CSP Sewer designed for very wide trenches.

CHAPTER 2 Storm Drainage Planning

Rainfall exceeding the soil's capacity of infiltration and storage results in runoff. In undeveloped areas, such runoff will be accommodated by the natural streams and watercourses, but as development takes place, the natural hydrological balance is changed, resulting in greater runoff due to the increase in impervious surface areas.

In response to this, and to limit the inconvenience to the public, man has, during history, developed techniques for accommodating the increased runoff, by constructing swales, ditches, culverts, sewers and canals. Over the years these techniques have been improved, as more knowledge was gained about the factors affecting storm water runoff (hydrology) and the conveyance (hydraulics) in pipes and open watercourses. Similarly, our ability to find more efficient ways of constructing storm drainage facilities has also increased.

The basic philosophy applied to the design of storm drainage facilities, followed in the past and still widely practiced today, is to collect as much storm water runoff as possible and rapidly discharge it through a system of pipes to the nearest outlet.

Nevertheless, it has become apparent that in many instances we have ended up creating new problems, which now may become very difficult and expensive to solve.

The major problems that have been created can be summarized as follows:

a) *high peak flows* in storm sewers and streams which require larger facilities at higher cost;
b) *lowering of water tables,* with a detrimental effect on existing vegetation, and, in low lying coastal areas, permitting salt water intrusion;
c) *reduction in base flows* in receiving streams, affecting aquatic life;
d) *excessive erosion* of streams and sedimentation in lakes, due to higher discharge velocities;
e) *increased pollution* of receiving streams and lakes due to industrial fallout on roofs, fertilizers from lawns and debris from streets and paved areas being conveyed directly to the streams;
f) *damage due to flooding*—runoff quantities which had been experienced rarely, now occur much more frequently.

Nature meant most of this water to soak back into the earth; present practices often prevent it.

Of major importance in the design of storm drainage facilities is the realization that all urban storm drainage systems are comprised of two separate and distinct systems, namely the *Minor System* and the *Major System.*

The minor system (or "convenience" system) consists of carefully designed closed and open conduits and their appurtenances, with capacity to handle runoff from a storm expected to occur with a certain frequency and in a way which will cause relatively minor public inconvenience.

The major system is the route followed by runoff waters when the minor system is inoperable or inadequate. The lack of a properly designed major system often leads to flooding causing severe damage.

It is not economically feasible to enlarge the minor system to obviate the need for the major system. By careful attention during the initial planning stage, a major system can usually be incorporated at no additional cost, and it often permits substantial cost savings.

In recent years a new philosophy has emerged, which departs from the past practices, by attempting to follow the natural hydrological processes as much as possible. For instance, in urban areas where hydrologic abstractions, (i.e. infiltration, depression storage, etc.) have been reduced or completely eliminated, facilities are designed to accommodate the abstractions lost through urbanization, permitting the runoff rates and volumes to remain close to those prior to development, or limited to an acceptable level.

The application of the "new" philosophy has come to be known by the term *Storm Water Management,* which may be defined as follows: "Storm water management is the combined efforts of governing agencies providing policies and guidelines, and professions responsible for design and construction of storm drainage facilities, to control the effects of storm water so that the threat not only to life and property, but also to the environment as a whole, can be minimized."

Management techniques consist of methods such as:

a) *Surface Infiltration,* where runoff is directed to pervious surfaces, (i.e. lawns, parks),

b) *Ground Water Recharge,* disposal of storm water by subsurface infiltration drainage, particularly in areas with a substratum of high porosity,

c) *Storm Water Detention,* temporary storage of excess runoff, with a subsequent regulated release rate to the outlet.

Another term which has become synonymous with Storm Water Management is the term *Zero Increase in Storm Water Runoff.* This is the implementation of storm water management to limit storm water runoff to flows that occurred prior to development. This criteria may be applied to one frequency of occurrence or may be designed for a series of frequencies.

Lifting lugs are provided to protect the exterior coating on this CSP.

