# Performance of In-Line Sediment Control Devices Under Field Conditions

C.P. Cavalhieri, S.J.A.M. Campos, A.L.C.F. Gallardo, O.Y. Bitar

**Abstract.** A wide variety of structural best management practices (BMPs) has been developed in the last few decades to control erosion-related problems at construction sites. Even though many BMPs exist to control erosion and sediment accumulation, there is very little research on their performance and this is even more pronounced when considering the performance of these devices working together and under field conditions. In an effort to address this issue, this study analyzes the performance of in-line devices installed at six drainage exits of a new highway under construction, all of them located upstream and 1.0 km to 2.5 km far from a surface intake in a public water supply reservoir. Altogether, three categories of devices were studied: gabions, silt fences and turbidity curtains. The performance of each device was assessed based on inspections at the construction site after heavy rains, by visually checking changes in the apparent color of the water and accumulation of sediments. Complementary, water quality monitoring data collected at the water intake were analyzed by comparing two different periods: before (from 2002 to 2007) and during (from 2008 to 2010) the construction of the highway. Results indicated that the six drainage exits with BMPs installed in-line did not affect the quality of the water at the surface intake. In addition to that, although each of these devices could not function properly due to unsatisfactory maintenance and sometimes by their own low filtration rates, all of them contributed to retain sediment and keep it close to the limits of the construction site.

**Keywords:** sediment accumulation control, in-line best management practices, highway construction.

## 1. Introduction

Construction activities usually disturb many elements of the natural environment. These land-disturbing activities include vegetation removal, earthworks and civil works, which concentrate stormwater runoff and, according to Barret *et al.* (1995), increase soil loss and pollutant discharges.

Among all the pollutants that can be carried away in a stormwater runoff, sediment is the most commonly documented and it is a significant component of nonpoint source pollution (USEPA, 2008). When runoff transports eroded soil to water bodies, many resulting adverse environmental impacts may affect aquatic ecosystems (Hedrick *et al.*, 2010), vegetation (Benjankar & Yager, 2012) and use of water resources. In doing so, it is imperative that construction activities incorporate all kinds of mitigation measures in order to reduce discharges of sediments and other pollutants in water bodies (Zech *et al.*, 2008).

In order to minimize negative impacts, especially those related to the intensification of erosion and its effects on water bodies (Forsyth *et al.*, 2006), a wide variety of structural best management practices (BMPs) is usually installed at construction sites (Theisen, 1992). These BMPs are engineered systems designed to treat runoff inside the boundaries of the construction site itself and, therefore, preventing unwanted material to be discharged into either the storm sewer system or surface water bodies (USEPA, 2004).

Even though many BMPs exist to prevent erosion-related problems from happening (Raskin *et al.*, 2005), there is very little research related to their performance, as emphasized by Faucette *et al.* (2009), and this situation is even more pronounced when considering the performance of these devices under field conditions and, therefore, outside the laboratory controlled conditions. Therefore, in an effort to address this issue, the goal of this study was to analyze the performance of in-line devices installed during the construction of a new highway. These devices were designed to work together in the prevention of erosion-related problems.

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## 2. Methods

This study analyzes the performance of in-line structural BMPs installed during the construction of a new highway close to a public water supply reservoir in the state of São Paulo (Brazil) and on an area predominantly formed by sandy clay and sandy loam soils.

All drainage exits of the construction site located upstream and up to 2.5 km far from a surface water intake were monitored. These drainage exits totaled six monitoring areas and the closest one to the water intake was approximately 1.0 km far from it (Fig. 1).

All six areas had a point of discharge from the construction site to the existing reservoir and in-line devices were installed to control sediment accumulation. At least two of the following devices were installed at each drainage exit: gabions, silt fences and turbidity curtains. The quantity of these structural BMPs, the distance from their respective drainage exits and their position in relation to each other are presented in Table 1, where "1$^{st}$" refers to the device that was first reached by the runoff, "2$^{nd}$" refers to the following device in the path of runoff, and so on (Fig. 2). In addition to that, all monitored areas were covered with grass, although slopes had not been necessarily covered right after their construction.

