8.6 Geonet Installation

8.6.1 Geonet Placement

1. As each roll is moved from the storage area by the Installer, the labels shall be removed by the Installer and submitted to the Site CQA Manager. The rolls of geonet shall be brought to the area to be lined with a front-end loader and support pipes set up such that the geonet roll is fully supported across its length. A spreader bar or similar device shall be used to prevent the lifting chains or slings from damaging the edges.
2. Care shall be taken to keep the geonet clean and free from debris prior to installation. If the geonet is not clean, it should be washed using a high-pressured hose prior to installation.
3. Each panel of the geonet shall be rolled out and installed in accordance with the approved shop drawings prepared by the Installer. The layout shall be designed to keep field joining of the geonet to a minimum and consistent with proper methods of geonet installation.
4. On slopes, the geonet shall be secured and rolled down the slope in such a manner as to continually keep the geonet panel in tension. If necessary, the geonet shall be positioned by hand after being unrolled to minimize wrinkles.
5. In areas where wind is prevalent, geonet installation should be started at the upwind side of the project and proceed downwind. The leading edge of the geonet shall be secured at times with sandbags or other means sufficient to hold it down during windy conditions.
6. The geonet shall not be welded to the geomembrane.
7. The geonet shall only be cut using scissors or other cutting tools approved by the Manufacturer that will not damage the underlying geosynthetics. Care shall be taken not to leave tools on the geonet.
8. Necessary precautions shall be taken to prevent damage to underlying layers during placement of the geonet.
9. During placement of geonet, care shall be taken not to entrap dirt or excessive dust within the geonet that could cause clogging of the drainage system and/or stones that could damage the adjacent geomembrane. If dirt or excessive dust is entrapped in the geonet, it should be hosed clean prior to placement of the next material on top of it. In this regard, care shall be taken in handling the sandbags to prevent rupture or damage of the sandbag.
10. Once the geonet is removed from the storage area by the Installer, it becomes the responsibility of the Installer.

8.6.2 Field Seams

The following requirements shall be met during installation of the geonet:

1. Adjacent rolls shall be overlapped by a minimum of 4 inches.
2. Overlaps shall be secured by tying. Tying can be achieved by HDPE fasteners or polymer braids. Tying devices shall be white or yellow for easy inspection. Metallic devices will not be permitted.
3. Tying shall be every 5 feet along the slope and base, every 6 inches in the anchor trench, and every 6 inches along end-to-end seams on the floor of the pond.
4. No horizontal seams shall be allowed on side slopes.
5. In the corners of the side slopes where overlaps between perpendicular geonet panels are required, an extra layer of geonet shall be unrolled along the slope, on top of the previously installed geonet from top to bottom of the slope.
6. When more than one layer of geonet is installed, joints shall be staggered.

8.7 Field Quality Control

1. The Installer shall provide the Site CQA Manager with Daily Summary Reports addressing the following:
   a. Underlying geomembrane approval for areas anticipated to be covered by geonet
   b. The total number and location of panels placed
   c. Location of repairs

2. The Field Installation Team Manager and the Site CQA Manager shall provide 100% inspection of the installation to ensure compliance with these technical specifications and Manufacturer recommended procedures.
   a. The surface of the geonet shall be clean and free of debris at the time of inspection.
   b. The Field Installation Manager shall record each roll number and lot number as panels are deployed, and a general description of the location of each panel.
   c. The Field Installation Manager and the Site CQA Manager shall inspect the overlap for each panel.
   d. The Field Installation Manager and the Site CQA Manager shall inspect the anchoring of the geonet.
   e. The Field Installation Manager and the Site CQA Manager shall inspect the geonet for any signs of defects or holes. Any areas requiring repair shall be marked and subsequently repaired in accordance with the Repair Procedures listed in these specifications.
   f. The Field Installation Manager and the Site CQA Manager shall reinspect, verify, and approve repairs and patches.
3. Repair Procedures
   a. Seams and non-seam areas of the geonet shall be inspected for defects, holes, and any sign of contamination by foreign matter in accordance with the Field Quality Control procedures listed in these specifications.
   b. Any defects shall be repaired by the Installer by placing a geonet patch with a minimum 12-inch overlap in all directions.
   c. The patch shall be secured to the original geonet panel by placing HDPE fasteners or polymer braids every 6 inches along the perimeter of the patch.
   d. For any repair method, surfaces shall be clean and dry at the time of the repair.
   e. Each completed repair shall be inspected and approved in accordance with the Field Quality Control procedures listed in this CQA Plan.

9.0 SELECT AGGREGATE

9.1 Leak Detection System Sump

1. Washed select aggregate, shall be used for bedding material around the leak detection sumps for the evaporation ponds; and other locations as shown in the approved construction drawings. The select aggregate shall be durable, resistant to weathering and shall be free organic material, and fines < 2% by dry weight.
2. The bedding aggregate shall have particle sizes that range from ¾ inch minimum diameter to 2.0 inch maximum diameter in accordance with ASTM C136.
3 The select aggregate shall have particle shapes that will not damage the FML with the use of a 10 oz/yd^2 non-woven geotextile cushion layer. The select aggregate shall be approved by the Engineer.

9.2 Conformance Testing

1. Gradation analysis shall be performed on samples from each source of the select aggregate to assure compliance with the project specifications.

9.3 Delivery, Storage and Handling

If select aggregate materials are delivered to the site prior to approval, materials shall be stockpiled on-site in areas as dictated by the Owner to facilite approval by the Engineer. Provision shall be implemented to minimize surface water or dust impacts on the stockpile. Removal and placement of the materials shall be conducted in a manner to minimize intrusion of soils adjacent to and beneath the stockpile.

9.4 Select Aggregate Placement

Select Aggregate Leak Detection System Bedding Layer

After geosynthetic placement has been approved, placement of non-woven geotextile in the floor of the leak detection system, and leak detection sump will ensure protection of the geosynthetics from the overlying select aggregate layer.

1. Leak Detection System Bedding Layer
    a. Placement of a 3 inch bedding layer in the bottom of the trench and on top of the geotextile consisting of select aggregate, 0.75 inch minimum diameter to 2.0 inch maximum diameter (maximum 2% fines by dry weight).
    b. Backfilling of the pipe will be allowed only after placement and workmanship have been approved by the Site CQA Manager.
    c. Backfilling around the pipe will be with the select aggregate to the depth and width shown on the construction drawings.
    d. Haunching of the select aggregate will provide stability to the pipe from the sides and from underneath.
    e. Placement of the select aggregate should be in gradual 4 inch to 6 inch lifts and tamped simultaneously with a blunt tamping tool to ensure the material is well consolidated under and around the pipe.
    f. Backfilling, with the select aggregate, should be brought up to a height of a minimum of 12 inches above the top of the pipe.
2. Leak Detection Sump Select Aggregate Placement
    a. Placement of a 2 foot layer in the sumps and on top of the geotextile consisting of select aggregate, 0.75 inch minimum diameter to 2.0 inch maximum diameter (maximum 2% fines by dry weight).
    b. Backfilling of the leak detection and riser pipes will be allowed only after placement and workmanship have been approved by the Site CQA Manager.
    c. Backfill around the leak detection and riser pipes will be with the select aggregate to the depth and width shown on the construction drawings.
    d. Placement of the select aggregate should be in gradual 4 inch to 6 inch lifts and teamped simultaneously with a blunt tamping tool to ensure the aggregrate is well consolidated under the sides of the pipes as well as around it.
    e. Care shall be taken during backfilling such that damage to the leak detection and riser pipes is avoided.