CONCEPTUAL DESIGN

When designing the storm drainage system the drainage engineer should examine the site of the proposed development, both by visual inspection and through the aid of topographical maps to obtain a better understanding of the natural drainage patterns.

Every effort should be made to co-ordinate proposed drainage facilities such as storm sewers and artificial channels with natural waterways in such a way that will be both aesthetically pleasing and functional.

To achieve these objectives it must be realized that urban drainage is *always* composed of two separate and distinctive systems, one to handle low intensity storms (the "minor" system) and another (the "major" system) which comes into use when the first system has insufficient capacity or becomes inoperable due to temporary blockage. When both systems are properly designed, they will provide a high level of protection against flooding, even during major storms, while usually being more economical than the conventional methods prevalent in many urban areas.

The Minor System

The minor system consists of carefully designed closed and open conduits and their appurtenances, with capacity to handle runoff from a storm expected to occur once within a one-year to five-year period and in a way which will cause relatively minor public inconvenience.

The criteria recommended for this system are as follows:

a) Level of Service—one or two-year rainfall intensity for normal residential areas, increasing up to five years for major traffic arteries and commercial districts.
b) Design to recognize surcharging to road surfaces, permitting the hydraulic gradient to follow roadways, resulting in a more economic system.
c) No connections other than to catchbasins and other inlet structures.
d) Foundation drains must not be connected by gravity to storm sewers, except where the sewers are sufficiently deep or large to prevent hydrostatic pressure in basements during surcharge conditions.
e) Minimum depth of cover to be a function of external loading, but the springline must always be below frost depth.
f) Downspouts should, wherever possible, be discharged to the ground, utilizing suitable splash pads.

The Major System

The major system is the route followed by runoff waters when the minor system is inoperable or inadequate. It is usually expensive to eliminate any need for a major system. By careful attention from the initial planning stage, a major system can usually be incorporated at no additional cost and will often result in substantial savings in the minor system as well, i.e., greater protection at less cost. The criteria recommended for this system are as follows:

a) Level of Protection—100-year frequency desirable, 25-year minimum.
b) Continuous road grades or overflow easements to open watercourses.
c) No damage may be caused to private structures due to flooding.
d) Surface flows on streets to be kept within reasonable limits.

METHODS TO REDUCE QUANTITY OF RUNOFF AND MINIMIZE POLLUTION

If the storm water is permitted to follow its natural hydrological process it will inevitably result in a reduction in the quantity of storm water runoff and a reduction of pollution loading in the receiving watercourses. Storm water should be directed into the soil, preferably to the same extent as nature did prior to development, and maybe to an even greater extent. By allowing storm water to infiltrate back into the soil it will not only reduce the quantity of runoff and recharge the water table, but the filtering properties of the soil will improve the water quality.

Whatever amount cannot be so accommodated at the point of rainfall should be detained in nearby locations for a controlled outlet to the receiving streams, with peak flows approaching the pre-development peak flows.

There are a variety of methods in common use today that can effectively control peak runoff rates, while at the same time, improving quality. The following Table 2.1 lists such methods along with their effectiveness.

Long lengths with fewer joints can lower the effective "n" value.

Table 2.1 Measures for reducing quantity of runoff and minimizing pollution

MEASURE	Reduce Volume of Runoff	Reduce Peak Rate of Runoff	Improvements to Runoff Water Quality	APPLICABILITY				
				Residential	Institutional	Commercial	Industrial	Highways
Roof water to grassed surfaces	X	X	X	X				
Contour grading	X	X		X				
Porous pavement								
– interlocking stones	X	X		X	X	X	X	
– gravelled surfaces	X	X		X	X	X	X	
– porous asphalt	X	X		X	X	X	X	X[1]
Grassed ditches	X	X	X	X	X	X	X	X
Infiltration basins	X	X	X	X	X	X	X	X
Blue-Green storage		X		X	X	X	X	
Ponding on flat roofs		X			X	X	X	
Ponding on roadways		X		X			X	
Ponding on parking lots		X			X	X	X	
Detention ponds (dry pond)		X	X	X	X	X	X	X
Retention ponds no freeboard			X					
Retention ponds with freeboard		X	X	X	X	X	X	
Subsurface disposal								
– perforated storm sewer	X	X	X	X	X	X	X	X
– infiltration trenches	X	X	X	X	X	X	X	X
– dry wells	X	X	X	X	X	X	X	X
Subsurface detention		X	X[2]	X	X	X	X	X