Besides having in common the purpose of preventing sediment from leaving the construction site and entering the existing reservoir, the three types of devices had the same nonwoven geotextile as one of their components. The main characteristics of this type of fabric are listed in Table 2.

The performance of each device was assessed by inspecting the construction site after heavy rains and considering two aspects: visible changes in the apparent color of the water and the accumulation of sediments. Particularly in relation to sediment accumulation, those caused by the presence of a silt fence were identified essentially by means of visual inspections at the construction site. Accumulations related to the existence of turbidity curtains were recognized by means of sediment samples collected by the end of the construction activities from the bottom of the reservoirs, upstream and downstream of this type of barrier (Fig. 3).

**Table 1** - Quantity, position and distance from each drainage exit of BMPs.

| Drainage exit | In-line structural BMPs | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Gabion | | | Silt fence | | | Turbidity curtain | | |
| | Quantity | Position | Distance (m) | Quantity | Position | Distance (m) | Quantity | Position | Distance (m) |
| # 1 | 1 | 1$^{st}$ | 60 | 2 | 2$^{nd}$ and 3$^{rd}$ | 80 and 120 | 1 | 4$^{th}$ | 165 |
| # 2 | - | - | - | 2 | 1$^{st}$ and 2$^{nd}$ | 40 and 50 | 2 | 3$^{rd}$ and 4$^{th}$ | 60 and 70 |
| # 3 | 2 | 1$^{st}$ and 2$^{nd}$ | 60 and 120 | 1 | 3$^{rd}$ | 260 | 1 | 4$^{th}$ | 295 |
| # 4 | 1 | 1$^{st}$ | 55 | - | - | - | 2 | 2$^{nd}$ and 3$^{rd}$ | 85 and 105 |
| # 5 | 1 | 1$^{st}$ | 45 | 1 | 2$^{nd}$ | 55 | 1 | 3$^{rd}$ | 95 |
| # 6 | 1 | 1$^{st}$ | 90 | 1 | 2$^{nd}$ | 160 | 1 | 3$^{rd}$ | 185 |

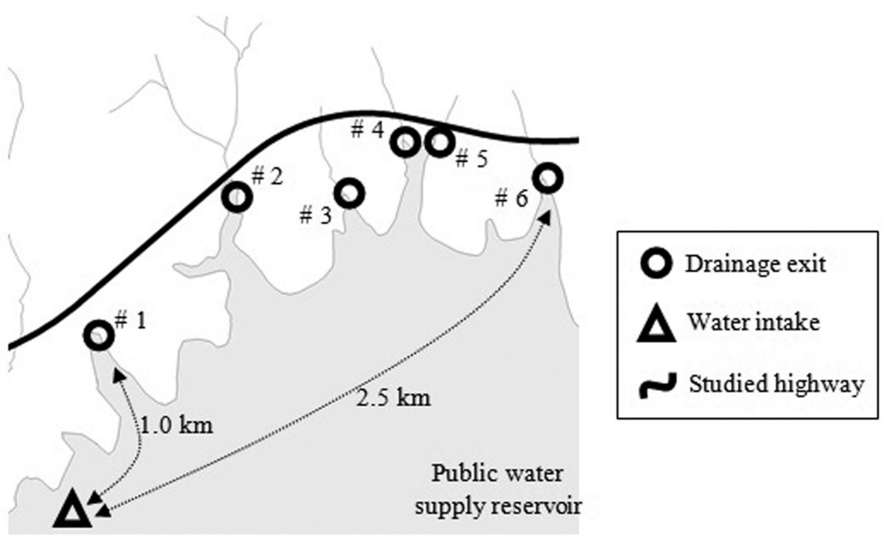


**Figure 1** - Location of the six drainage exits monitored during the construction activities.

In addition to that, the water quality monitoring data collected at the surface water intake were analyzed. Two parameters were considered, both affected by the presence of suspended sediment in the water body: turbidity and conductivity. The monitoring data were analyzed by comparing two different periods: before (from 2002 to 2007) and during (from 2008 to 2010) the construction of the new highway. It is important to highlight that, although samples were collected only once every two months and without any reference to the weather conditions during sampling, these monitoring data were relevant to identify any significant changes in the reservoir.