10.0 GEOTEXTILE

10.1 Geotextile Properties

1. The 10 oz/yd^2 non-woven geotextile is specified for the leak detection sump aggregate cushion wrap. Additionally, 10 oz/yd^2 non-woven geotextile is specified for the evaporation pond leak detection sump aggregate cushion wrap. The geotextile shall meet the specifications provided in **Table III.2.8**.
2. The minimum roll width shall be 15 feet, and the maximum roll length shall be 300 feet.

10.2 Manufacturer's Quality Control Documentation

Prior to installation commencement of any geonet composite material, the Contractor shall provide to the Site CQA Manager the following information certified by the manufacturer for the delivered geotextile.

1. Each roll delivered to the project site shall have the following identification information:
    - Manufacturer's name
    - Product identification
    - Thickness
    - Roll number
    - Roll dimensions
2. Quality control certificates, signed by the manufacturer's quality assurance manager. Each certificate shall have roll identification number, sampling procedures, frequency, and test results.

At a minimum, the following test results/certifications shall be provided in accordance with applicable test/certification requirements specified in **Table III.2.8**:

- Thickness (ASTM D5199)
- Weight (ASTM D5261)
- Tensile strength (ASTM D4632)
- Elongation (ASTM D4632)
- CBR puncture strength (ASTM D6241)
- Trapezoidal tear strength (ASTM D4533)
- Coefficient of permeability (ASTM D4491)
- Permittivity (ASTM D4491)
- Flow rate (ASTM D4491)
- UV resistance (ASTM D4355)
- Apparent opening size (ASTM D4751)

10.3 Conformance Testing

1. Conformance testing shall be performed by an independent Quality Assurance Laboratory approved by the Engineer at a minimum of one (1) per 100,000 ft^2. The Site CQA Manager or Installer shall obtain the samples from the roll, mark the machine direction and identification number. The number of lots and samples will be determined in accordance with ASTM D4354. The following conformance tests shall be conducted at the independent laboratory:
   - Weight (ASTM D5261)
   - Tensile strength (ASTM D4632)
   - CBR puncture strength (ASTM 6241)
   - Trapezoidal tear strength (ASTM D4533)
   - Apparent opening size (ASTM D4751)
2. These conformance tests shall be performed in accordance with **Table III.2.8.**
3. Conformance test results shall be reviewed by the Site CQA Officer, and lots shall be accepted or rejected prior to the placement of the geotextile. Test results shall meet, or exceed, the property values listed in **Table III.2.8.** If the sampling results do not meet property values for any individual lot sample, the lot shall be resampled and retested. This retesting shall be paid for by the manufacturer or installer. If the test values from the resamples pass the acceptable specification values listed in **Table III.2.8,** the lot shall be accepted.

10.4 Delivery, Storage and Handling

1. The geotextile shall be packaged in rolls, uniformly wound onto suitable cylindrical forms or cores to aid in handling and unrolling. Each roll shall be packaged to protect the material from damage due to ultraviolet light and moisture during normal storage and handling.
2. Each roll shall be clearly marked with the following:
   - Manufacturer's name
   - Roll width and length
   - Brand name of the product
   - Manufacturer lot or control number
3. Off-loading and storage of the geotextile shall be performed by the Contractor.
4. Storage of the geotextile shall be in accordance with ASTM D-4873. The material shall not be exposed to sunlight for longer than 14 days.
5. The Installer shall be responsible for moving the geotextile from the storage area to the cell area for installation. The Installer shall be responsible for replacing any geotextile material damaged during installation.

10.5 Installation Leak Detection Sump

1. Sump Preparation
   a. Before the geotextile is placed into position in the leak detection sumps, the following procedures will be completed.

1) The subgrade at the bottom and sides of the sumps shall be carefully prepared in accordance with this CQA Plan.
2) Underlying geosynthetics have been installed in accordance with this CQA Plan.

2. Geotextile Installation
   a. After geosynthetic placement has been approved by the Site CQA Manager, the Geotextile Installer shall place the non-woven geotextile in the bottom to ensure protection of the underlying geosynthetics from the overlying select aggregate layer.
      1) Exposure of the geotextiles to the elements between lay down and cover shall be a maximum of 14 days.
      2) The 10 oz/yd^2 non-woven geotextile shall be placed atop the underlying geosynthetics in the leak detection sump. The geotextile shall be placed such that the centerline of the geotextile lines up with the centerline of the trench. The geotextile shall be joined by overlapping with heat bond or sewing. Overlapped seams shall have a minimum overlap of 24 inches.
      3) The Installer shall take care not to damage the underlying geosynthetic materials. The Installer is responsible for any damage to the geotextile and underlying geosynthetics caused during geotextile installation.
3. Field Quality Control
   a. The Site CQA Manager shall inspect the installation for proper placement, sufficient overlap and damaged material. Damaged areas will be repaired in accordance with the Repair Procedures of this CQA Plan.
4. Repair Procedures
   a. A geotextile patch shall be placed over the damaged area and extend three feet beyond the perimeter of the tear or damage.
   b. The Site CQA Manager shall verify repairs.
5. Select Aggregate Installation
   a. Placement of the 2 feet of select aggregate in the leak detection sumps shall be performed by the Contractor.
6. Detection Sump Pipe Installation
   a. Installation of the SDR 11 HDPE sump riser pipes will be performed in accordance with the Geopipe Specifications.

11.0 GEOPIPE

11.1 General

The design of the leak detection extraction riser pipes employ a 4-inch partial perforated/partial solid-walled SDR 11 leak detection sump riser pipe.

The sump extraction geopipes rise along the evaporation pond sideslope to allow extraction of liquid from the leak detection sumps. Leak detection piping design is shown on Engineering Drawings.

11.2 HDPE Geopipe Material Properties

1. High Density Polyethylene (HDPE) Pipe is the preferred material utilized for the leak detection pipe will be manufactured in accordance with ASTM D714 and have the following physical characteristics:
   a. Solid wall 4-inch diameter HDPE Discopipe as manufactured by Phillips 66, or approved equal, with a standard dimension ratio (SDR) of 11 as shown on the Engineering Drawings.
   b. HDPE pipe shall meet the requirements of cell classification PE 445574C or higher cell classification in accordance with ASTM D3350.
   c. The slots or perforations must conform with the Engineering Drawings.
   d. The pipe shall be as uniform as commercially practical in color, opacity, density, and other physical properties.

   e. Apart from structural voids and hollows associated with some profile wall designs, the pipe fittings shall be homogeneous throughout and free from visible cracks, holes, foreign inclusions or other defects.
2. HDPE Pipe Fittings and Joints
   a. HDPE fittings shall be manufactured in accordance with the requirements of ASTM E714.
   b. End caps for the clean-out risers will be of low pressure type HDPE, or similar with stainless steel hardware.
   c. The pipe shall be joined by the method of thermal butt fusion or electrofusion as outline in ASTM D2657. All joints shall be made in strict compliance with the Manufacturer's recommendations.
   d. Mechanical connections of the polyethylene pipe to auxiliary equipment such as valves, pumps and tanks shall be through flanged connections that shall consist of the following:
      1) A stainless steel back-up, polyethylene flange shall be thermally butt-fused to the stub end of the pipe.
      2) A 316 stainless steel back up ring on both sides of the connection shall be used as approved by the Owner.
   e. Blind Flange connections shall be made in accordance with Manufacturer's recommendations.

11.3 Manufacturer's Quality Control Documentation

Prior to installation of the geopipe (HDPE), the Contractor shall provide the following information certified by the manufacturer for the delivered geopipe:

1. Manufacturer's certification verifying that the quality of the raw materials used to manufacture the geopipe meets the Manufacturer specifications.
2. Each geopipe length delivered to the project site shall have the following identification information:
   - Manufacturer's name
   - Pipe size
   - Ring stiffness constant classification or SDR number
   - Production code designating plant location, machine, and date of manufacture.
3. Each length of pipe and each fitting shall be marked with the name of the Manufacturer, size, and class. All gaskets shall be marked with the name of Manufacturer, size, and proper insertion direction.

