NOTE: This 1989 report provides some historical perspectives on the evolution of the stormwater management program in Colorado and, in some respects, what wound up being in initial publication of Volume 3 of the USDCM in early 1990s. The BMPs that were eventually included in Volume 3 were selected with the help of extensive input from and debate by many professionals in Colorado and other part of United Sates, based on each BMPs potential for long term performance, maintainability and survival.

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BMP PRACTICE ASSESSMENT FOR THE DEVELOPMENT OF COLORADO'S STORMWATER MANAGEMENT PROGRAM

I. Introduction

A work group of the Technical Committee of the State of Colorado Stormwater Task Force was assembled to identify and asses the best management practices often discussed and described in technical literature. All of these BMPs have been suggested as methods to reduce pollutant loads entering the waters of the United States. The goal of the work group was to identify for the State which BMPs appear to have most applicability in Colorado's climate, which BMPs need further research before state-wide acceptance and which ones clearly are not effective.

The members of the work group were:

Ben Urbonas	Work Group Coordinator, Urban Drainage and Flood Control District
David Lystrom	U.S. Geological Survey
Paul Sorensen	Delta Environmental Consultants, Inc.
Sue Morea	Camp Dresser and McKee, Inc.

Their contribution and the contribution of others that provided comment and information to the group is acknowledged.

A. Need for BMP Assessments

State of Colorado is exploring the options for the development of a State-wide urban stormwater management program. The need for this program at a State level of government is the result of the 1987 Clean Water Act passed by U.S. Congress in early 1988. As a NPDES delegated State, Colorado will have to administer the separate stormwater discharge permit program mandated by the act. Subsequent rules proposed by the U.S. Environmental Protection Agency emphasize the development of state-wide stormwater management programs with the goal of reducing pollutants carried to the waters of United States by urban stormwater runoff.

The technical and not-so-technical literature suggest a number of techniques to reduce the pollutant load in urban runoff. Because these techniques do not depend on mechanical water quality treatment facilities, as a group they have been labeled as best management practices (i.e., BMPs). Unfortunately, none of the BMPs suggested have been field tested in the semi-arid or arid climates.

Some of the BMPs should perform as described in literature, but others may not do well in a climate of limited precipitation with extended periods between rainstorms or snowmelt. In fact the state-of-the-art in reliably using BMPs is not well developed even for the eastern areas from where most of the performance data come from. This point was noted as follows by Roesner et. al. (1988) after a considerable literature review concerning field performance of various BMPs along the eastern seaboard:

Among all these BMP devices the most promising and best understood are detention and extended detention basins and ponds. Less reliable in terms of predicting performance, but showing promise, are sand filter beds, wetlands, infiltration basins, and percolation basins. All of the latter appear to be in their infancy and lack the necessary long-term field testing that would provide data for the development of sound design practices.

Clearly, the meteorological conditions are very different in the semi-arid portions of the U.S. from the east coast and the Technical Committee urges cautious in what is adopted as appropriate BMPs for Colorado. The Technical Committee evaluated a number of commonly suggested best management practices for potential effectiveness. This report discusses the potential use of each of the BMPs as candidates for Colorado's stormwater management (i.e., SWM) program. The Technical Committee also suggests field testing, evaluation, and development of design guidelines for some of the BMPs that appear to need more technical development before use in Colorado.

B. Maximum Extent Practicable Technology (MEP)

The Technical Committee of Colorado's Stormwater Task Force is not clear how the term "Maximum Extent Practicable" is to be interpreted. It appears that the States will have a degree of flexibility in how it defines this term in their own SWM programs.

As a result, the Committee assumed that MEP, for the most part, is synonymous with the use of BMPs that it has evaluated. In other word, it was assumed that compliance with the separate stormwater NPDES permit conditions will be primarily judged on how well the community is adhering to the use of the BMPs stipulated in its permit. This means that water quality monitoring will not be the basis for enforcement action, but instead will be used as the basis for problem identification and BMP requirements in future permits.

C. Construction Phase vs. Post Construction

The Technical Committee evaluated candidate BMPs for applicability during the two phases of urbanization. The first is the temporary and relatively short period of actual side development. During this phase the land is often stripped of its vegetation, the soils are moved to prepare the site for the new development and streets, utilities and buildings are constructed. The primary concern during this phase is the soil erosion by rainfall or snowmelt runoff.

During the second phase includes the control of stormwater pollutant loads from the developed urban area. This phase is long term and will last for the duration of the SWM program or as long as the urban development is in place, whichever outlasts the other. The concerns after the construction phase includes erosion control and the control of various pollutant loads found in stormwater runoff.

Because construction of roads, highways, rail lines, airports, buildings and other facilities can occur outside the urban area, most of techniques suggested for the construction phase also can be applied to construction activities not normally associated with urbanization.