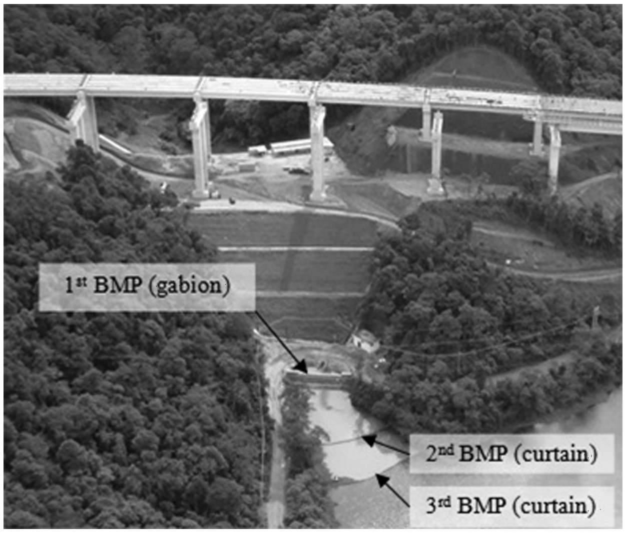


**Figure 2** - Drainage exit # 4 and its three structural BMPs installed to control sediment accumulation.

## 3. Results

The results were grouped into the three categories as follows.

### 3.1. Visual changes in the apparent color

Based on visual inspections, silt fences and turbidity curtains were effective in reducing the apparent color of the runoff from the construction site.

In the case of silt fences, it was evidenced by the color of the water that passed through the pervious fabric, once it clearer than the runoff ponded behind the fences. However, the fabric clogged relatively fast and, in order to keep the water flowing through the fences, the geotextile had to be either cleaned or replaced very frequently (Fig. 4). In rela-

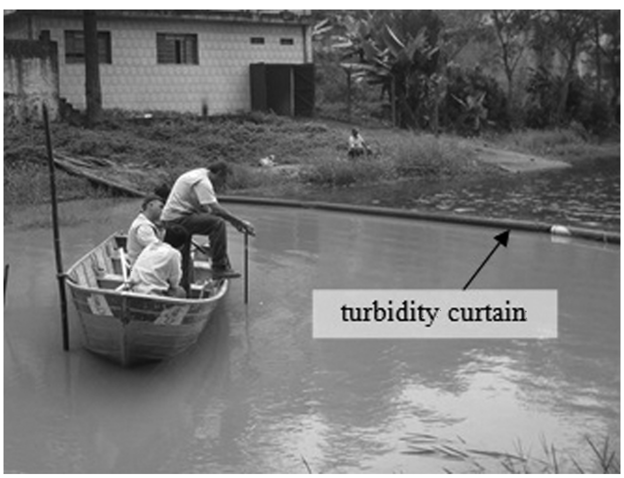


**Figure 3** - Sediment sample being collected upstream of a turbidity curtain (3rd BMP at drainage exit # 6) during the monitoring activities.

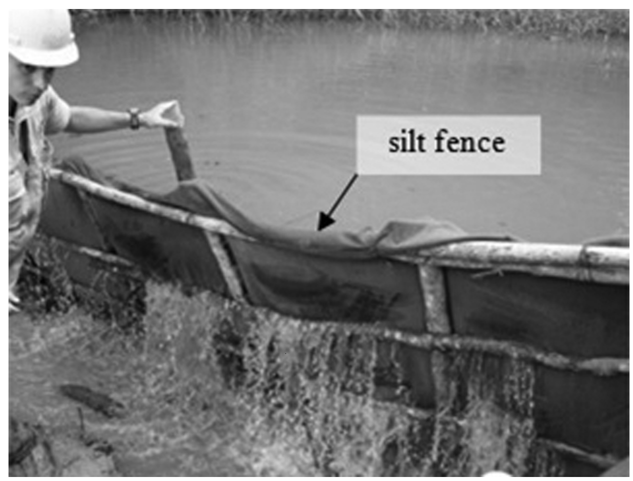


**Figure 4** - Runoff passing through the pervious fabric of a silt fence (3rd BMP at drainage exit # 3) right after being partially cleaned.