1. See “Porous Pavements” page 43
2. See “Underground Detention” page 161

Twin 180 m long smooth line, 2400 mm diameter provide cooling water at the Crist Steam Generating Plant of Gulf Power Company.

Surface Infiltration

One method of reducing runoff is to make maximum use of the pervious surfaces in lawns, green belts and parklands. By discharging roof water onto lawns, a large percentage of the roof runoff may be absorbed into the soil. For minor storm events the designer may use the same runoff factors for roofs as for sodded areas. In such cases this will generally mean a reduction in runoff of about 60-70 percent for the roof area. To prevent the downspout discharge from reaching the foundation drains, it is very important that splash pads be placed below the downspouts. This will prevent erosion and permit water to flow freely away from the foundation wall. The downspouts should, wherever practical, be placed in a location which will avoid problems during freezing temperatures, such as icing of driveways, and preferably where the runoff can reach grassed areas. This will also increase the time of concentration, resulting in further reduction in runoff. Additional infiltration and delay in runoff can often be achieved by means of contour grading of the site.

Special "recharge basins" can also be included as part of the drainage system in areas where the percolation rate is fair to high. They are similar to detention basins, but permit recharging of groundwater while detaining only the excess runoff.

Porous Pavements

Various types and shapes of precast concrete paving blocks with perforations have been in use in Europe for many years. During the second world war, perforated concrete paving stones were even used for airport runways, since they permitted extensive grass growth through the perforations, making the runways less noticeable from the air. The idea was later used to provide hard surfaces for little-used fire routes within apartment complexes, since they give an appearance similar to the surrounding park areas. The additional value as a "low runoff" type of pavement soon became apparent to drainage engineers; precast interlocking blocks, with or without perforations, and other porous materials such as clear cut stone, clay brick chips and cinders have successfully replaced impervious surfaces for use in parking areas, driveways, medians and boulevards. For sites with a high ratio of impervious areas, such as apartment sites and shopping centers, this form of paving will be most beneficial.

More recently a porous asphalt, where no fine materials are used in the mix, but slightly more asphalt is used as a binder, has been developed. The omission of the fine particles does not seem to reduce the overall strength of the asphalt pavement significantly, but leaves channels for water to pass through. The base material should be composed of graded crushed stone to permit storage for the water until it percolates into the soil. The permeability of the underlying soil determines the depth of the stone base.

Although the experience with this type of paving in frost areas is still limited, it has indicated that ice and snow conditions and snow removal are the same as for any other paving. No problems have been encountered with regard to heaving if the underlying soil is free-draining, but swelling type clay soils could present difficulties and may not be suitable for this type of pavement.

Effects on Water Quality

The concepts used for detention and reduction of storm water runoff not only regulate the amounts and rate of runoff of storm water, but also are an important factor in reducing pollution. Sedimentation basins, underground recharge systems and detention facilities all have treatment capabilities. Runoff from roofs, directed over grassed surfaces rather than being piped directly to a storm sewer, will receive a substantial reduction in pollution through its travel over-land or through percolation into the soil. Perforated storm sewers with a properly designed filter material will permit initial runoff (the "first flush") which contains most of the pollutants, to be temporarily stored in the underground system for gradual percolation into the soil. The voids in the stone filter material will permit treatment of pollutants somewhat similar to the action of a septic tile bed.