11.4 Delivery, Storage and Handling

1. Off-loading and storage of the geopipe shall be performed by the Contractor.
2. Storage of the geopipe shall not exceed 17 rows high, as per Manufacturer's recommendation.
3. The Contractor shall be responsible for moving the pipes and fittings from the storage area to the area of pipe installation. The Contractor shall be responsible for replacing any material damaged during transport or installation.

11.5 Quality Assurance

1. Finished Product Evaluation
   a. Each length of pipe produced shall be checked by production staff for the items listed below. The results of measurements shall be recorded on production sheets which become part of the Manufacturer's permanent records.
      1) Pipe in process shall be checked visually, inside and out for cosmetic defects (grooves, pits, hollows, etc.).
      2) Pipe outside diameter shall be measured using a suitable periphery tape to ensure conformance with ASTM D1785.
      3) Pipe wall thickness shall be measured at 12 equally spaced locations around the circumference at both ends of the pipe to ensure conformance with the Manufacturer's specifications.
      4) Pipe length shall be measured.

5) Pipe marking shall be examined and checked for accuracy.
6) Pipe ends shall be checked to ensure they are cut square and clean.

11.6 Installation

1. Leak Detection Sump Preparation
   a. Before the leak detection riser geopipe is placed into position in the sumps, the following procedures will be completed:
      1) The subgrade at the bottom and sides of the sumps shall be carefully prepared as shown on the Engineering Drawings by the Contractor.
      2) The subgrade will be covered by a bentonite liner and 60 mil HDPE liner (composite liner) by the Liner Installer according to the Engineering Drawings.
2. Geotextile Installation
   a. After composite liner placement has been approved, the Installer shall place the non-woven geotextile in the bottom of the leak detection sumps to ensure protection of the composite liner from the overlying select aggregate layer in accordance with the Geotextile Cushioning Fabric specifications.
3. Select Aggregate Installation
   a. Placement of 2 feet of select aggregate in the sumps and above the geotextile consisting of 0.75 inch minimum diameter to 2.0 inch maximum diameter (min 2% fines by dry weight) will be performed."Spading" with shovels or any other activities which could jeopardize the underlying composite liner's integrity will not be allowed.
4. Leak Detection Pipe Installation
   a. High Density Polyethylene (HDPE) Leak Detection Pipe Installation
      1) Installation of the 12-inch or 4-inch diameter SDR 11 HDPE pipe in the leak detection and leak detection sumps will be performed in such a manner as not to jeopardize the integrity of the pipe.
      2) Each pipe section shall be accurately placed to the line and alignment called for on the Engineering Drawings.
      3) The leak detection sumps shall be kept free from any deleterious material, water or backfill to prevent damage to the pipe. The Contractor shall provide means and devices to remove promptly and dispose of any deleterious material, or water entering the area of pipe laying.
      4) Installation practices shall conform with ASTM D2321 and any specific manufacturer's recommendations.
      5) HDPE pipe joints shall be butt fused in the field in accordance with the manufacturer's instructions. Fused joints, when tested for tension and pressure, shall be stronger than the pipe itself.
      6) As many sections of pipe as practical shall be fused together outside of the composite lined area to minimize damage to the composite liner during pipe fusion.
      7) No connection shall be made where joint surfaces and joint materials have been soiled until such surfaces are thoroughly cleaned.
      8) As the work progresses, the interior of pipes shall be kept clean. After each line of pipe has been laid along the side slope, it shall be carefully inspected and earth, trash, rags, and other foreign matter removed from the interior.
      9) Slots/perforations on the bottom 6 feet of the leachate extraction and leak detection riser pipes shall be as shown on the Engineering Drawings.
5. Field Quality Control
   a. After completion of each section of the leak detection geopipe; the joints and alignment along the side slopes shall be true to line and alignment.
   b. The Site CQA Manager shall inspect the installation. The pipe shall be completely free from any cracks and from protruding joint materials, deposits of sand, mortar, dirt, debris or other materials on the inside.

c. After the OCD has been given 72 hours prior notification, placement of a geotextile layer will be completed over the leak detection pipe as shown on the Engineering Drawings.

12.0 ENGINEERING CERTIFICATION

Construction tasks, other than mass excavation and general earthmoving, will be subject to OCD notification and submittal of sealed Construction Plans and Technical Specifications. An Engineering Certification Report, incorporating the laboratory and field data, shall be submitted by Engineer to the New Mexico Energy, Minerals and Natural Resources Department, Oil Conservation Division confirming that the subgrade, liner, and leak detection system have been installed in compliance with the project specifications and the CQA Plan. The Engineering Certification Report shall be sealed by a Professional Engineer registered in good standing with New Mexico; and who has applicable expertise in liner and geosynthetics engineering.

TABLES

Table III.2.1	Summary of Required CQA Standards
Table III.2.2	Technical Specifications: Geosynthetic Clay Liner
Table III.2.3	Technical Specifications: 60-mil HDPE Double-Sided Textured Geomembrane
Table III.2.4	Technical Specifications: 60-mil HDPE Smooth Geomembrane
Table III.2.5	Technical Specifications: 30-mil Reinforced Polyester Geomembrane
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TABLE III.2.1 – Summary of Required CQA Standards (Sheet 1 of 2)

Element	Key Property	CQA/CQC Test	Sampling Plan	Sampling Frequency (Minimum)	Standard Test Method
Excavation Required: Subgrade Layer Material Evaluation	Maximum Density	Proctor Test	Judgmental	1 per 5,000 cy or soil material change	ASTM D698
Fill Required: Subgrade Layer Material Evaluation	Maximum Density	Proctor Test	Judgmental	1 per 5,000 cy or soil material change; 4 per acre per 6-inch lift	ASTM D698
Subgrade Layer & Structural Fill Construction Quality Evaluation	In-Place Density	Nuclear Density Test	Random within the grid	4 per acre per 6-inch thick lift	ASTM D6938
	Surface of final lift to be free of stones greater than 1/2".	Visual	Judgmental	100%	NA
Geosynthetic Clay Liner Material	Conformance	Mass per unit area, Free Swell, Fluid Loss, Peel Strength, Hydraulic Conductivity, Index Flux	Systematic	1 per 100,000 sf	ASTM D5261, D5890, D5891, D5887, D6496, D5587
	Surface Defects	Visual	100%	100%	NA
Liner Geomembrane Material	Conformance	Thickness, Density, Tensile properties, Tear resistance, Carbon black content, Carbon black dispersion, Puncture resistance, Mass/unit area	Systematic	1 per 100,000 sf	ASTM D5994, D1505/0792, D6693, D1004, D4218, D5996, D4833, D5261, D4751, D4632, D4833
	Surface Defects	Visual	100%	100%	NA
Liner Geomembrane Seaming Procedures	Subgrade	Visual	100%	100%	NA
	Anchor Trench	Visual	100%	100%	NA
	Temporary Anchor	Visual	100%	100%	NA
	Sheet Placement	Visual	100%	100%	NA
	Overlap of Sheets	Measurement	100%	100%	NA
	Cleanliness of Seam	Visual	100%	100%	NA
	Extent of Grinding	Measurement	100%	100%	NA

Note: Where reference is made to one of the above standards, the revision in effect at the time of construction shall apply.