**Table 2** - Properties of the nonwoven geotextile used as a component of the devices.

| Mechanical properties | Test method | Geotextile |
|---|---|---|
| Wide width tensile strength | NBR 12824 | ≥ 12 kN/m |
| Elongation | NBR 12824 | ≤ 75% |
| Grab tensile strength | ASTM D 4632 | ≥ 800 N |
| CBR Puncture strength | NBR 13359 | ≥ 2.5 kN |
| Permeability | ASTM D 4491 | ≥ 0.35 cm/s |
| Apparent opening size (AOS) | ASTM 4751 | 0.11 mm to 0.21 mm |

tion to the turbidity curtains, the water retained behind them had too much apparent color, whereas the color of the water right after the curtains was not significantly different from that of the rest of the reservoir (Fig. 5).

Gabions also helped to reduce the apparent color of the runoff. However, based on visual data, reduction of the apparent color performed by this device was not significant when compared to silt fences and turbidity curtains.

### 3.2. Sediment accumulation

Sediment accumulated behind (upstream) and in front of (downstream) gabions, silt fences and turbidity curtains. In general, material accumulated behind gabions had a larger equivalent diameter in comparison to those found near silt fences and turbidity curtains. In addition, gabions and silt fences that were not properly kept in good conditions were damaged by material overtopping them (Figs. 6 and 7).

Sediment samples were collected downstream up to 12 m far from turbidity curtains. The results indicate that material from the construction site was not completely retained by the floating barriers, which may also be a consequence of unsatisfactory maintenance. The levels of sediments accumulated right before and right after the curtains are listed in Table 3.


**Figure 6** - Material accumulated behind the gabion (1st BMP) at drainage exit # 4, almost overtopping it.

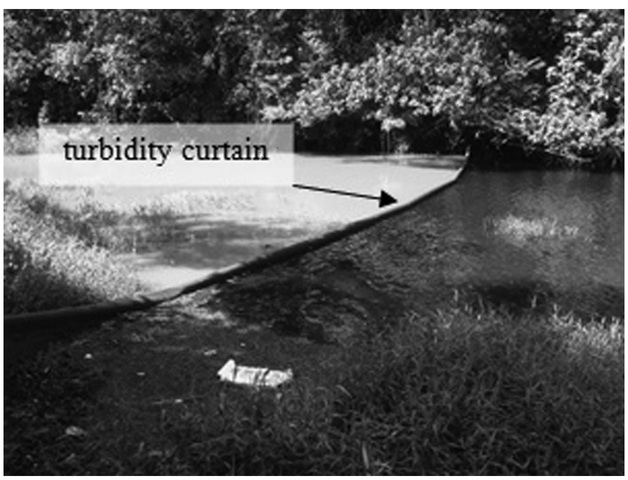


**Figure 5** - Apparent color of the water behind (darker) and in front of (lighter) a turbidity curtain (4th BMP at drainage exit # 3).


**Figure 7** - Silt fence damaged due to the excess of sediment and the unsatisfactory maintenance (2nd BMP at drainage exit # 5).

**Table 3** - Levels of sediments accumulated before and after the turbidity curtains.

| Drainage exit* | Level of sediments at different distances from the curtain | | | | | |
|---|---|---|---|---|---|---|
| | Upstream (before) the curtain | | Downstream (after) the curtain | | | |
| | Distance (m) | Level (m) | Distance (m) | High (m) | Distance (m) | High (m) |
| # 3 | 2.0 | 0.36 | 1.0 | 0.72 | 12.6 | 0.50 |
| # 4** | 2.3 | 1.05 | 3.7 | 0.16 | - | - |
| # 5 | 4.8 | 0.53 | 4.0 | 0.40 | 16.5 | 0.31 |
| # 6 | 2.0 | 0.75 | 3.0 | 0.40 | 10.1 | 0.22 |

(*) Sediment was collected at drainage exits # 1 and # 2 but was not quantified.
(**) Curtain at this drainage refers to the 3rd structural BMP presented in Table 1.

### 3.3. Comparison of water quality monitoring data

Results of the water quality monitoring for turbidity and conductivity are illustrated in Figs. 8 and 9. In addition to that, the federal turbidity limit of 40 NTU for superficial raw water intended for human consumption is plotted in Fig. 8.