FOUNDATION DRAINS

In the past, most foundation drains were often connected to the sanitary sewers, where such were available; otherwise they were served by sump pumps. With the growing demand for increased sewage treatment capacities, it became logical to eliminate as much extraneous flow from the sanitary sewers as possible, and some municipalities started to prohibit foundation drain connections to sanitary sewers, preferring to connect them to the storm sewer. The additional expense of extending storm sewers to serve the full length of all streets rather than to catch basins only, and the extra depths needed in order to connect the foundation drains by gravity, were considered to be worth the cost.

Only later did we realize that a problem was created, much larger than the one we were trying to solve.

Since it is not economically feasible to size storm sewers to accommodate every possible runoff eventuality, times occurred when the storm sewer backed up to levels above the basement floors, with the result that storm water flowed into foundation drains and caused the condition it was supposed to prevent (see Figure 2.1).

The condition became considerably worse where roof-water leaders were also connected to the same outlet pipe as the foundation drains. In addition to the high cost involved, this method resulted in many flooded basements as well as extensive structural damage to basements from the hydrostatic pressure exerted. Standard methods of construction cannot withstand a hydrostatic pressure of more than 150 to 300 millimetres before damage takes place.

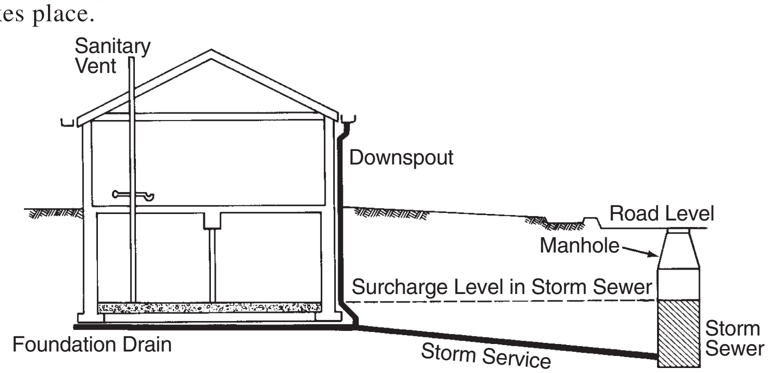
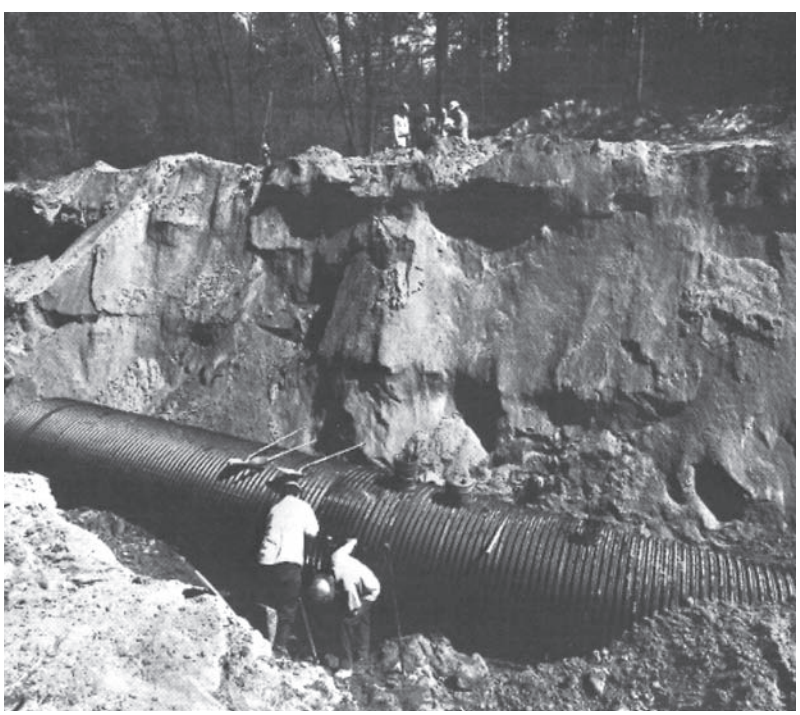