TABLE III.2.1 – Summary of Required CQA Standards (Sheet 2 of 2)

Element	Key Property	CQA/CQC Test	Sampling Plan	Sampling Frequency (Minimum)	Standard Test Method
Liner Geomembrane Seams	Test Seams	Tensiometer	Systematic	In accordance with specifications	NA
	Field Hot Wedge Seams	Non-Destructive Tests (Pressure Dual Seam)	100%	100%	NA
		Destructive Tests (peel & shear strength)	Random within the grid and Judgmental	1 per 500 linear feet	ASTM D6392
	Field Extrusion Fillet Seams	Non-Destructive Tests (Vacuum Box Testing)	100%	100%	ASTM D4437
		Destructive Tests (peel & shear strength)	Random within the grid and Judgmental	1 per 500 linear feet	ASTM D6392
Geonet	Conformance	Thickness, Density, Wide width tensile properties, Mass per unit area, Carbon black, Melt index	Systematic	1 per 100,000 sf	ASTM D4354, D1777, D1505, D7179, D5261, D4218, D1238
	Anchor Trench	Visual	100%	100%	NA
	Temporary Anchor	Visual	100%	100%	NA
	Sheet Placement	Visual	100%	100%	NA
	Overlap and Tying of Sheets	Measurement	100%	100%	NA
Protective Soil Layer	Permeability	Lab Permeability	Random	1 per Source	ASTM D2434 or Falling Head
	Particle Size	Gradation of Soil	Random	1 per 1,500 cy	ASTM C136
	Thickness of Protective Soil Layer	Surveying or Direct Test	Within the grid	5 per acre	NA
Geotextile	Conformance	Mass per unit area, Trapezoidal tear strength, Puncture strength, Grab tensile strength, Apparent opening size	Systematic	1 per 100,000 sf	ASTM D5261, D4533, D6241, D4632, D4751
	Overlap	Measurement	100%	100%	NA
	Seams	Visual Observation	100%	100%	NA
Leachate Collection System	Grade	Surveying	NA	1 per 50 lf	NA
	Product specs, placement and workmanship	Visual Observation	100%	100%	NA
Leachate Pipe Envelope	Minimize clogging, facilitate flow	Gradation of Aggregate	Random	1 per Source	ASTM C136
	Placement and workmanship	Visual Observation	100%	100%	NA

Note: Where reference is made to one of the above standards, the revision in effect at the time of construction shall apply.

TABLE III.2.2 - Technical Specifications: Geosynthetic Clay Liner (GCL)

MATERIAL	PROPERTY	QUALIFIER	UNIT	VALUE	TEST METHOD	MANUFACTURER QC TEST FREQUENCY (MINIMUM)	CONFORMANCE QA TEST FREQUENCY (MINIMUM)
Nonwoven Cover Geotextile	Mass/Unit Area	Minimum	oz/yd^2	6.0	ASTM D5261	200,000 ft^2	100,000 yd^2
Bentonite	Free Swell	Minimum	ml	24/2g	ASTM D5890	100,000 lb	100,000 yd^2
	Fluid Loss	Maximum	ml	18	ASTM D5891	100,000 lb	100,000 yd^2
	Moisture Content	Maximum	%	35	ASTM D5993	100,000 lb	NA
Woven Base Fabric	Mass/Unit Area	Minimum	oz/yd^2	3.2	ASTM D5261	200,000 ft^2	NA
GCL (as manufactured)	Mass of GCL[2]	Minimum	lbs/ft^2	0.81	ASTM D5993	40,000 ft^2	100,000 yd^2
	Tensile Stress (Machine Direction)	Minimum	lbs/in	30	ASTM D6768	40,000 ft^2	NA
	Peel Strength	Minimum	lbs/in	3.5	ASTM D6496	40,000 ft^2	100,000 yd^2
	Permeability[3]	Maximum	cm/sec	$5x10^{-9}$	ASTM D5887	30,000 yd^2	100,000 yd^2
	Flux	Maximum	cm^3/sec-cm^2	$1x10^{-8}$	ASTM D5887	30,000 yd^2	100,000 yd^2
	Shear Strength[4]	Minimum @ 200 lbs/ft^2	lbs/ft^2	500	ASTM D6243	Periodic	NA
Geotextile and Reinforcing Yarns	% Strength Retained[5]	Minimum	%	65	ASTM D6768	Yearly	NA

Notes:

1. *Standard test methods updated to reflect most current industry standards.*
2. *Mass of GCL and bentonite measured after oven drying per stated test method at 0% moisture content.*
3. *Value represents GCL permeability after permeation with deaired, deionized water @ 5 psi maximum effective confining stress and 2 psi head pressure. See GRI-GCL3 for termination criteria.*
4. *Value represents minimum percent retained from manufactured value after oven aging at 60^{0}C 50 days.*
5. *Typical peak value for specimen hydrated for 24 hours and sheared under a 200 psf normal stress.*

TABLE III.2.3 - Technical Specifications: 60-mil HDPE Single-Sided and Double-Sided Textured Geomembrane

PROPERTY	QUALIFIER	UNIT	VALUE	TEST METHOD	MANUFACTURER QC TEST FREQUENCY (MINIMUM)	CONFORMANCE QA TEST FREQUENCY (MINIMUM)
Thickness	Min Average Lowest individual for 8 of 10 values Lowest individual for any 10 values	mils mils mils	60 54 51	ASTM D5994	Per Roll	100,000 ft^2
Density	Minimum	g/cc	0.94	ASTM D792 or D1505	100,000 ft^2	100,000 ft^2
Tensile Properties (each direction): Break Strength Yield Strength Elongation - break Elongation - yield	 Min Average Min Average Min Average Min Average	 lb/in lb/in % %	 228 126 700 12	ASTM D6693, Type IV	100,000 ft^2	100,000 ft^2
Tear Resistance	Min Average	lbs	42	ASTM D1004	20,000 lbs	100,000 ft^2
Puncture Resistance	Min Average	lbs	108	ASTM D4833	20,000 lbs	100,000 ft^2
Carbon Black Content	Min Range	%	2.0 – 3.0	ASTM D4218	20,000 lbs	100,000 ft^2
Carbon Black Dispersion	Rating	NA	Note 1	ASTM D5596	20,000 lbs	100,000 ft^2
Stress Crack Resistance	Minimum	hours	500	ASTM D5397 Appendix	Per GRI GM 10	NA
Asperity Height	Min Average	mils	20	ASTM D7466 GRI GM 13	every second roll	100,000 ft^2
Standard Oxidation Time	Min Average	minutes	100	ASTM D3895	200,000 lbs	NA
Oven Aging at 85°C Standard Oxidation Time - % Retained after 90 days	Min Average	%	55	ASTM 3895	Each Formulation	NA
UV Resistance High Pressure Oxidation Induction Time - % Retained after 1,600 hours	Min Average	%	50	ASTM D5885	Each Formulation	NA

Notes:

1. *Dispersion only applies to near spherical agglomerates. 9 of 10 views shall be Category 1 or 2. No more than 1 view from Category 3.*
2. *Standard test methods will be updated to reflect the most current industry standards.*

SEAM PROPERTIES HDPE GEOMEMBRANE				
PROPERTY	**QUALIFIER**	**UNIT**	**VALUE**	**TEST METHOD**
Thickness	Minimum	mils	60	ASTM D5994
Bonded Seam Strength (1) [Shear Strength]	Minimum	lb/in	121	ASTM D6392
Tensile Properties (1)(2) [Peel Strength]: • Hot Wedge Fusion Weld • Fillet Extrusion Weld	 Minimum Minimum	 lb/in lb/in	 98 78	 ASTM D6392 ASTM D 6392
Air-Pressure (3)(4)	Minimum	psi	3	GRI GM6
Vacuum (3)	Minimum	psi	3	NA

Seam Notes:

1. *Value listed for shear and peel strengths are for four out of five test specimens. Fifth specimen can be as low as 80 percent listed values.*
2. *Break, when peel testing, occurs in liner material itself, not through peel separation (FTB).*
3. *See Section 7.9 for Field Quality Control requirements and testing extrusion and fusion welds.*
4. *Initial pressure 27-37 psi for 5 minutes.*