Mean values and standard deviations for turbidity and conductivity are respectively listed in Figs. 10 and 11. These values were calculated based on two different periods: before (2002-2007) and during (2008-2011) the construction.

## 4. Discussion

The limitations of the methods used in this study are: (a) sampling at the water intake only once every two months without any reference to the weather conditions, (b) positive effects that diffusion naturally exerts on water quality with distance indirectly incorporated into the monitoring data at the water intake, and (c) lack of quantification of sediment collected at two drainage exits. Nevertheless, the results of this study were sufficiently consistent to indicate that the construction of the highway did not cause significant changes in the water reservoir and that the structural BMPs had an important role in that.

According to the water quality monitoring data at the surface intake, turbidity and conductivity were not statically different before and during the construction of the highway (Fig. 10). Therefore, discharges from disturbed areas did not affect the quality of the water in the catchment region and, as a result, had no influence on water treatment activities, such as coagulant dosing and sludge generation and disposal, as it might have happened (Emelko *et al.*, 2011).

In-line devices installed during the highway construction worked as a system that provided slow filtration, as described by Paterniani *et al.* (2011). Either in-line BMPs or slow filtration systems require very low filtration rates to remove suspended particles, which may be accelerated by using either polyacrylamide (Hayes *et al.*, 2005) or an active component from *Moringa oleifera* seeds (Sánchez-Martín *et al.*, 2010). Additionally, both of them must be pre-treated when turbidity levels are high, to prevent them from clogging quickly. Considering in-line BMPs in the context of slow filtration processes, gabions worked as a pre-treatment unit during the construction activities because the relatively large spaces between the blocks tended to retain larger materials, whereas silt fences and turbidity curtains retained smaller particles.

Finally, although gabions, silt fences and turbidity curtains could not function properly due to unsatisfactory maintenance and could not completely retain sediments from the construction site, these three devices contributed

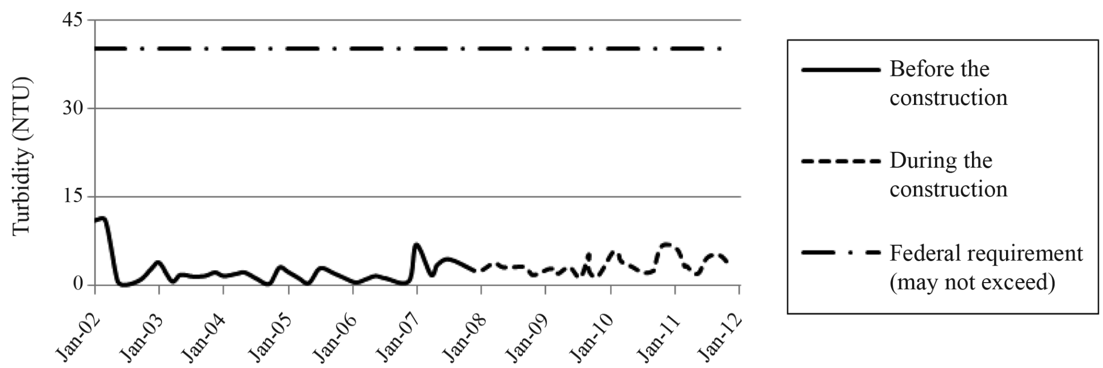


**Figure 8** - Turbidity at the superficial water intake before and during the construction. Source: adapted from Cetesb (2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011 and 2012) and Sabesp (2009, 2010 and 2011).