Figure 2.1 Foundation drain and downspout connected to storm sewer by gravity

Some areas experiencing this problem have preferred to increase the sewer design criteria from a two-year to five or even ten-year rainfall frequency. This conflicts with the present emphasis of reducing runoff, but even if it did not, many indeterminable factors not yet recognized in storm drainage design will make it impossible for the designer to predict with any degree of accuracy what storm frequency the system will actually be able to handle before hydrostatic pressure will occur on basements. Due to the variations in storm patterns and runoff conditions, a system designed for a ten-year frequency may, in some areas, be able to accommodate a storm of much higher intensity, and in other locations considerably less. With a different storm pattern the condition could be reversed.

If foundation drains are connected by gravity to storm sewers of less capacity and the hydraulic grade line exceeds the basement elevation, protection against flooding of basements cannot be obtained.

Another possibility could be sump pump installations which can discharge to the ground or to a storm sewer. This would transfer the problem to the individual homeowner, who may not be too pleased with a device which, as a result of mechanical or power failure, may cause flooding to his basement. The resulting damage, however, would not cause structural failure to the basement, as pressure equalizes inside and outside. Although the inflowing water would be relatively clean storm water rather than sewage, this solution does not seem very desirable when projected for areas expecting a large urban growth.



Standard CSP structural designs permit unrestricted trench width.

An alternative solution is a separate foundation drain collector, being a third pipe installed in the same trench as the sanitary sewer but with connection to foundation drains only (see Figure 2.2). The method has several advantages and, for many new areas it may be the best solution. A foundation drain collector will:

a) eliminate the probability of hydrostatic pressure on basements due to surcharged sewers;
b) eliminate infiltration into sanitary sewers from foundation drains;
c) permit shallow storm sewers, design for lower rainfall intensity, and could reduce length of storm sewers, resulting in cost savings for the storm sewer system;
d) permit positive design of both the minor and major storm drainage systems.

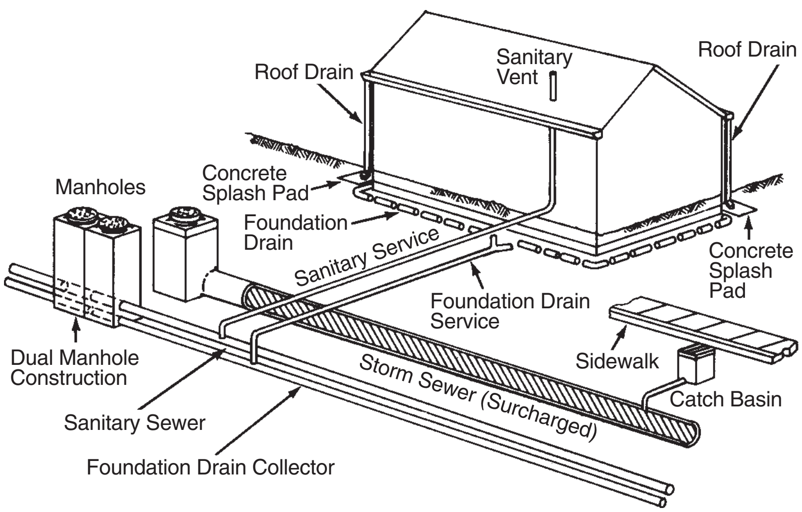


Figure 2.2 Foundation drain connected to foundation drain collector by gravity

Since it does require an outlet with free discharge even during severe storm conditions, it may not be practicable in all areas, particularly within built-up areas where storm sewer outlets have already been provided.

ENVIRONMENTAL CONSIDERATIONS OF RUNOFF WATERS

This section addresses environmental and legal constraints that should be considered in planning and designing underground disposal systems for storm water runoff.