D. Areas Undergoing Land Use Change vs. Developed Areas.

The Technical Committee also evaluated the BMPs for applicability in areas that are fully developed and for areas that are in the process of land use change (i.e., development or redevelopment). Some of the BMPs are relatively easy to incorporate into a site plan at the time land is being developed. At the same time, these same practices may be impractical in areas that are already developed. The amount of land area a BMP requires is probably the most important consideration to determine how well it may fit into an existing development.

Retrofitting of land intensive BMPs are considered to be not practical in densely urbanized areas. There should be clear evidence to show that a significant impairment in the uses of receiving water will be removed by a land intensive BMP before it is considered for use in a totally urbanized area. Because indiscriminate use of facilities to treat stormwater quality may not be practical or economically feasible, the work group evaluated BMPs with the term "Maximum Extent Practicable" in mind. It was felt that this term in the 1987 Clean Water Act implies that the methods to be used for the control of stormwater quality should be applied with "practical" considerations in mind.

E. General Use of BMPs

The use of Best Management Practices should not be treated lightly or indiscriminately. Each is a facility or an activity that has to be matched to the site for which it is to be employed. As a result, the work group recommends that a careful technical evaluation be performed before any of the BMPs described here are selected for the site. Most of the BMPs require careful planning, design and construction to be effective. In addition, each of the BMPs will require long term commitment to finance their operation, maintenance and eventual restoration or replacement.

II. Erosion Control during Construction

Erosion control during construction has become a requirement in many of the States. The evidence of sediment erosion on construction sites and of its deposition in the downstream waterways is abundant. Impacts of this sediment deposition include silting over aquatic habitat, loss of hydraulic capacity in downstream bridges and culverts and increased cost of maintenance along downstream waterways to restore and maintain flood carrying capacity. Lack of adequate erosion and sedimentation practices during construction transfers the cost of erosion and sediment deposition to the downstream residents and to the general public. It often requires the use of tax dollars to eventually mitigate the problems it creates.

A. Urban Construction Sites

Urban construction sites produce sediment movement off-site in several ways. Eroded soils are transported to neighborhoods by wind and water. In addition, construction vehicles leaving construction sites carry soils on their tires and deposit them along city streets. All of the migrating soils end up in city storm drain systems and, eventually, in the receiving waterways.

The Technical Committee evaluated only most commonly used erosion control techniques and suggests their use for various phases and types of construction. Other techniques to control sediment movement off-site should also be considered by local jurisdiction; however, the Technical Committee has not specifically evaluated them and does not offer guidance or suggestions as to their use. The techniques evaluated are described in **Section II. D. Erosion Controls during Construction**. The Technical Committee suggests that each of the erosion control practices be considered for the following:

1. Mobilization Phase

During the mobilization phase of urban construction steps need to be taken early to prepare the site for soil disturbance. Any of the following erosion control practices are appropriate during the mobilization phase to prepare for construction activities:

Slope Stabilization
Sediment Barriers

2. Active Construction Phase

During the active construction phase the Technical Committee suggests that the first items to be installed on the site be the erosion control facilities. Any of the following erosion control techniques should be considered for use during the active construction period:

Slope Stabilization
Sediment Barriers
Flow Velocity Controls
Sedimentation Basins

3. Completion and Move-Out Phase

As the active construction phase is being completed and the contractor is preparing to vacate the site the Technical Committee suggests that site be prepared for its final use. That will generally include the removal of sedimentation barriers, final repair of any damaged or eroded velocity control facilities and the removal of sediments and restoration to design grades of all sedimentation basins. All of this site preparation the entire site should be seeded to revegetate with appropriate other plants, and mulched. The following should be used during the completion and move-out phase of construction:

Site cleanup and final grading
Revegetation

B. Roadway and Highway Projects

Roadway projects should be treated similarly as urban construction sites. In fact there is very little difference between roadway construction and urban construction. As a result the Technical Committee suggests that all highways, airports, roadways, railroads and all other construction activities outside urban areas be required to control erosion just like urban construction sites. Conditions can vary significantly between sites, thus, erosion control plans should be prepared that recognize site-specific conditions.

The practices listed under Section II.D. below all apply to roadway and other transportation construction projects. Specific guidance for erosion control on roadway construction projects is contained in Colorado Department of Highways (1978) - Erosion Control Manual. It describes many of the techniques discussed under Section II.D. below and contains guidance on the design and installation of interception ditches or barriers, temporary diversions, flexible pipes, geotextile fabrics, straw bales, check dams, silt fences, sandbags, temporary berms, slope drains, sediment traps, temporary chemical treatments, pumping, slope treatment, wood flumes, etc. Many of these techniques have been used by the Highway Department and, as a result, have been demonstrated to work in the field.

C. Institutional Considerations

Effective erosion control is not going to occur unless local institutions have the interest, commitment and manpower to insure that it occurs. The Technical Committee recommends

D. Erosion Control Practices during Construction

There are a number of erosion control practices that can be applied during the construction. Some of the more commonly used ones and their applicability are discussed next. These need to be applied selectively to each to insure that site erosion is contained on-site. Since not all of the listed practices need to be applied to each site, an engineering evaluation has to be made which of these practices will be best for any specific site.