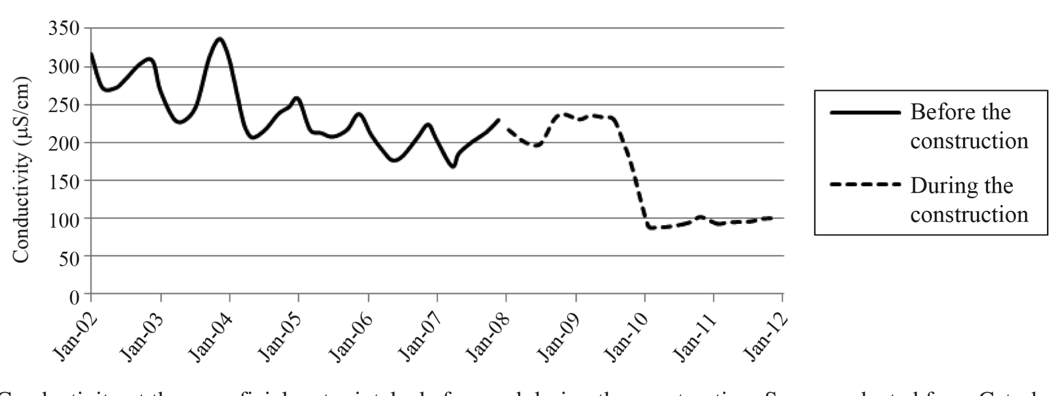


**Figure 9** - Conductivity at the superficial water intake before and during the construction. Source: adapted from Cetesb (2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011 and 2012) and Sabesp (2009, 2010 and 2011).

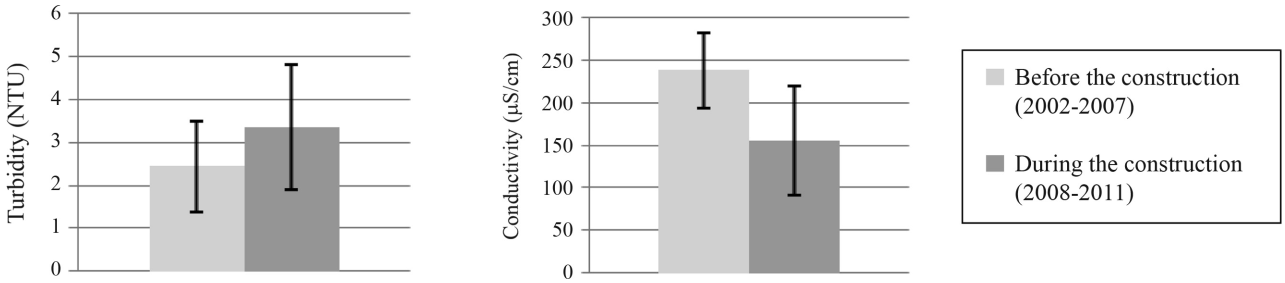


**Figure 10** - Turbidity and conductivity mean values and standard deviations at the superficial water intake before and during the construction. Source: adapted from Cetesb (2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011 and 2012) and Sabesp (2009, 2010 and 2011).

significantly to improve the control on sediment accumulation. It was evidenced, for example, by the sediment spread over a relatively small area, which BMP had positive effects on environmental recovery activities, such as reduction and facilitation of dredging to remove sediment accumulations, as pointed out by Fulazzaky & Abdul Gany (2009).

## 5. Conclusions

Results observed during the construction of the new highway indicate that structural BMPs, such as those analyzed in this study, have an important role in retaining soil, clarifying water and, therefore, controlling erosion-related problems. In addition to that, the integrated use of these devices results in important gains, such as improvement in controlling sediment accumulation, maintenance of water quality beyond the construction site, and even positive effects on environmental recovery activities.

However, it is important to highlight that gabions, silt fences and turbidity curtains do need maintenance in order to work properly. Continued maintenance is as important as the devices themselves to achieve and maintain the expected performance.

In the same way, in-line structures can be damaged by severe storms, once such configuration requires very low filtration rates to remove the suspended particles from the runoff. That is one of the reasons why advances in technologies that have the potential to accelerate deposition and filtration processes are really relevant in this field of science.

Finally, although gabions, silt fences and turbidity curtains were unable to completely retain sediments from the construction site, our results indicated that in-line structures are able to bring considerable benefits in large infrastructure projects, such as the construction of highways. Therefore, BMPs may be successfully applied to similar contexts as long as continued maintenance, proper installation and design criteria are duly considered.

## References


ABNT (1993) Geotêxteis - Determinação da resistência à tração não-confinada - Ensaio de tração de faixa larga - NBR 12824. Associação Brasileira de Normas Técnicas, Rio de Janeiro, Rio de Janeiro, Brazil, 5 p.

ABNT (1995) Geotêxteis - Determinação da resistência ao puncionamento estático - Ensaio com pistão tipo CBR - NBR 13359. Associação Brasileira de Normas Técnicas, Rio de Janeiro, Rio de Janeiro, Brazil, 4 p.