Various sources of data do attempt to define the character and concentrations of pollutants generated from urban areas.[1, 2, 3] An extensive database was gathered for the Water Planning Division of the U.S. Environmental Protection Agency (E.P.A.). The E.P.A. established the National Urban Runoff Program (N.U.R.P.) in 1978.[4] As part of this program, average concentrations for various pollutants were established (Table 2.2). The average concentration or median event mean concentrations were based on data from 28 projects throughout the United States.

Perspective on the possible impacts of subsurface disposal of storm water runoff can be gained from information available on the land treatment of municipal wastewater. Design guidelines for the use of these systems are defined in detail in the "Process Design Manual for Land Treatment of Municipal Wastewater," published jointly by the U.S. Environmental Protection Agency, U.S. Army Corps of Engineers, and U.S. Department of Agriculture.[5]

The main stimulus to elimination of storm sewer discharge into surface waters has been concern over its impact on public health and aquatic biological communities. As combined sanitary storm sewer systems have been identified and direct discharges reduced, attention has focused on the quality of storm water.

In order to effectively address the storm water issue, U.S. Congress amended section 402 of the Clean Water Act in the course of enacting the Water Quality Act of 1987. Section 402 now requires E.P.A. to promulgate regulations establishing permit application requirements for certain storm water discharges and separate storm sewer systems.

The proposed rules are intended to develop a framework for National Pollutant Discharge Elimination System (N.P.D.E.S.) permits for storm water discharges associated with industrial activity; discharges from large municipal separate storm sewer systems (systems serving a population of 250,000 or more); and discharges from medium municipal separate storm sewer systems (systems serving a population of 100,000 or more, but less than 250,000).[6]

The general reference for ground water quality is drinking water standards since many near-surface or water table aquifers constitute the main source of public water supplies. For areas affected by saltwater intrusion or locations with naturally poor quality ground water, disposal of poor quality surficial storm water is not a serious concern. The EPA-proposed drinking water standards are listed in Table 2.3.

This twin CSP diversion is more than a kilometre long.

If ground water contaminants are substantially higher in the area of concern than any of the current listed standards for drinking water quality, future use as a public water supply is doubtful and the subsurface disposal permitting process should be greatly simplified.

Most State Health Departments prohibit direct discharge of storm water runoff into underground aquifers. Recharge systems are not utilized in some states because these requirements place restrictions on storm water infiltration systems. Under water pollution law in Ohio, for example, offenders can be charged with polluting ground water but those charges must be made and proven in a court of law.[7]

Some northern states use large quantities of road de-icing salts during winter months. These states have tended to refrain from use of storm water recharge systems fearing possible contamination of ground water. To prevent ground water pollution, some agencies in California require a 3 m aquifer clearance for drainage well construction.[8] Drainage wells are readily capable of polluting ground water supplies and local regulatory agencies should be consulted concerning the amount of aquifer clearance required for a specific project.

Ground Water Quality Process

Chemical analyses of water commonly report constituent concentrations as "total." This designation implies that nitrogen, for example, is a total of dissolved and particulate phases. The principle dissolved nitrogen species are ammonia, soluble organic nitrogen, nitrite, and nitrate. The particulate can be either absorbed nitrogen, organic matter containing nitrogen, or insoluble mineralogic phases with nitrogen in the lattice.

The particulate in the various elements are also represented in the suspended sediments. The distinction is sometimes important as soils and interstitial areas of some aquifers can filter out particulate or suspended solids thereby reducing the impact of the various pollutants on the ground water. This is particularly important in the case of bacteria.

The natural filtration of runoff water by the soil removes most harmful substances before they can reach the water-bearing aquifer. *Nearly all pathogenic bacteria* and many chemicals are filtered within 1-3 m during vertical percolation, and within 15-60 m of lateral water movement in some soil formations.[9]

Tests made by the US. Department of Agriculture for the Fresno Metropolitan Flood Control District, indicated heavy metals such as lead, zinc, and copper were present in the upper few centimeters of storm water infiltration basin floors. Generally after 10 to 15 years of storm water collection, this layer may require removal or other treatment where a build-up of concentrations of these elements has occurred. The particular locations tested by U.S.D.A. had soils with a relatively high clay content.[7] Layers of fine sands, silts, and other moderately permeable soils also very definitely improve the quality of storm water. This concept underlies the practice of disposing of domestic sewage in septic tanks with leach lines or pits, and the land disposal techniques.