1. Revegetation.

a) Assessment

The Technical Committee finds the use of Revegetation to be an effective soil erosion control BMP only after construction has been completed. It is suggested that revegetation should take place immediately after construction is completed to reestablish a vegetative cover on disturbed lands. On projects that cover large areas it is suggested revegetating all areas as soon as land disturbance activities are completed for each potion of the site.

Revegetation in a semi-arid climate requires time. Successful native perennial vegetation may need two or more years to become established to a degree where it provides erosion protection. As a result, revegetation is not considered effective as an intermediate or short-term solution. While construction is occurring, other methods, such as mulching, sediment barriers, and other erosion control techniques need to be used to temporarily control water and wind erosion of surface soils.

b) Specific Guidance.

Conduct field and soil analysis to determine the types of seed, fertilizer, soil enhancers, etc. to use for each site. Mulch all newly seeded areas to help retain soil moisture, to stabilize the slopes and to control erosion until vegetation develops. Temporary watering of newly seeded areas can assist the grasses to become established.

Limit grassed side slopes, whenever feasible, to no steeper than three feet horizontal for each foot of vertical rise. This will facilitate maintenance of revegetate areas and insure surface stability of the slope whenever heavy rains occur.

The following references provide practical guidance and criteria for Revegetation of construction sites and disturbed areas in Colorado:

Colorado Department of Highways (1978)
Arapahoe County (1988)
Summit Water Quality Committee (1988),
Aurora, City of (1987).

2. Slope Stabilization

a) Assessment

Slope stabilization is a BMP that includes all non-vegetative practices to increase the stability of earthen slopes, thereby helping to control erosion of surface soils. The Technical Committee finds the use of slope stabilization to be an effective soil erosion control BMP in very steep terrain. It is suggested that slope stabilization take place early during construction period.

b) Specific Guidance.

As suggested under "Revegetation" above, limiting grassed side slopes, whenever feasible, to no steeper than three feet horizontal for each foot of vertical rise will help to reduce soil erosion. Unlike the delay in establishing a sound vegetative cover, slope stabilization is not constrained by nature. Specific techniques that may be used include the application of netting or matting on the surface, contour plowing of the surface, mulching, construction of cribbing, buttressing or retaining walls, and the placement of riprap.

The following references provide practical guidance and criteria for installation and maintenance of slope stabilization of construction sites:

Colorado Department of Highways (1978)
Arapahoe County (1988)
Summit Water Quality Committee (1988),
Aurora, City of (1987).

3. Sediment Barriers

a) Assessment

Sediment barriers slow runoff to trap sediments, thereby preventing them from leaving the site. The Technical Committee finds the use of sediment barriers to be an effective soil erosion control BMP during construction. It is suggested that sediment barriers be erected before construction begins and be maintained until the site is mulched and seeded.

b) Specific Guidance.

Erect barriers below disturbed areas likely to erode such as at base of steep slopes and ahead of drainageways, stormwater inlets, street gutters and culverts. Sediment barriers can be constructed using straw bales, filter fences, inlet barriers, siltation berms, and siltation traps.

The following references provide practical guidance and criteria for the erection and maintenance of sediment barriers at construction sites:

Colorado Department of Highways (1978)

Arapahoe County (1988)

Summit Water Quality Committee (1988)

Aurora, City of (1987)

4. Runoff Control

a) Assessment

Runoff control prevents or slows surface runoff on a construction site, thereby preventing erosion at the site. The Technical Committee finds the use of runoff controls, whenever site conditions permit, to be an effective soil erosion control BMP during construction. It is suggested that runoff control facilities be erected as construction begins and be maintained until all site work is completed and the site is revegetate.

b) Specific Guidance.

Erect runoff control facilities throughout the site as appropriate. Runoff controls include wind rows, rundowns, sediment barriers, berms, detention and/or retention ponds, velocity control facilities and grade checks.

The following references provide practical guidance and criteria for the erection and maintenance of runoff control facilities at construction sites:

Arapahoe County (1988);
Aurora, City of (1987);
Colorado Department of Highways (1978);
Summit Water Quality Committee (1988);
UDFCD (1969).

5. Flow Velocity Control

a) Assessment

Runoff flow velocity controls slow down surface runoff velocities to be non-erosive or to reduce the erosive potential of the flow. The Technical Committee finds the use of flow velocity controls, to be particularly an effective BMP during construction when installed along waterways and their tributaries. It is suggested that flow velocity controls be erected early during the construction period and be maintained throughout the life of the project. Some of these facilities may become a permanent part of the completed site and will require ongoing maintenance after the construction period.

b) Specific Guidance.

Erect velocity control facilities, as appropriate, along all waterways and their tributaries. Flow velocity controls include grade checks, slope drains, spreaders, energy dissipaters, chack dams, drop structures and diversion berms.