TABLE III.2.4 - Technical Specifications: 60-mil HDPE Smooth Geomembrane

PROPERTY	QUALIFIER	UNIT	VALUE	TEST METHOD	MANUFACTURER QC TEST FREQUENCY (MIN)	CONFORMANCE QA TEST FREQUENCY (MIN)
Thickness	Min Average Min Individual Lowest individual for any 10 values	mils mils mils	60 54 51	ASTM D5199	Per Roll	100,000 ft^2
Density	Minimum	g/cc	0.94	ASTM D792 or D1505	100,000 ft^2	100,000 ft^2
Tensile Properties (each direction): Break Strength Yield Strength Elongation - break Elongation - yield	 Min Average Min Average Min Average Min Average	 lb/in lb/in % %	 228 126 700 12	ASTM D6693, Type IV	100,000 ft^2	100,000 ft^2
Tear Resistance	Min Average	lbs	42	ASTM D1004	20,000 lbs	100,000 ft^2
Puncture Resistance	Min Average	lbs	108	ASTM D4833	20,000 lbs	100,000 ft^2
Carbon Black Content	Min Range	%	2.0 – 3.0	ASTM D4218	20,000 lbs	100,000 ft^2
Carbon Black Dispersion	Rating	NA	Note 1	ASTM D5596	20,000 lbs	100,000 ft^2
Stress Crack Resistance	Minimum	hours	500	ASTM D5397 Appendix	Per GRI GM 10	NA
Standard Oxidation Time	Min Average	minutes	100	ASTM D3895	200,000 lbs	NA
Oven Aging at 85ºC Standard Oxidation Time - % Retained after 90 days	Min Average	%	55	ASTM D3895	Each Formulation	NA
UV Resistance High Pressure Oxidation Induction Time - % Retained after 1,600 hours	Min Average	%	50	ASTM D5885	Each Formulation	NA

Notes:

1. *Dispersion only applies to near spherical agglomerates. 9 of 10 views shall be Category 1 or 2. No more than 1 view from Category 3.*
2. *Standard test methods will be updated to reflect the most current industry standards.*

SEAM PROPERTIES HDPE GEOMEMBRANE				
PROPERTY	**QUALIFIER**	**UNIT**	**VALUE**	**TEST METHOD**
Thickness	Minimum	mils	60	ASTM D5199
Bonded Seam Strength (1) [Shear Strength]	Minimum	lb/in	121	ASTM D6392
Tensile Properties (1)(2) [Peel Strength]: • Hot Wedge Fusion Weld • Fillet Extrusion Weld	 Minimum Minimum	 lb/in lb/in	 98 78	 ASTM D6392 ASTM D 6392
Air-Pressure (3)(4)	Minimum	psi	3	GRI GM6
Vacuum (3)	Minimum	psi	3	NA

Seam Notes:

1. *Value listed for shear and peel strengths are for four out of five test specimens. Fifth specimen can be as low as 80 percent listed values.*
2. *Break, when peel testing, occurs in liner material itself, not through peel separation (FTB).*
3. *See Section 7.9 for Field Quality Control requirements and testing extrusion and fusion welds.*
4. *Initial pressure 27-37 psi for 5 minutes.*

TABLE III.2.5 - Technical Specifications: 30-mil Reinforced Polyester Geomembrane

PHYSICAL PROPERTIES				
PROPERTY	**QUALIFIER**	**UNIT**	**VALUE**	**TEST METHOD[1]**
Thickness	Minimum Average	mils	30	ASTM D5199
Density	Minimum	oz/yd^2	30 ± 2	ASTM D1505
Break Strength	Minimum	lb	550	ASTM D751 Grab Test Method Procedure A
Break Elongation	Minimum	%	20	ASTM D751
Tear Strength	Minimum	lb	40	ASTM D751
Puncture Resistance	Minimum	lb	275	ASTM D4833
Hydrostatic Resistance	Minimum	psi	800	ASTM D751, Procedure A
Bursting Strength	Minimum	lb	750	ASTM D751, Ball Tip

SEAM PROPERTIES				
PROPERTY	**QUALIFIER**	**UNIT**	**VALUE**	**TEST METHOD[1]**
Bonded Seam Strength	Minimum	lb	575	ASTM D751 Grab Test Method Procedure A
Peel Adhesion	Minimum	lb/2 in	40	ASTM D413

Notes:
1. *Standard test methods will be updated to reflect the most current industry standards.*

TABLE III.2.6 - Typical Wedge Temperature Ranges for Hot Wedge Seaming of Thermoplastic Liners

Liner Type	Fahrenheit (°F)	Celsius (°C)
HDPE		
Minimum[1] Temperature	600	320
Maximum[2] Temperature	750	400

Notes:
[1] For dry, warm weather seaming conditions
[2] For damp, cold weather seaming conditions

TABLE III.2.7 -Technical Specifications: HDPE Geonet

PROPERTY	QUALIFIER	UNIT	VALUE	TEST METHOD	MANUFACTURER QC TEST FREQUENCY	CONFORMANCE QA TEST FREQUENCY
Thickness	Minimum	mils	200	ASTM D5199	50,000 ft^2	100,000 ft^2
Density	Minimum	g/cm^3	0.94	ASTM D1505 ASTM D792	50,000 ft^2	100,000 ft^2
Melt Index	Range	g/10 min	≤ 1.0	ASTM D1238	Per Lot	NA
Carbon Black Content	Range	%	2.0 - 3.0	ASTM D4218	50,000 ft^2	100,000 ft^2
Tensile Strength (Machine Direction)	Minimum	lb/in	45	ASTM D5035 ASTM D7179	50,000 ft^2	100,000 ft^2
Mass Per Unit Area	Minimum	lb/ft^2	0.16	ASTM D5261	50,000 ft	100,000 ft^2
Transmissivity (loaded)	Minimum	m^2/sec	$1x10^{-3}$	ASTM D4716	500,000 ft^2	100,000 ft^2

Notes:

1. *Standard test methods will be updated to reflect the most current industry standards.*

TABLE III.2.8 - Technical Specifications: 10 oz/yd² and 12 oz/yd² Non-Woven Geotextile[1]

PROPERTY	QUALIFIER	UNIT	VALUE		TEST METHOD	MANUFACTURER QC TEST FREQUENCY	CONFORMANCE QA TEST FREQUENCY
Mass per unit area	MARV	oz/yd^2	10	12	ASTM D5261	90,000 ft^2	100,000 ft^2
Grab tensile strength	MARV	lbs	260	320	ASTM D4632	90,000 ft^2	100,000 ft^2
Grab elongation	MARV	%	50	50	ASTM D4632	90,000 ft^2	100,000 ft^2
CBR Puncture strength	MARV	lbs	725	925	ASTM D6241	540,000 ft^2	1 per project
Trapezoidal tear strength	MARV	lbs	100	125	ASTM D4533	90,000 ft^2	NA
Apparent opening size (AOS)	MaxARV	US Sieve	100	100	ASTM D4751	540,000 ft^2	1 per project
Permittivity	MARV	sec^{-1}	1.0	0.8	ASTM D4491	540,000 ft^2	1 per project
Water flow rate	MARV	gpm/ft^2	75	60	ASTM D4491	540,000 ft^2	1 per project
UV resistance	MARV	% retained @ 500 hours	70	70	ASTM D4355	Per Formulation	NA

Notes:

1. *Values reported in weaker principal direction.*
2. *All values listed are Minimum Average Roll Values (MARV) unless otherwise noted, calculated as typical -2 standard deviations.*
3. *MaxARV represents typical +2 standard deviations.*
4. *Geotextiles with greater or equivalent properties may be used for select application.*
5. *Standard test methods will be updated to reflect the most current industry standards.*