One of the major traffic-related contaminants is lead. Although lead is primarily exhausted as particulate matter, it is fairly soluble. Ionic lead tends to precipitate in the soil as lead sulfate and remains relatively immobile due to low solubility.[10] Ionic forms can also be tied up by soil microorganisms, precipitation with other anions, ion exchange with clay miner-

Table 2.2 Median EMCs for all sites by land use category

		Residential		Mixed		Commercial		Open/Non-urban	
Pollutant		Median	CV	Median	CV	Median	CV	Median	CV
Biochemical Oxygen Demand	mg/l	10.0	0.41	7.8	0.52	9.3	0.31	–	–
Chemical Oxygen Demand	mg/l	73	0.55	65	0.58	57	0.39	40	0.78
Total Suspended Solids	mg/l	101	0.96	67	1.14	69	0.85	70	2.92
Total Lead	μg/l	144	0.75	114	1.35	104	0.68	30	1.52
Total Copper	μg/l	33	0.99	27	1.32	29	0.81	–	–
Total Zinc	μg/l	135	0.84	154	0.78	226	1.07	195	0.66
Total Kjeldahl Nitrogen	μg/l	1900	0.73	1288	0.50	1179	0.43	965	1.00
Nitrite + Nitrate	μg/l	736	0.83	558	0.67	572	0.48	543	0.91
Total Phosphorus	μg/l	383	0.69	263	0.75	201	0.67	121	1.66
Soluble Phosphorus	μg/l	143	0.46	56	0.75	80	0.71	26	2.11

Legend:
mg/l = milligrams per litre
μg/l = micro grams per litre
CV = coefficient of variation

Table 2.3 EPA-proposed regulations on interim primary drinking water standards, 1975[1]

Constituent or Characteristic	Value	Reason For Standard
Physical		
Turbidity, mg/l	1[2]	Aesthetic
Chemical, mg/l		
Arsenic	0.05	Health
Barium	1.0	Health
Cadmium	0.01	Health
Chromium	0.05	Health
Fluoride	1.4-2.4[3]	Health
Lead	0.05	Health
Mercury	0.002	Health
Nitrate as N	10	Health
Selenium	0.01	Health
Silver	0.05	Cosmetic
Bacteriological		
Total coliform, per 100 mg	1	Disease
Pesticides, mg/l		
Endrin	0.0002	Health
Lindane	0.004	Health
Methoxychlor	0.1	Health
Toxaphene	0.005	Health
2, 4-D	0.1	Health
2, 4, 5-TP	0.01	Health

1 The latest revisions to the constituents and concentrations should be used.
2 Five mg/l of suspended solids may be substituted if it can be demonstrated that it does not interfere with disinfection.
3 Dependent on temperature; higher limits for lower temperatures.

als, absorption by organic matter, or uptake by plants. Once ionic lead reaches the ground watertable, precipitation, ion exchange, or absorption can still reduce the available lead. Surface and ground water quality samples collected near a major highway interchange in Miami, Florida, revealed that lead concentrations were very low.[12] The interaction of lead with the high bicarbonate probably caused precipitation in the surface water borrow pond. Sediment concentrations were relatively high.

If impure water is allowed to enter directly into coarse gravel or open joints in rocks, the impurities may enter into and contaminate adjacent ground waters. Sites that are underlain with highly permeable strata, or cracked and jointed rocks have the best capabilities for rapid disposal of surface waters. Unless adequate arrangements are made to treat contaminated water, or to filter impurities, infiltration systems may degrade the ground water quality. Faults and intrusions, should always be evaluated for their effect on ground water occurrence, on quality, and on direction of movement. If the underlying rock strata is fractured or crevassed like limestone, storm water may be diverted directly to the ground water, thereby receiving less treatment than percolation through soil layers.