The following references provide practical guidance and criteria for the design, erection and maintenance of flow velocity control facilities at construction sites:

Arapahoe County (1988);
Aurora, City of (1987);
Colorado Department of Highways (1978);
Summit Water Quality Committee (1988);
Urban Drainage and Flood Control District (1969).

6. Sedimentation Basins

a) Assessment

Sediment basins trap surface runoff from frequently occurring storms and release it over an elevated outlet. This results in a substantial portion of the sediments being trapped within the basin. The Technical Committee finds the use of sedimentation basins to be a very effective BMP during construction when installed downstream of the construction activity. It is suggested that sedimentation basins be erected first as construction period begins and be maintained (i.e., excess sediment deposits removed) while construction continues. Some of these facilities may be a part of a permanent on-site detention basin of the completed site. In such cases they will need to be cleaned out and finished to perform the detention basin function before site work is completed.

b) Specific Guidance.

Construct sedimentation basins to have a volume below the outlet sufficient for the storage of the anticipated sediment load that is expected to occur during the construction period. In addition, provide a surcharge volume equal to the 50 percent runoff event from the site assuming the runoff coefficient from the construction site will be C = 0.4.

The following references provide practical guidance and criteria for the design, erection and maintenance of sedimentation basins at construction sites:

Arapahoe County (1988);
Aurora, City of (1987);
Colorado Department of Highways (1978);
Oscayan (1975);
Summit Water Quality Committee (1988);
Urbonas, Guo and Tucker (1989);
UDFCD (1969).

III. Areas Undergoing Land Use Changes

There are opportunities for the installation of structural BMPs in areas undergoing land use changes that do not exist in areas that are fully developed. The best time to require such BMPs is during annexation and/or zoning when land use densities are being negotiated. Failing that, the next best time is during the platting process when the subdivision agreements between the city (or county) and the land owner are being prepared. The most difficult time is when a building permit is being requested for a platted parcel. At that time the city (or County) may have contractual obligations as to how the land owner may use each parcel of land.

The use of structural BMPs is not the entire answer in controlling urban runoff quality. Non-structural BMPs are an essential part of any stormwater quality management program for areas undergoing land use changes. Among them are local permitting procedures, technical criteria and enforcement programs that are needed to insure all of the required BMPs are appropriately applied.

A. Non-structural Measures

The Technical Committee identifies and evaluated a number of non-structural BMPs that are described in literature. A judgment was rendered as to its appropriateness and effectiveness. Obviously, the following represents the collective opinion of the Technical Committee; however, it does not represent complete consensus or the belief that the Technical Committee has discovered the ultimate truth. This will have to evolve with time as the State and the urban areas gain experience in stormwater quality management.

1. Building and Site Development Codes

Adoption of building and site development codes that recognize the need for stormwater quality control is an essential building block of a stormwater quality management program. Without them the city staff has no legal authority to base its technical requirement to get the job done. The Technical Committee suggests that urban areas adopt codes and regulations that clearly spell out the following:

Goals and Objectives
Responsibilities and Authorities for Implementation
Appeals or Conflict Resolution Process
Enforcement Procedures, Including Penalties
Responsibilities for Ongoing Operation and Maintenance
Program Funding Commitments

2. Site Disturbance Permits

The Technical Committee suggests that communities adopt a site disturbance permit system. Whenever building, site grading or general construction is to take place, the landowner or his agent should first obtain a permit. They should spell out, among other provisions, the responsibilities for control of erosion on the site. There appears to be four type of site disturbance permits that could be required.

a) Building Permits

A building permit, in addition to the traditional requirement associated with the construction of structures, should also contain conditions for the associated site work. Requirements for drainage facilities, site grades, landscaping requirements, on-site detention (where applicable), site erosion control, separate water quality facilities (if any) etc. need to be spelled out so that the building inspector(s) know what to look for.

b) Grading Permits

A grading permit program is recommended for adoption to control site grading, excavation and filling operations that may take place in advance or independent of any building of structures. The primary objective of a grading permit would be to control soil erosion.

c) Construction Permits

A construction permit is similar to a building permit, except is involves more than a single structure on a single lot. It covers construction of facilities and buildings for an entire subdivision, commercial development or an industrial site. Again the permit would spell out specific site development requirements including erosion control, drainage, and water quality facilities.

d) General Permits for Small Sites

The Technical Committee suggests that a general permit program be developed by the State and implemented by local jurisdictions that cover the construction on small sites. Infill single lot construction or a maximum acreage could be the basis for such a permit, thereby relieving administrative burden of having to deal with individual site development permits for these small sites. A general permit by the State could spell out minimum soil erosion control practices to be used during construction. Local jurisdiction could the either adopt these minimum requirements or adopt their own.

3. Vegetative Practices

Use of vegetated areas for the removal of pollutants has been suggested in literature by Maryland (1985) and several contributing authors in DeGroot (1982), Roesner (1988) and Urbonas (1986). It appears that vegetative practices by themselves have a very limited effect on stormwater quality. They are best used in combination with other BMPs.