ATTACHMENT III.2.A

CQA FORMS

Form No.	Title
1.	Liner Quality Control Project Specifications
2.	Approval/Authorization to Proceed Form
3.	Field Observation Report
4.	Field Compaction Testing Form
5.	GCL Inventory Control Log
6.	FML Inventory Control Log
7.	Geonet Inventory Control Log
8.	Geotextile Inventory Control Log
9.	Leak Detection and Extraction Geopipe Inventory Control Log
10.	FML Trial Seaming Test Log
11.	FML Seaming Log
12.	FML Seam Pressure Test Log
13.	FML Destructive Field Test Record
14.	FML Seam Vacuum Test/Repair Log
15.	GCL Deployment Log
16.	FML Deployment Log
17.	Geonet Deployment Log
18.	Geotextile Deployment Log

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LINER QUALITY CONTROL PROJECT SPECIFICATIONS

1.0 Project Data

Site Name: ______________________ Date Prepared: __________

Project/Cell: ______________________

Project Number: ______________________ Project Start Date: __________

Project Size: __________ Acres or ft^2

Location: ______________________

____

Client Contact: ______________________

Phone: ______________________

Site Phone: ______________________

		Initials
Project Manager:	______________________	________
CQA Officer:	______________________	________
CQA Technicians:	______________________	________
	______________________	________
	______________________	________

Project Documentation Available

CQA Plan: ______ Construction Drawings: ________ Health and Safety Plan: ________

Other: __________________

Comments: ______________________

____

____

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LINER QUALITY CONTROL PROJECT SPECIFICATIONS

2.0 Subgrade/Soil Liner

2.1 Grade Control (Survey) Area: ________ Acres or ft^2 ***N/A*** ☐

Performed By: ____________________ Date Performed: ________

Tolerance (vert): ________ feet or inches As-Built Drawing(s) Available? Y or N

____

Thickness: ________ feet or inches **Standard = 1 per acre**

2.2 Compaction ***N/A*** ☐

		Sample ID	Maximum Density	Optimum Moisture
Reference Proctor(s):	________ lb/ft^3			
Standard (ASTM D698):	________			
Modified (ASTM D1557):	________			

Specifications:

Density: ________ % of Optimum Moisture: ________ lb/ft^3

________ lb/ft^3

Number of Lifts: ________ Lift Thickness (inches):

Loose: ________ Compacted: ________

Field Test Frequency: ________ per: acre/li yd^3 other units: ________

Compaction Test Method: Nuclear Density Meter or Other: ________

Total Number of Density Tests Required: ____________ **Standard = 4/acre/lift**

Field Permeability Tests required: Y or N Perm Test Method: ______________

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LINER QUALITY CONTROL PROJECT SPECIFICATIONS

2.3 Soil Classification Standards *N/A* ☐

Acceptable USCS: (circle or box)

GW	SW	ML	MH
GP	SP	CL	CH
GM	SM	OL	OH
GC	SC		

Subgrade/Liner Material Testing:

in situ ________ borrow source: ____________

Testing Frequency		Quality Requirements	
Project	NMED/OCD	Project	NMED/OCD

Grain Size:

#200 Sieve ________________________ (percent passing)

C_u (D_{60}/D_{10}) ________________________

Other ________________________

Atterberg Limits: P.I.

Liquid Limit ________________

Plastic Limit ________________

Other ________________

Laboratory Permeability: ________________

2.4 Surface Preparation Y or N *N/A* ☐

_______ smooth surface

_______ remove angular material

_______ remove organic material

_______ remove rocks greater than _________ inches

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LINER QUALITY CONTROL PROJECT SPECIFICATIONS

3.0 Geosynthetics | **Conformance Tests**

3.1 GCL *N/A* ☐

Area: ________ Acres or ft^2

Specifications:

collected by: ________
performed by: ________
frequency: ________
total number: ________

3.2 FML *N/A* ☐

Specifications: ________ 60 mil
________ other

frequency: ________
total number: ________

HDPE Smooth: Area: _____ Acres or ft^2

HDPE Textured: Area: _____ Acres or ft^2

Other: ________ Area: _____ Acres or ft^2

3.3 Geotextile *N/A* ☐

Specifications: oz
Woven or Nonwoven

Area: ________ Acres or ft^2

collected by: ________
performed by: ________
frequency: ________
total number: ________

3.4 Geonet *N/A* ☐

Area: ________ Acres or ft^2

Specifications: ________ thickness

with Geotextile:
upper ________ lower _____

collected by: ________
performed by: ________
frequency: ________
total number: ________

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LINER QUALITY CONTROL PROJECT SPECIFICATIONS

4.0 Detection System **Leak** ___ **Leachate** ___ **Conformance Tests**

4.1 Piping ***N/A*** ☐

Collection System — Specifications: ____________
Linear Quantity — Material: ____________
Diameter: ____________

Risers — Specifications: ____________
Linear Quantity — Material: ____________
Diameter: ____________

4.2 Aggregate ***N/A*** ☐ — collected by: _______

Specifications: — performed by: _______

greater than — frequency: _______

smaller than — total number: _______

4.3 Geotextile ***N/A*** ☐

Specifications: oz — collected by: _______

Woven or Nonwoven — performed by: _______

frequency: _______

Area: ________ Acres or ft^2 — total number: _______

4.4 Sump ***N/A*** ☐

Design volume: ________ yd^3 or gallons

Double Lined? Y or N

Area of double liner: _____ ft^2

5.0 Protective Soil Layer ***N/A*** ☐ **Conformance Tests**

Area: ________ Acres or ft^2 — performed by: _______

frequency: _______

Thickness (inches): _____ — total number: _______

Volume: ________ yd^3

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APPROVAL/ AUTHORIZATION TO PROCEED

TO:

FROM:

PROJECT NAME:

PROJECT NO.:

DATE:

The following liner system surface is deemed acceptable on a visual inspection by Liner Contractor Representative:

LAYER:

1. Subgrade ______________________
2. Geosynthetic Clay Liner (GCL) ______________________
3. HDPE Geomembrane (FML) ______________________
4. Geotextile ______________________
5. Geonet ______________________
6. Detection System ______________________
7. Protective Soil Layer (PSL) ______________________

LOCATION: ______________________to______________________

______________________to______________________

______________________to______________________

REMARKS: ____

____

____

Authorized By: ______________________
(Liner Contractor Representative)

____
(Authorized Signature)

____
(Date)

Accepted By: ______________________
(CQA Manager)

____
(Authorized Signature)

____
(Date)

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FIELD OBSERVATION REPORT

TO:

FROM:

PROJECT NAME:

PROJECT NO.:

DATE: **TIME:** **EST. % COMPLETE:**

Weather
☐ Clear ☐ Snow ☐ Warm
☐ Overcast ☐ Foggy ☐ Hot
☐ Rain ☐ Cold ☐ ___________

Site Conditions
☐ Clear ☐ Dusty
☐ Muddy ☐ __________
Temperature Range _______

Day
☐ Monday ☐ Thursday
☐ Tuesday ☐ Friday
☐ Wednesday ☐ ____________

Persons Contacted/Present at Site:

Work Observed/In-Progress:
Photos included in this report are intended to generally show the progress of the project. They are not intended to indicate the quality or deficiency of the work unless specifically noted.

