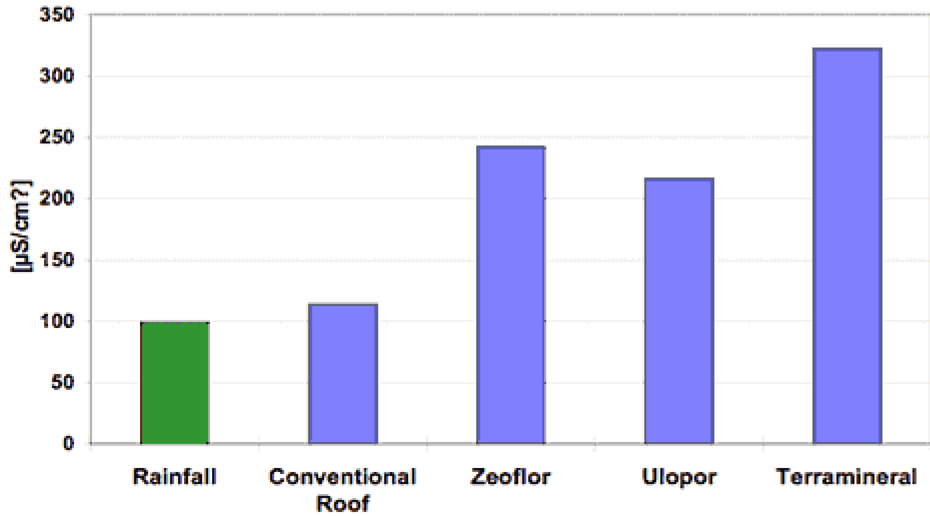

Illustration 3: Electrical conductivity (median) of the runoff from tested substrates between 8/7/97 and 1/21/98.

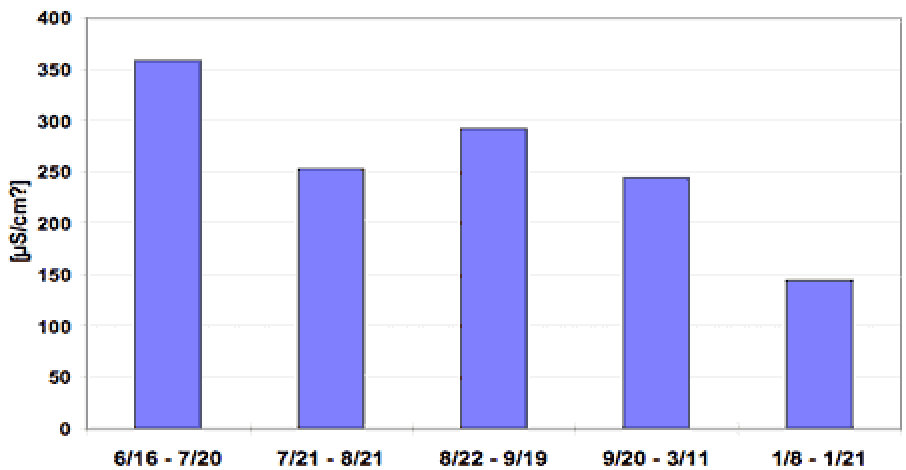

Illustration 4: Change in conductivity of the runoff as a median of the three tested substrates

Precipitation is characterized as very soft and poorly buffered (aggressive) because of its low pH and its low general hardness (8). This study shows that all the tested substrates cause a rise in the pH. The pH of the rain water was measured as slightly acidic throughout the study. The runoff from the conventional roof was even more acidic, with a minimum pH of 3.2. Regarding buffering ability (especially during longer rain events)

Zeoflor and Terramineral "Z" were more suitable than Ulopor. Runoff from all test plots showed a decreasing pH during longer rain events because of the shorter retention times.