Vegetative practices, as defined here, include grassed swales, grass buffer/filter strips and tributary and drainageway landscaping practices. BMPs such as grassed swales or buffer strips will help remove the course to medium sized sediment from stormwater, but have a limited effect on the removal of very finer sediment. According to Stahre (1990) and some of the contributing authors to DeGroot (1982) and Urbonas (1986), a significant portion of the pollutants in stormwater are attached to the finer sized sediment particles.

While only marginally effective in the removal of pollutants associated with very fine sediment, grass buffer/filter strips appear to be a very low cost way of removing a significant portion of courser sediments, trash and debris that is often associated with urban runoff. In addition, areas covered by grasses and other vegetation appear to be very efficient in trapping pollutants that fall to the ground between storm events. Thus, vegetative practices, in combination with other non-structural BMPs that reduce the amount of impervious surface, are likely to reduce the pollutant loads reaching receiving waters of the State.

Specific guidance for the use of vegetative practice should contain types of vegetation, slope and soil preparation, adequacy of soils and maximum permissible velocities that should not be exceeded whenever flow is directed over vegetated areas.

For this practice to be effective, the grasses need to be uniformly established on the entire surface. Maintenance for this BMP will include mowing, watering, weed and pest control and repair or replacement of damaged areas. Eventually the trapped sediments will accumulate as to interfere with runoff from paved areas. When that happens it will be necessary to remove the to layer of turf and to revegetate the area.

The following references contain discussions or guidance about the effectiveness of vegetative practices and/or how to design and install them:

Colorado Department of Highways (1978)
DeGroot (1982)
Maryland (1985)
Roesner (1988)
Schueler (1987)
Stahre (1990)
Urbonas (1986)

4. Street and Parking Lot Drainage Design Standards

In areas undergoing development or redevelopment the Technical Committee suggests that the policy of using curb and gutter along streets and within parking lots be reexamined. Where it is possible to utilize roadside swales or borrow ditches runoff can be detained at each driveway, slowing it down and reducing the rate of runoff in the downstream system. In many cases it may be possible to spread the runoff from parking lots across grass buffer/filter strips, taking advantage of the benefits possible from vegetative practices discussed earlier. This technique is discussed in greater detail by Maryland (1985), Schueler (1987), Stahre (1990), Roesner (1988) and Urbonas (1986).

This is not a technique to be used indiscriminately. Often site constraints, such as steep slopes or limited right-of-way will make this BMP impractical. Nevertheless, it is a practice that deserves consideration because of its simplicity and low cost. Instead of curb and gutter, elevated automobile wheel stops and concrete pavement edging could be used to accomplish the vehicle control and pavement demarcation functions provided by curb and gutter.

5. Technical Criteria and Design Standards

The Technical Committee recommends that for the sake of consistent application of all of the BMPs adopted by any municipality that a set of technical criteria and design standards be adopted. Such criteria and standards do not necessarily need to be developed independently for each community. The State can develop a set of guidelines, or all communities in a metropolitan area can jointly develop a single set of criteria and standards. Each municipality in turn can then adopt the appropriate BMPs by reference for their use.

A good example of this is the Urban Drainage and Flood Control District's Urban Stormwater Drainage Criteria Manual (USDCM) which addresses stormwater quantity. It was originally developed in 1969 under the direction of Denver Regional Council of Governments with funds received from HUD. All the local general purpose governments in the Denver area have adopted it for use in the planning and design of drainage and flood control projects.

Some of the local jurisdictions have subsequently adopted their own manuals that set forth their policy and clarify how the information in the USDCM is to be used within their jurisdictional boundaries. The majorities of the local governments refer to the technical sections of the USDCM rather than repeat its technical sections. This allows for regional updates to the technical sections to occur through by revising only the USDCM. This approach eliminates the need to revise a large number of manuals to simply update the technical sections as better, state-of-the-art, information is developed.

6. Zoning Actions

Since, according to EPA (1983), the stormwater pollutant loads increase in proportion to the amount of impervious surfaces in the watershed, zoning can play a major role in reducing pollutant loads. This non-structural BMP directly affects the land use decisions of the community, a role jealously guarded by cities and counties. The following are offered as discussion items for consideration as the stormwater quality management program is being formulated for Colorado:

a) Zoning Incentives

Encourage communities to provide incentives to provide more open space in individual developments. These could be reduced parking ratios, greater building heights, density trades, etc., all aimed at increasing the open space and reducing the amount of impervious surface.

b) Alternate Land Uses

Communities could also be encouraged to reexamine their long term comprehensive land use plans. The goal could be to determine if land uses that have less impervious surface could be used more frequently.

B. Structural Best Management Practices

The Technical Committee evaluated a number of structural BMPs most often cited in the technical literature. The Committees goal was to examine each BMP in light of the semi-arid climate found in Colorado's high plains . As a result, the conclusions reached probably do not extend to the mountainous regions of the state.