Items Discussed/Observations:

Materials Delivered to Site:

Requested Revisions or Interpretations:

Items to Verify:

Information or Action Required:

☐ Attachments

Copies: ☐ Owner ☐A/E ☐ Contractor ☐ Consultants ☐______ ☐ __________ ☐ File

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FIELD COMPACTION TESTING RESULTS

PROJECT TITLE: ______________________ **PROJECT NO.:** ______________________
OWNER: ______________________ **DATE:** ______________________
PROJECT LOCATION: ______________________ **PAGE NO.:** ______________________

Testing Instrument: ______________________ **Technician:** ______________________
Reference Density (pcf): ______________________ **Reference Moisture (%):** ______________________

Test Number	Dry Density (pcf)	% Proctor	% Moisture

Test Number	Dry Density (pcf)	% Proctor	% Moisture

Note: See Figure for test locations

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GCL INVENTORY CONTROL LOG

PROJECT NAME: ______ PROJECT NUMBER: ______
CLIENT: ______ CONTRACTOR: ______
PROJECT LOCATION: ______ SHEET NUMBER: ______

MATERIAL TYPE: ______ DATE OF INVENTORY: See Below
MATERIAL IDENTIFICATION: ______ INVENTORY MONITOR: ______
MATERIAL MANUFACTURER: ______ UNLOADING METHOD: ______

	ROLL NUMBER	LOT NO.	MATERIAL DIMENSIONS			MANUF. QC CERT. (Y/N)	CONFORMANCE SAMPLE (Y/N)	DATE OF INVENTORY
			LENGTH (FT)	WIDTH (FT)	THICKNESS OF WEIGHT			
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FML INVENTORY CONTROL LOG

PROJECT NAME: ______________________ PROJECT NUMBER: __________
CLIENT: ______________________ CONTRACTOR: __________
PROJECT LOCATION: ______________________ SHEET NUMBER: __________

MATERIAL TYPE: ______________________ DATE OF INVENTORY: __________
MATERIAL IDENTIFICATION: ______________________ INVENTORY MONITOR: __________
MATERIAL MANUFACTURER: ______________________ UNLOADING METHOD: __________

	ROLL NUMBER	MATERIAL ID NO.	MATERIAL DIMENSIONS			MANUF. QC CERT. (Y/N)	CONFORMANCE SAMPLE (Y/N)	DATE OF INVENTORY
			LENGTH (FT)	WIDTH (FT)	THICKNESS OF WEIGHT			
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GEONET INVENTORY CONTROL LOG

PROJECT NAME: ______ PROJECT NUMBER: ______
CLIENT: ______ CONTRACTOR: ______
PROJECT LOCATION: ______ SHEET NUMBER: ______

MATERIAL TYPE: ______ DATE OF INVENTORY: See Below
MATERIAL IDENTIFICATION: ______ INVENTORY MONITOR: ______
MATERIAL MANUFACTURER: ______ UNLOADING METHOD: ______

	ROLL NUMBER	MATERIAL ID NO.	MATERIAL DIMENSIONS			MANUF. QC CERT. (Y/N)	CONFORMANCE SAMPLE (Y/N)	DATE OF INVENTORY
			LENGTH (FT)	WIDTH (FT)	THICKNESS OF WEIGHT			
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2								
3								
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GEOTEXTILE INVENTORY CONTROL LOG

PROJECT NAME: ______ PROJECT NUMBER: ______
CLIENT: ______ CONTRACTOR: ______
PROJECT LOCATION: ______ SHEET NUMBER: ______

MATERIAL TYPE: ______ DATE OF INVENTORY: See Below
MATERIAL IDENTIFICATION: ______ INVENTORY MONITOR: ______
MATERIAL MANUFACTURER: ______ UNLOADING METHOD: ______

	ROLL NUMBER	MATERIAL ID NO.	MATERIAL DIMENSIONS			MANUF. QC CERT. (Y/N)	CONFORMANCE SAMPLE (Y/N)	DATE OF INVENTORY
			LENGTH (FT)	WIDTH (FT)	THICKNESS OF WEIGHT			
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2								
3								
4								
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6								
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LEAK DETECTION AND EXTRACTION GEOPIPE INVENTORY CONTROL LOG

PROJECT NAME: ____________________ PROJECT NUMBER: ____________
CLIENT: ____________________ CONTRACTOR: ____________
PROJECT LOCATION: ____________________ SHEET NUMBER: ____________

MATERIAL TYPE: ____________________ DATE OF INVENTORY: See Below
MATERIAL IDENTIFICATION: ____________________ INVENTORY MONITOR: ____________
MATERIAL MANUFACTURER: ____________________ UNLOADING METHOD: ____________

	TYPE	QUANTITY	MATERIAL DIMENSIONS			MANUF. QC CERT. (Y/N)	TOTAL LENGTH	DATE OF INVENTORY
			LENGTH (FT)	DIAM. (IN)	PIPE SDR			
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FML TRIAL SEAMING TEST LOG

PROJECT NAME: ____________________ PROJECT NUMBER: ____________________
OWNER: ____________________ CONTRACTOR: ____________________
PROJECT LOCATION: ____________________ SHEET NUMBER: ____________________

PROJECT SPECIFICATIONS

FUSION	TEXTURED:	PEEL	______ lbs/in	SHEAR	______ lbs/in
	SMOOTH:	PEEL	______ lbs/in	SHEAR	______ lbs/in
EXTRUSION	TEXTURED:	PEEL	______ lbs/in	SHEAR	______ lbs/in
	SMOOTH:	PEEL	______ lbs/in	SHEAR	______ lbs/in

DATE	TIME	QC INITIALS	WELDER'S INITIALS	MACHINE NUMBER	WEDGE WELDS		EXTRUSION WELDS		PULL	FIELD TEST RESULTS				
					Temperature	Speed	Barrel Temp	Pre-Heat Temp		Test #1	Test #2	Test #3	Test #4	Test #5
									P					
									P					
									S					
									P					
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FML SEAMING LOG

PROJECT NAME: ____________________ PROJECT NUMBER: __________

OWNER: ____________________ CONTRACTOR: __________

PROJECT LOCATION: ____________________ SHEET NUMBER: __________

SEAMING LOCATION: ____________________

	DATE	PANEL #/PANEL #	APPROX. LENGTH WELDED	START TIME	SEAMER INITIALS	MACHINE #	TEMP SETTING	SPEED SETTING	DESTRUCTIVE TEST	MONITORED BY
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FML SEAMING PRESSURE TEST LOG

PROJECT SPECIFICATIONS	
MIN START PSI:	
TEST DURATION:	
MAX PSI DROP:	

PROJECT NAME: ______________________ PROJECT NUMBER: ____________

OWNER: ______________________ CONTRACTOR: ____________

PROJECT LOCATION: ______________________ SHEET NUMBER: ____________

PRESSURE TEST LOCATION: ______________________

	DATE	PANEL #/PANEL #	TESTER	TIME		PRESSURE		MONITORED BY	PASS/FAIL
				START	FINISH	INITIAL	FINAL		
1									
2									
3									
4									
5									
6									
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FML DESTRUCTIVE FIELD TEST RECORD

PROJECT NAME: ____________________ **PROJECT NUMBER:** ____________________
OWNER: ____________________ **CONTRACTOR:** ____________________
PROJECT LOCATION: ____________________ **SHEET NUMBER:** ____________________

PROJECT SPECIFICATIONS

FUSION	TEXTURED:	PEEL	_____ lbs/in	SHEAR	_____ lbs/in
	SMOOTH:	PEEL	_____ lbs/in	SHEAR	_____ lbs/in
EXTRUSION	TEXTURED:	PEEL	_____ lbs/in	SHEAR	_____ lbs/in
	SMOOTH:	PEEL	_____ lbs/in	SHEAR	_____ lbs/in

DATE	DT #	QC INITIALS	WELDER'S INITIALS	MACHINE NUMBER	WEDGE WELDS		EXTRUSION WELDS		PULL	FIELD TEST RESULTS				
					Temperature	Speed	Barrel Temp	Pre-Heat Temp		Test #1	Test #2	Test #3	Test #4	Test #5
									P					
									P					
									S					
									P					
									P					
									S					
									P					
									P					
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Parkhill