ASTM (2009) Standard Test Method for determining filtering efficiency and flow rate of a geotextile for silt fence application using site-specific soil - D 4491. ASTM International. West Conshohocken, Pennsylvania, USA, 6 p.

ASTM (2008) Standard Test Method for Grab Breaking Load and Elongation of Geotextiles – D 4632. ASTM International. West Conshohocken, Pennsylvania, USA, 4 p.

ASTM (2012) Standard Test Method for Determining Apparent Opening Size of a Geotextile – D 4751. ASTM International. West Conshohocken, Pennsylvania, USA, 7 p.

Barret, M.E.; Kearney, J.E.; McCoy, T.G. & Malina, J.F. (1995) An evaluation of the use and effectiveness of temporary sediment controls. (CRWR Online Report 95-6) Austin: Center for Research in Water Resources, 148 pp.

Benjankar, R. & Yager, E.M. (2012) The impact of different sediment concentrations and sediment transport formulas on the simulated floodplain processes. Journal of Hydrology, v. 450-451:11, p. 230-243.

Cetesb – Companhia de Tecnologia de Saneamento Ambiental (2003) Relatório de qualidade das águas interiores do estado de São Paulo 2002 - 0103-4103. Diretoria de engenharia, tecnologia e qualidade ambiental, São Paulo, São Paulo, Brasil, 279 p.

Cetesb – Companhia de Tecnologia de Saneamento Ambiental (2004) Relatório de qualidade das águas interiores do estado de São Paulo 2003 - 0103-4103. Diretoria de engenharia, tecnologia e qualidade ambiental, São Paulo, São Paulo, Brasil, 273 p.

Cetesb – Companhia de Tecnologia de Saneamento Ambiental (2005) Relatório de qualidade das águas interiores do estado de São Paulo 2004 - 0103-4103. Diretoria de engenharia, tecnologia e qualidade ambiental, São Paulo, São Paulo, Brasil, 307 p.

Cetesb – Companhia de Tecnologia de Saneamento Ambiental (2006) Relatório de qualidade das águas interiores do estado de São Paulo 2005 - 0103-4103. Diretoria de engenharia, tecnologia e qualidade ambiental, São Paulo, São Paulo, Brasil, 488 p.

Cetesb – Companhia de Tecnologia de Saneamento Ambiental (2007) Relatório de qualidade das águas interiores do estado de São Paulo 2006 - 0103-4103. Diretoria de engenharia, tecnologia e qualidade ambiental, São Paulo, São Paulo, Brasil, 327 p.

Cetesb – Companhia de Tecnologia de Saneamento Ambiental (2008) Relatório de qualidade das águas interiores do estado de São Paulo 2007 - 0103-4103. Diretoria de engenharia, tecnologia e qualidade ambiental, São Paulo, São Paulo, Brasil, 537 p.

Cetesb – Companhia de Tecnologia de Saneamento Ambiental (2009) Relatório de qualidade das águas interiores do estado de São Paulo 2008 - 0103-4103. Diretoria de engenharia, tecnologia e qualidade ambiental, São Paulo, São Paulo, Brasil, 528 p.

Cetesb – Companhia Ambiental do Estado de São Paulo (2010) Relatório de qualidade das águas interiores no estado de São Paulo 2009 - 0103-4103. Diretoria de tecnologia, qualidade e avaliação ambiental, São Paulo, São Paulo, Brasil, 310 p.

Cetesb – Companhia Ambiental do Estado de São Paulo (2011) Qualidade das águas superficiais no estado de São Paulo 2010 - 0103-4103. Diretoria de engenharia e qualidade ambiental, São Paulo, São Paulo, Brasil, 298 p.

Cetesb – Companhia Ambiental do Estado de São Paulo (2012) Qualidade das Águas Superficiais no Estado de São Paulo 2011 - 0103-4103. Diretoria de Engenharia e Qualidade Ambiental, São Paulo, 356 pp.

Emelko, M.B.; Silins, U. & Bladon, K.D. (2011) Implications of land disturbance on drinking water treatability in a changing climate: demonstrating the need for "source water supply and protection" strategies. Water Research, v. 45:2, p. 461-472.