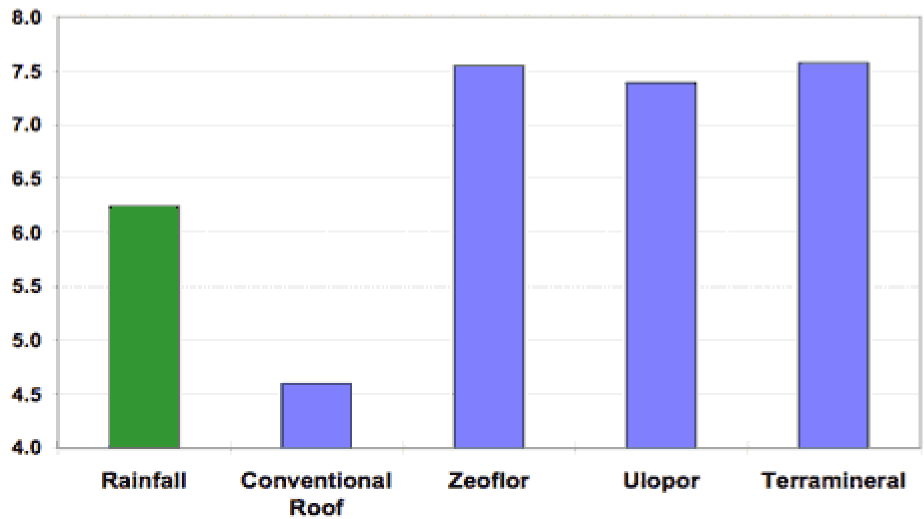

Illustration 5: pH (median) of the runoff from the tested substrates between 8/7/97 and 1/21/98

Conclusions about the relative quantity of contaminants discharged from the different substrates can be drawn from the turbidity of the runoff. Turbidity was measured using a photometer manufactured by Perkin Elmer for the frequencies of 245, 420 and 539 nm. The expanded slate caused a notably small degree of turbidity. Especially in the beginning of the study the difference in coloration and turbidity compared to the other two substrates was visible. The turbidity in runoff from Terramineral was comparably high because of the pumice component in the substrate. However, the highest turbidity was observed in runoff from a recently installed conventional bituminous roof.

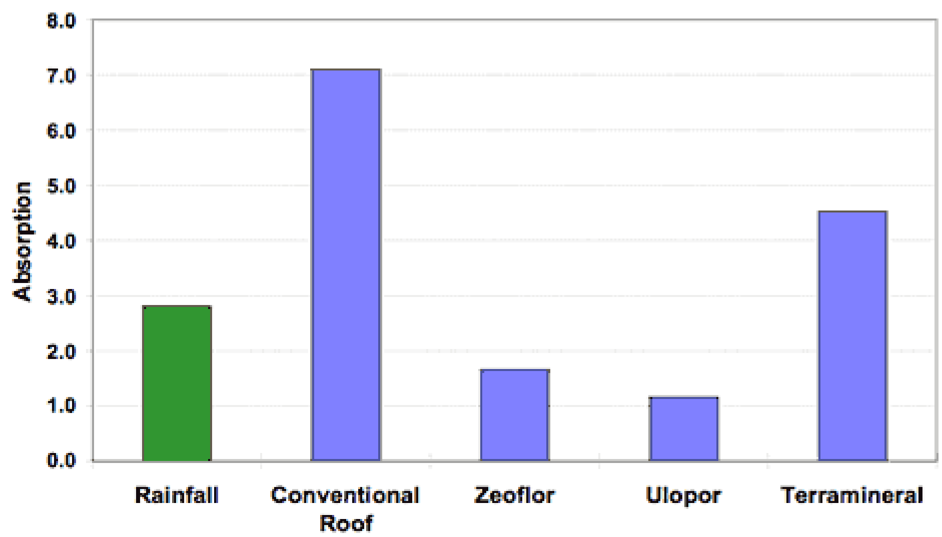

Illustration 6: Turbidity of runoff, measured at 420 nm, from the tested substrates between 8/7/97 and 1/21/98

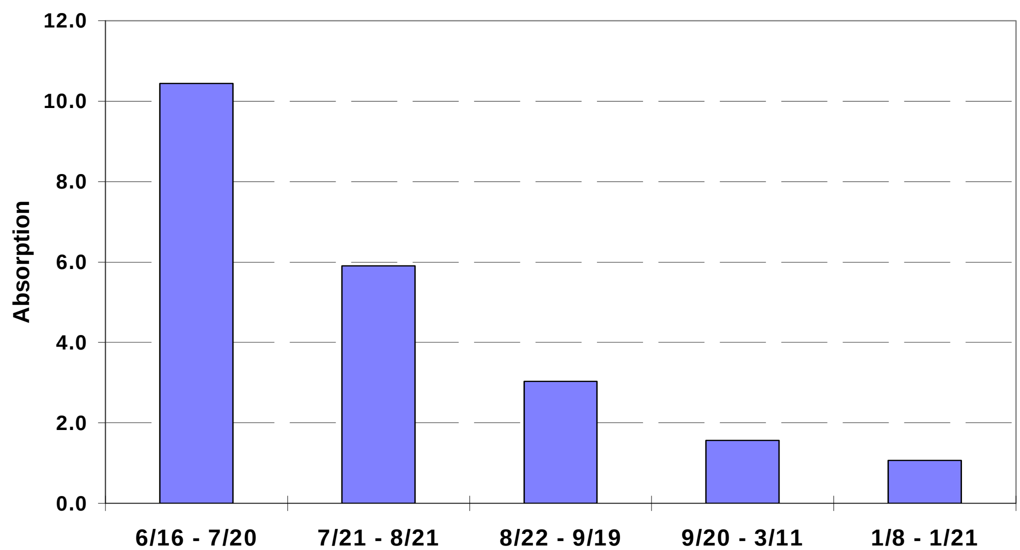

Illustration 7: Change in turbidity of runoff, measured at 420 nm, from tested substrates from 8/7/97 to 1/21/ 98