1. Porous Pavement

a) Assessment

Porous pavement has been used with some reported success (see, DeGroot (1982), Urbonas (1986), Roesner (1988)) in the eastern United States. It is designed to permit rainfall to infiltrate through the surface and into the ground. In theory, this turns paved areas into pervious surfaces, thereby reducing runoff and pollutant loads. Porous pavement may be constructed using asphalt or concrete by leaving the fines out of the pavement material mixture. Discussions with engineers from areas where porous pavement has been tried indicate that concrete pavement performs better than its asphalt counterpart because it can be made structurally sound with fairly significant pores in the pavement matrix.

The Technical Committee has serious concerns about this BMP. Colorado's winter climate is very hard on any pavement as is attested by the number of potholes found each spring. The severity of diurnal temperature fluctuations causing multiple freeze and thaw cycles breaks up any pavement whenever water infiltrates into its matrix. Porous pavement is an ideal candidate for this to occur.

In addition, much of Colorado's pavement sits on expansive soils. Every effort is made to keep water from reaching the sub-grade to keep the soils from swelling and contracting. Porous pavement, on the other hand, is designed to get the water to the sub-grade. Whenever pavement surface is distressed it is overlaid with a new surface layer. Sealing of the surface will occur when pavement is overlaid, after which it is no longer "porous pavement."

Finally, it is inevitable that the same sediments that wash off impervious surfaces will tend to fill the pores of porous pavement. The atmospheric fallout can be very significant in semi-arid climates accelerating the pavement clogging process. Once the pores are filled, porous pavement is no longer porous and all the benefits it is supposed to provide are no longer available.

b) Specific Guidance.

The Technical Committee recommends that the State install and test the performance of porous pavement at numerous locations in Colorado. Tests sections need to be monitored for at least five years. Test cores should be taken annually to a depth of one foot below the pavement section to evaluate how rapidly the pores accumulate sediments and how natural weathering and site conditions affect pavement life. If this practice shows promise after this test period, the State should then proceed to develop technical specifications for the design, installation and maintenance of porous pavement as an acceptable stormwater BMP.

The following references contain discussion about porous pavement:

CDM (1985)
DeGroot (1982)
Schueler (1987)
Urbonas (1986)
Roesner (1988)

2. Surface Infiltration Facilities

a) Assessment

Surface infiltration is a means of shifting the surface stormwater runoff to groundwater flow. This practice is routinely required in Florida, Maryland and New Jersey. Earl Shaver, in Roesner (1988), reported significant rate of failure of these installations in Maryland. An unofficial report indicates similar experience in New Jersey. On the other hand, there are very few reports of failure coming out of Florida. It appears that the very flat terrain and porous soils in Florida, in conjunction with what may be reasonable loading rates may be the key to effective use of this BMP. Except for very select locations, soils and land slopes in Colorado do not appear very suitable for this BMP.

The Technical Committee has concerns about this BMP for use in Colorado. This BMP may be very effective, but it will require careful development of criteria for where it is appropriate to use and how to properly design, install and maintain. Peter Stahre, in Roesner (1988), describes a procedure used in Sweden that appears to have sound technical basis and is backed up by a fairly successful application of this technology in the field. The Technical Committee suggests this be studied further for application in Colorado. It appears that surface infiltration facilities are only feasible where soils are permeable, the bedrock and the seasonal groundwater are situated well bellow the infiltration surface. It also appears that this BMP is only feasible for relatively small development sites.

b) Specific Guidance.

The Technical Committee recommends that the State evaluate the site selection and design procedure used in Sweden as described by Stahre in Roesner (1988) and in Stahre (1990) for use in Colorado. It is further recommended that this BMP be field tested at several installations over a five year period. The testing should include infiltration performance for rainfall and snowmelt runoff and the effects on groundwater levels and quality.

The following references contain discussion about surface infiltration:

CDM (1985)
DeGroot (1982)
EPA (1988)
Schueler (1987)
Urbonas (1986)
Roesner (1988)
Stahre (1990)

3. Percolation Trenches

a) Assessment

A percolation trench is another means of shifting the surface stormwater runoff to groundwater flow. It is similar to a leaching trench installation for a septic tank effluent disposal. Stormwater is routed to a trench filled with uniform sized gravel, where it is detained in the pore spaces of its rock media. The water then infiltrates into the ground through trench sides and bottom. It appears that surface infiltration facilities are only feasible where soils are permeable, the bedrock and the seasonal groundwater are situated well bellow the infiltration surface. It also appears that this BMP is only feasible for relatively small development sites (i.e., less than 10 acres).

This practice is routinely used in Maryland. Earl Shaver, in Roesner (1988), reported that this practice has experienced some failure, but at lesser rate than was experienced for surface infiltration facilities.

Until such time that sound site selection, design, installation and maintenance standards are developed, the Technical Committee is concerned about the use of this BMP in Colorado. Peter Stahre in Roesner (1988) and in Stahre (1990), describes a procedure used in Sweden for detemining site suitability and design of percolation trenches. The Technical Committee suggests this methodology be studied further for application in Colorado.