Structural plate storm sewer encloses stream in an urban area.

Breeding and Dawson[13] tell about a system of 127 recharge wells used by the City of Roanoke, Virginia, to dispose of storm runoff from newly developing industrial and residential areas. Several major faults exist in the underlying bedrock. These faults play a significant role in the effectiveness of the drainage wells, and also in the movement of ground water. The authors also indicate that these direct conduits to ground water have caused quality degradation in one area; however, "ground water users in adjacent Roanoke County have not experienced quality problems that could be connected to this means of storm water disposal."

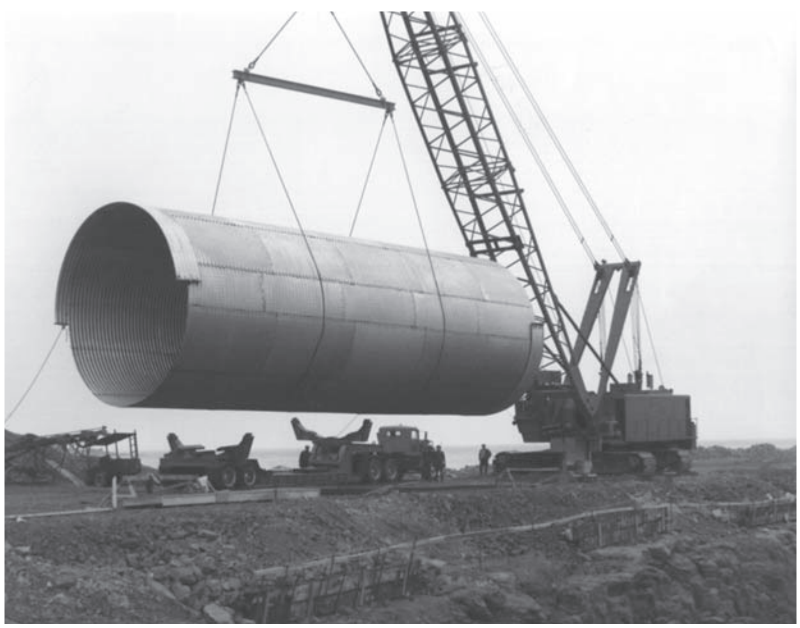
The case cited illustrates the possibility of ground water contamination in areas where fractured and highly permeable rock layers exist, providing conduits for widespread movement of contaminants. It is, therefore, important in the planning stages of a large subsurface storm water disposal project to identify the underlying soil strata in terms of its hydraulic, physical, and chemical characteristics. Pertinent *physical characteristics* include texture, structure, and soil depth. Important *hydraulic characteristics* are infiltration rate, and permeability. *Chemical characteristics* that may be important include pH, cation-exchange capacity, organic content, and the absorption and filtration capabilities for various inorganic ions.

If detailed ground water quality analyses are available it is possible to compute the solution-mineral equilibrium.[14] This approach does not guarantee that an anticipated chemical reaction will occur but does indicate *how* many ionic species *should* behave. The items referring to physical and hydraulic characteristics are addressed to some extent in other chapters of this manual. Further discussion of the chemical characteristics of soils is beyond the scope of this manual. Definitive information on this subject can be obtained by consulting appropriate references, for example, Grim,[15] or other textbooks on the subject. The importance of proper identification of the hydraulic characteristics of the rock strata has been noted above.

Ground Water Monitoring

Environmental laws and regulations now in force require the monitoring of ground water where adverse effects to its quality may result from disposal and storage of solid and liquid wastes. Monitoring systems have not, as yet, been required for ground water recharge utilizing storm water.

A view of the 18 lines of 1200 mm diameter fully perforated corrugated steel pipe used as a recharge system.



Large diameter structural plate pipe for handling high volumes of runoff.

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