Nitrogen compounds are introduced in two ways:

1. by means of dry dust particles and
2. by compounds dissolved or suspended in rain water

Nitrate and ammonium account for approximately 1/6 of fine dust particles in Berlin (11). These contaminants are associated with the water soluble components of wind-borne dust. Sources of dissolved nitrates in rainfall are nitrogen oxides that mainly originate from internal combustion engines or from furnaces. The nitrate concentration in rain water shows a distinct seasonal dependency. Especially in the biologically active summer months, high nitrate concentrations are apparent. The reason for this is the faster oxidation of nitrogen oxides associated with high temperatures. Ammonia from agricultural use of fertilizers and from cattle is transformed into ammonium in the atmosphere.

At the test plots the introduction of nitrate in precipitation was 1.98mg/m^2 per day. This was distinctively lower than the amount of 7.4 mg/m^2 measured for inner city areas like Potsdamer Platz (10). The introduction of ammonium at the rate of 1.19 mg/m^2 per day during the study was also below the rate of 2.4mg/m^2 per day measured by TÜV. The illustrations show the discharge of total nitrogen which includes N from both NO3-N and NH4-N. This method of reporting is necessary because within the test plots ammonia is transformed into nitrate through nitrification.

Zeoflor and Ulopor show good net results for nitrogen. Terramineral also binds nutrients but in distinctively smaller quantities compared to the other substrates. This is due to the high nutrient content of the pumice, which was derived from a former agricultural area.