If there is one criticism of all percolation trenches, it is that their continued operation depends on maintaning open pores in the rock fill media and the surrounding soils. Once these pores fill with sediments carried by stormwater, the infiltration trench will no longer function. To restore them to operation, the entire facility has to be excavated and totally rebuilt. Unfortunately, if the adjacent soils become choked with fine sediments, it may not be possible to rehabilitate the installation.

It is extremely important to remove sediment from water before they enter the trench. This may be done using grass buffer/filter strips and replaceable filters installed inside stormwater inlets. In addition, stormwater should not be permitted to enter an infiltration trench during the construction phase of a development. Sediment laden runoff from a construction site will permanently clog a trench or severely cut its life expectancy.

b) Specific Guidance.

The Technical Committee recommends that the State evaluate the site selection and the design procedures described by Stahre in Roesner (1988) and by Stahre (1990) for use in Colorado. It is further recommended that this BMP be field tested at several installations over a five year period. The testing should include infiltration performance for rainfall and snowmelt runoff, the effects on groundwater levels and quality, and the rate of pore volume loss in the rock fill media and adjacent soils.

The following references contain discussion about percolation trenches:

CDM (1985)
DeGroot (1982)
Schueler (1987)
Urbonas (1986)
Roesner (1988)
Stahre (1990)

4. Retention Ponds

a) Assessment

Retention ponds is a term sometimes used to describe detention facilities that maintain a permanent pool of water between storm events. Stormwater is routed to a retention pond where it is captured in a surcharge volume above the permanent pool. The water in the pond is displaced entirely or in part by the inflow during a storm. The surcharge volume drains off leaving behind a pond that is a mixture of the new inflow and the water that was there before the runoff process began.

This practice is widely used for the removal of some of the pollutant load found in stormwater. The long term average performance of a well designed retention pond is somewhat predictable; however, it is not possible to predict how well it will perform during an individual runoff event.

Retention ponds treat stormwater through physical sedimentation process while runoff is occurring and through biological process that may be taking place between storms. The latter appears to be somewhat effective in reducing the concentrations of dissolved nutrients in the water column.

The Technical Committee is more comfortable in being able to predict the average performance of the sedimentation process than the biological processes that may occur within a retention pond. These are not well understood even in the eastern regions of United States where most of the performance date is currently available.

The Technical Committee believes that retention ponds are effective in the removal of suspended solids and somewhat effective in the removal of dissolved nutrients. Data on the performance of two retention ponds located within the Cherry Creek Watershed are available through the Cherry Creek Basin Authority. Mulhern and Steele reported in Roesner (1988) that a retention facility removed 16 percent of the phosphorous load. Although this seems like a very small removal rate, the test facility was pond located on a golf course that was not designed for the purpose of water quality enhancement. Mulhern and Steele did not report on the removal rates for other constituents.

b) Specific Guidance.

The Technical Committee suggests that the State provide funds to study field performance of retention ponds to optimize their design parameters for Colorado. Also, the Technical Committee suggests this methodology be developed into sound criteria for Colorado. One specific issue that has yet to be answered is what size of watershed that is required to maintain a permanent pool in the retention pond. The evaporation rates are high in the high plains of Colorado and a sufficient base flow needs to be present to keep the pool from drying up.

The following references contain discussion about retention ponds:

CDM (1985)
DeGroot (1982)
Douglas County (1986)
Schueler (1987)
Urbonas (1986)
Roesner (1988)
Stahre (1990)

5. Extended Detention Basins

a) Assessment

The term Extended Detention Basin describes detention facilities that capture a specific design volume of urban runoff and release it over an extended period (24- to 48-hours). These facilities do not have a permanent pool, but are designed to drain completely between storm events.

This practice is also used, often inappropriately, throughout the United States for the removal of some of the pollutant load found in stormwater. The long term average performance of a well designed extended detention basin is also somewhat predictable; however, just like for retention ponds, it is not possible to predict how well it will perform during an individual runoff event.

Extended detention basins remove pollutants through a physical sedimentation process which occurs during and immediately after the runoff event. There is no apparent help from biological activity within these basins.

The Technical Committee finds that extended detention basins can be designed to be effective in the removal of suspended solids and most of the pollutants that adsorb to these solids. This conclusion is substantiated by various papers in DeGroot (1982), Urbonas (1986), Roesner (1988). In addition, EPA (1987) Stahre (1990) and others have evaluated and reported on their performance. On the other hand, extended detention appears to have a very limited capability to remove dissolved constituents such as nutrients.

In well designed installations, annual TSS removal efficiencies in excess of 70 percent have been reported. On the other hand, detention basins that have not been designed for the removal of pollutants in some cases have reported very little if any net annual TSS removal.

b) Specific Guidance.

The Technical Committee suggests that the State provide funds to install and study field performance of extended detention ponds. Technical criteria can then be refined for the use of this BMP in Colorado. In the meantime, the sizing guidance for the capture of the 80th percentile runoff event can be formalized for various municipalities using the procedure suggested by Urbonas, Guo and Tucker (1989). Design of basin design geometry is well described in Douglas County (1986), Schueler (1987), DeGroot (1982), Urbonas (1986) Roesner (1988) and Stahre (1990).