Faucette, L.B.; Governo, J.; Tyler, R.; Gigley, G.; Jordan, C.F. & Lockaby, B.G. (2009) Performance of compost filter socks and conventional sediment control barriers used for perimeter control on construction sites. Journal of Soil and Water Conservation, v. 64:1, p. 81-88.

Forsyth, A.R.; Bubb, K.A. & Cox, M.E. (2006) Runoff, sediment loss and water quality from forest roads in a southeast Queensland coastal plain Pinus plantation. Forest Ecology and Management, v. 221:1, p. 194-206.

Fulazzaky, M.A. & Abdul Gany, A.H. (2009) Challenges of soil erosion and sludge management for sustainable development in Indonesia. Journal of Environmental Management, v. 90:8, p. 2387-2392.

Hayes, S.A.; McLaughlin, R.A. & Osmond, D.L. (2005) Polyacrylamide use for erosion and turbidity control on construction sites. Journal of Soil and Water Conservation, v. 60:4, p. 193-199.

Hedrick, L.B.; Welsh, S.A.; Anderson, J.T.; Lin, L.S.; Chen; Y.S. & Wei, X.C. (2010) Response of benthonic macroinvertebrate communities to highway construction in an Appalachian watershed. Hydrobiologia, v. 641:1, p. 115-131.

Fulazzaky, M.A. & Abdul Gany, A.H. (2009) Challenges of soil erosion and sludge management for sustainable development in Indonesia. Journal of Environmental Management, v. 90:8, p. 2387-2392.

Paterniani, J.E.S.; Silva, M.J.M.; Ribeiro, T.A.P. & Barbosa, M. (2011) Pre-filtration in boulder and slow sand filtration with non-woven synthetic layers and granulated vegetal coal to improve quality in wastewater treated by constructed wetlands. Eng. Agríc., v. 31:4, p. 803-812.

Raskin, L.; DePaoli, A. & Singer, M.J. (2005) Erosion control materials used on construction sites in California. Journal of Soil and Water Conservation, v. 60:4, p. 187-192.

Sabesp - Companhia de Saneamento Básico do Estado de São Paulo (2009) available at http://site.sabesp.com.br/uploads/file/monitoramento/conama_357_2009_inorganico.pdf and downloaded on December 10th 2012.

Sabesp - Companhia de Saneamento Básico do Estado de São Paulo (2010) available at http://site.sabesp.com.br/uploads/file/monitoramento/conama_357_2010_inorganico.pdf and downloaded on December 10th 2012.

Sabesp - Companhia de Saneamento Básico do Estado de São Paulo (2011) available at http://site.sabesp.com.br/uploads/file/monitoramento/conama_357_2011_inorganico.pdf and downloaded on December 10th 2012.

Sánchez-Martín, J.; Ghebremichael, K. & Beltrán-Heredia, J. (2010) Comparison of singles-step and two-step purified coagulants from Moringa oleifera seed for turbidity and DOC removal. Bioresource Technology, v. 101:15, p. 6259-6261.

Theisen, M.S. (1992) The role of geosynthetics in erosion and sediment control: an overview. Geotextiles and Geomembranes, v. 11:4, p. 535-550.

USEPA - United States Environmental Protection Agency (2004) The use of best management practices (BMPs) in urban watersheds - EPA/600/R-04/184. Office of research and development, Cincinnati, Ohio, USA, 271 p. Available at: http://nepis.epa.gov/Adobe/PDF/2000D1LM.pdf.

USEPA - United States Environmental Protection Agency (2008) Environmental impact and benefits assessment for proposed effluent guidelines and standards for the construction and development category - EPA-821-R-08-009. Office of water, Washington, District of Columbia, USA, 253 p. Available at: http://water.epa.gov/scitech/wastetech/guide/construction/upload/2008_11_25_guide_construction_proposed_proposed-env-20081120.pdf.

Zech, W.C.; Halverson, J.L. & Clement, T.P. (2008) Intermediate-scale experiments to evaluate silt fence designs to control sediment discharge from highway construction sites. Journal of hydrologic engineering, v. 13:6, p. 497-504.