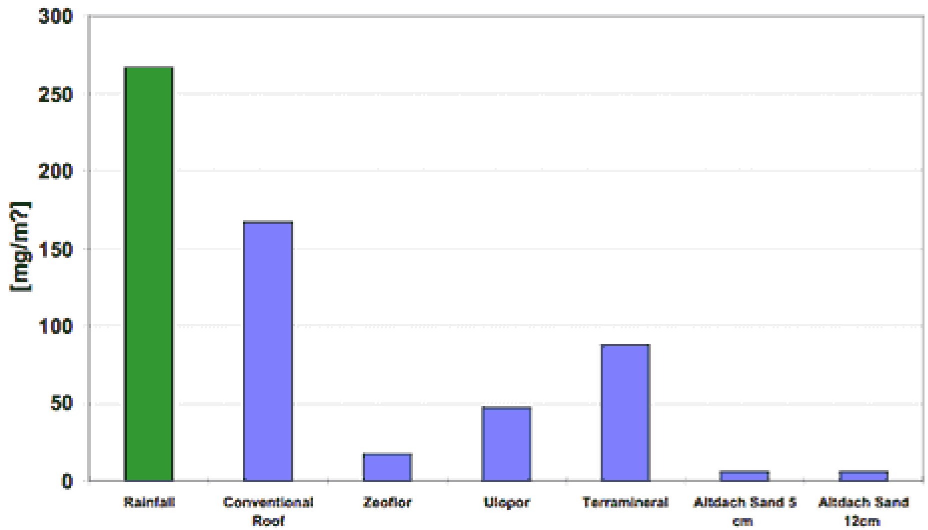

Illustration 8: Total nitrogen discharged from 8/7-11/3/97 and from 1/8 –1/21/98

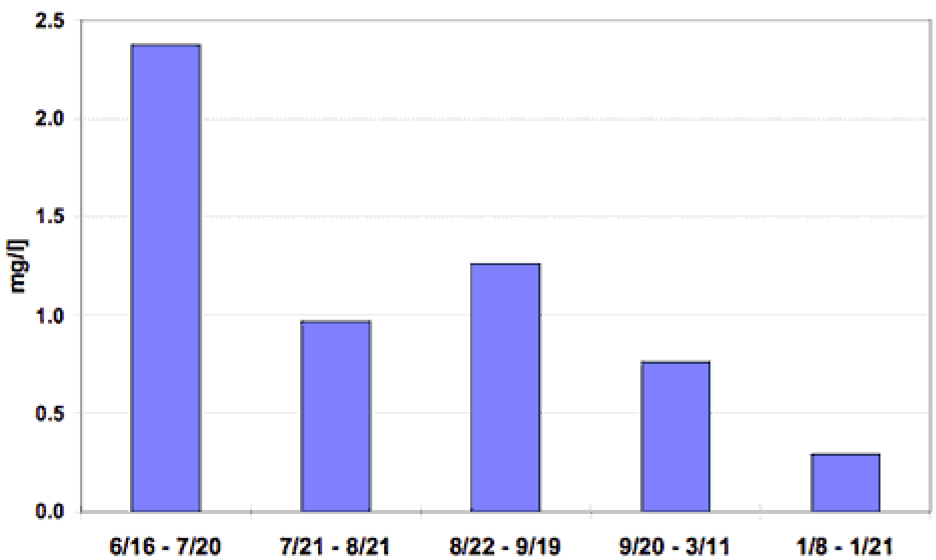

Illustration 9: Total nitrogen discharged (median of the three tested substrates)

Phosphate originates, like ammonia, mainly from the agricultural use of fertilizers and reaches Berlin through wind borne dust that can transport contaminants large distances. The average concentration of phosphate in the runoff from the test plots was 1.9 mg/l. This comparably high concentration of phosphate in the runoff as well as in the rain water is due to the proximity of the agricultural trial fields of the Technical University of

Berlin and Humboldt University. There are no apparent trends in the pattern of phosphate discharge over time.

Phosphate is the growth limiting factor on roofs and a significant amount of retention can only be expected after the successful establishment of vegetation. This is especially apparent from the measurements on the older green roofs that were taken for comparison. The discharge from these roofs was 5-10 mg/m^2 lower than the discharge from the still newly planted (and mostly bare) test plots.

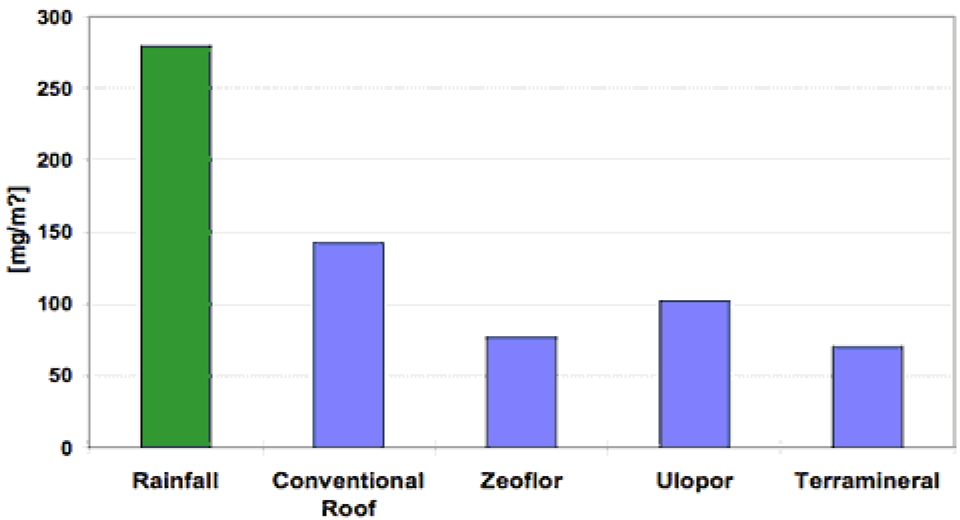

Illustration 10: Discharge of o-PO4-P from 8/7-11/3/97 and from 1/8 –1/21/98

Results

Green roofs can clearly help protect surface waters. The four-year study of the Forschungsprojekt Englische Straße showed a significant retention of contaminants. The magnitude of this effect is dependent of the depth and the nature of the substrate as well as the nature of the vegetation.   A preliminary study was commissioned to help with the choice of substrate for some of the roofs at the Potsdamer Platz. The goal was to find substrates that would help to minimize the discharge of contaminants and/or retain nutrients. The characteristics of promising substrates were tested. The study yielded the following results: the pumice content (from an agricultural source) of the substrate Terramineral causes a higher discharge of contaminants. The substrates Zeoflor and Ulopor were only available in limited grain sizes (4-8mm and 1-11mm). This led to higher runoff during heavy rain events. Based on the study results a two-layer system was installed, utilizing Terramineral and Ulopor, therefore combining the positive characteristics of the two substrates with respect to water and nutrient retention. Weeds initially germinated in the Terramineral substrate as a result of its origin. The weeds disappeared in the first dry periods of summer. Compared to substrates with a high content of organic matter and targeted applications of fertilizer, a slightly slower development of the vegetation was noticeable.

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