The following references contain discussion about retention ponds:

CDM (1985)
DeGroot (1982)
Douglas County (1986)
Schueler (1987)
Urbonas (1986)
Roesner (1988)
Urbonas, Guo and Tucker (1989)
Stahre (1990)

6. Wetlands

a) Assessment

Wetlands, either artificial or natural are being used as the final step for the removal of nutrients in some of the publically owned treatment plats. Their use is encouraged in Maryland for the purification of stormwater. Unfortunately, the little data that is available show contradictory findings. It appears that wetlands, in combination with expended detention, can be very effective in the reduction of TSS concentrations.

They also offer hope for the reduction of nutrients; however, the Technical Committee has not found sufficient data in literature to indicate that wetlands are going to be effective for this over an extended period. Most of the data to date have come from wastewater treatment facilities where the effluent from the wetlands has concentrations of phosphorous equivalent to what is found in untreated urban runoff.

A study by USGS (1986) of a wetland in Florida located downstream of a retention pond showed an increase in annual load of orthophosphorous, and virtually no effect on the concentrations of total phosphorous, as the effluent from the retention pond flowed through the wetland. The majority of the pollutants were removed by the upstream pond. On the other hand, the wetland removed 20 to 40 percent of nitrogen constituents (i.e., organic nitrogen, nitrate, ammonia, etc.).

The Technical Committee finds that it is premature to use wetlands for stormwater management BMP in Colorado. This technique is promising, but needs considerable research to provide the public with appropriate site selection and site design parameters. In the meantime, the use of wetlands along tributary waterways could be encouraged on strictly voluntary basis.

b) Specific Guidance.

The Technical Committee suggests that the State provide funds to study field performance of wetlands. This is needed to develop information for judging site suitability and to develop design parameters for use within Colorado. Many questions remain to be answered, one of which is the minimum size of the watershed needed to produce adequate base flow to permanently sustain a wetland in a semi-arid climate.

The following references contain discussion about wetlands:

DeGroot (1982)
EPA (1988)
Roesner (1988)
Schueler (1987)
Urbonas (1986)
USGS (1986)

7. Sand Filters

a) Assessment

The use of sand filters for the reduction of pollutants found in stormwater runoff from a commercial site in Austin Texas was reported by Veenhuis in Roesner (1988). They found,

Average removal efficiencies of the pond and filter system for suspended solids, biochemical oxygen demand, total phosphorous, total organic carbon, chemical oxygen demand, and dissolved zinc were between 60 and 80 percent. However, the average dissolved solids load was about 13 percent larger in the outflow than in the inflow. Average loads of total nitrite plus nitrate nitrogen were about 110 percent larger in the outflow than in the inflow.

These are expensive to install (i.e., $16,000 per acre of watershed served). Also, they do require to be cleaned on a regular basis as they tend to clog rather quickly. The Technical Committee finds this BMP to be one of the more expensive ones to install and operate.

b) Specific Guidance.

The Technical Committee suggests that this BMP be refined for use in Colorado. It should not be on of the mandated BMPs, but should be made an optional one for use by local governments, industry and the land developer. It is believed that local studies will be needed to develop design guidance for use within Colorado.

The following reference contains a discussion about the use and performance of sand filters:

Roesner (1988)

IV. Post Land Use Change Period & Existing Urbanized Areas

A. Public Education

1. What is the Problem?

2. How Can You Help?

3. Efficient Use of Fertilizers

4. Proper Use and Disposal of Pesticides

B. Animal Control

C. Pesticide, Herbicide, Oil and Antifreeze Disposal

The disposal of used crankcase oil and antifreeze is a significant problem in urban areas. Most communities don not have an active program to collect and dispose of these products, as a result individuals sometimes discard through their trash collection programs or pour it down a storm drain or gutter.

The Technical Committee encourages that communities develop pesticide, herbicide, used oil and used antifreeze collection and disposal programs. This will require an infrastructure for the collection and disposal of these products and an ongoing educational program to inform the residents of its availability.

D. Street Sweeping

Studies by Robert Pitt for EPA and the findings by EPA (1983) revealed that street sweeping has only a marginal water quality benefit. It will pick up course sediments and litter, but it has limited ability to remove from the street surfaces fine sediments and dissolve pollutants. EPA (1983) concluded that a street sweeping frequency of every two days, using vacuum type sweepers, has the potential of reducing the pollutant load between two to five percent.

Clearly this BMP requires the commitment of large municipal resources for a very marginal return of improvement in water quality of runoff. As a result the Technical Committee recommends that this practice be considered for occasional sweeping to reduce the amount of city litter, trash and debris entering the receiving waters.

E. Retrofitting of Structural BMPs in Areas of Concern

F. Elimination of Illicit Discharges

1. Illicit Cross Connections to Storm Drains

2. Illegal Dumping of Pollutants

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