FML SEAM VACUUM TEST/REPAIR LOG

PROJECT NAME: ______________________ PROJECT NUMBER: ______________________
OWNER: ______________________ CONTRACTOR: ______________________
PROJECT LOCATION: ______________________ SHEET NUMBER: ______________________

TEST/REPAIR LOCATION: ______________________ MONITOR: ______________________

	REPAIR DATE	PANEL	TYPE OF REPAIR	REPAIR TECH	NUMBER OF LEAKS	TESTING TECH ID	DATE ACCEPTED	COMMENTS
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3								
4								
5								
6								
7								
8								
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Parkhill

GCL DEPLOYMENT LOG

PROJECT NAME: ______________________ PROJECT NUMBER: ____________
CLIENT: ______________________ CONTRACTOR: ____________
PROJECT LOCATION: ______________________ SHEET NUMBER: ____________

DEPLOYMENT LOCATION: ______________________ MONITOR: ____________

PANEL NUMBER	ROLL NUMBER	APPROXIMATE LENGTH (FT)	APPROXIMATE WIDTH (FT)	APPROXIMATE AREA (FT^2)	DATE INSTALLED
			TOTAL LINER PLACED (FT^2):	0.0	

Parkhill

FML DEPLOYMENT LOG

PROJECT NAME: ____________________ PROJECT NUMBER: ____________
CLIENT: ____________________ CONTRACTOR: ____________
PROJECT LOCATION: ____________________ SHEET NUMBER: ____________

DEPLOYMENT LOCATION: ____________________ MONITOR: ____________

PANEL NUMBER	ROLL NUMBER	APPROXIMATE LENGTH (FT)	APPROXIMATE WIDTH (FT)	APPROXIMATE AREA (FT^2)	DATE INSTALLED
		TOTAL LINER PLACED (FT^2):		0.0	

Parkhill

GEONET DEPLOYMENT LOG

PROJECT NAME: ____________________ PROJECT NUMBER: __________
CLIENT: ____________________ CONTRACTOR: __________
PROJECT LOCATION: ____________________ SHEET NUMBER: __________

DEPLOYMENT LOCATION: ____________________ MONITOR: __________

PANEL NUMBER	ROLL NUMBER	APPROXIMATE LENGTH (FT)	APPROXIMATE WIDTH (FT)	APPROXIMATE AREA (FT^2)	DATE INSTALLED
			TOTAL LINER PLACED (FT^2):	0.0	

Parkhill

GEOTEXTILE DEPLOYMENT LOG

PROJECT NAME: ____________________ PROJECT NUMBER: ____________

CLIENT: ____________________ CONTRACTOR: ____________

PROJECT LOCATION: ____________________ SHEET NUMBER: ____________

DEPLOYMENT LOCATION: ____________________ MONITOR: ____________

PANEL NUMBER	ROLL NUMBER	APPROXIMATE LENGTH (FT)	APPROXIMATE WIDTH (FT)	APPROXIMATE AREA (FT^2)	DATE INSTALLED
			TOTAL LINER PLACED (FT^2):	0.0	

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III.3.B	GEOTEXTILE REFERENCE DOCUMENTATION
III.3.C	GEONET REFERENCE DOCUMENTATION
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III.3.E	HDPE PIPE REFERENCE DOCUMENTATION
III.3.F	BASIN DISPOSAL WASTEWATER LABORATORY RESULTS

1.0 INTRODUCTION

Basin Disposal, Inc. (BDI) is an existing Surface Waste Management Facility (SWMF) providing oil field waste liquids (OFWL) disposal services. The existing BDI facility is subject to regulation under the New Mexico Oil and Gas Rules, specifically 19.15.36 NMAC, administered by the Oil Conservation Division (OCD) of the NM Energy, Minerals, and Natural Resources Department (NMEMNRD). This document is a component of the “Application for Permit Renewal” that proposes continued operations of the existing approved waste processing and disposal capabilities. The Facility is designed in compliance with 19.15.36 NMAC, and is operated in compliance with a Surface Waste Management Facility Permit issued by the OCD. The Facility is owned and operated by, Basin Disposal Inc.

BDI only accepts liquid waste from the production and exploration of oil fields in northwest New Mexico and the surrounding areas. The existing facility is organized in a pattern that allows for specific liquid waste acceptance, treatment, evaporation, or injection of clean liquid.

1.1 Site Location

BDI is located in unincorporated San Juan County on 27.77 acres entirely within Section 3, Township 29 North, Range 11 West approximately 3 miles north of the intersection of Highway 550 and 64 (**Figure II.1.1**). Coordinates for the approximate center of the BDI site are Latitude 36°45’19.92” and Longitude -107°58’58.73”. The site is situated approximately 4 miles north of the San Juan River, and about 4.7 miles south of the Animas River on Crouch Mesa, about 500 feet and 400 feet in elevation above these respective river plains. The site occupies the West Fork of Bloomfield Canyon, an ephemeral drainage channel that drains south to the San Juan River. The site slopes gently to the east and southeast, from a maximum elevation of 5,750 feet to less than 5,700 feet. Detailed site characterization documentation is provided in **Volume IV**.

1.2 Facility Description

The existing BDI facility is comprised of 27.77 acres and is comprised of the following:

- 2 existing evaporation ponds (1 pending construction)
- 12 existing receiving tanks (6 pending construction)
- 4 existing oily water receiving tanks
- 3 existing skimmed oil tanks
- 3 existing oil heating tanks
- 3 existing settling tanks
- 7 existing oil sales tanks (2 pending construction)
- 3 existing filtered water tanks
- 4 existing bleach tanks
- 1 existing concrete sludge solidification basin
- 2 existing covered below grade tanks (containment sumps)
- 1 existing UIC Class II injection well for disposal of produced water
- 2 existing separation tanks
- Various support facilities including an office, a maintenance building, roads, and a storm water detention basin.

Oil field wastes are delivered to the BDI SWMF from oil and gas exploration and production operations in northwestern New Mexico and southwest Colorado. The Site Plan provided as **Figure II.1.2** identify the locations of the Disposal facilities, evaporation/storage ponds, and all structures. Perimeter of the site is surrounded by commercial/industrial businesses on three sides and buffered by a bluff on the west side of the Facility.

2.0 SUMMARY

19.15.36.17 NMAC Specific requirements applicable to evaporation, storage, treatment, and skimmer ponds:

B. Construction, standards.

(3) Liner specifications. Liners shall consist of a 30-mil flexible PVC or 60-mil HDPE liner, or an equivalent liner approved by the division. Synthetic (geomembrane) liners shall have a hydraulic conductivity no greater than 1 x 10^{-9} cm/sec. Geomembrane liners shall be composed of an impervious, synthetic material that is resistant to petroleum hydrocarbons, salts and acidic and alkaline solutions. Liner materials shall be resistant to ultraviolet light, or the operator shall make provisions to protect the material from sunlight. Liner compatibility shall comply with EPA SW-846 method 9090A.

Geosynthetics have a proven track record in a variety of civil engineering applications, primarily over the past 30 years. Fluid containment design provides a unique opportunity to incorporate a range of engineered materials that exceed the equivalent performance of soils. The design of the Basin Disposal Evaporation Ponds includes several examples of geosynthetics used for their superior characteristics, usually applied in conjunction with soil layers:

- Geomembranes (flexible membrane liners) provided as barrier layer in the primary and secondary liner system (**Attachment III.3.A**)
- Geotextiles serving as cushioning layers and as filters to maintain flow (**Attachment III.3.B**)
- Geonets deployed as drainage layers and in leak detection systems (**Attachment III.3.C**).
- The use of HDPE (High Density Polyethylene) pipping systems (**Attachment III.3.E**)

Geosynthetics are selected in the design process for their performance characteristics in the project's site-specific environmental setting. Laboratory analysis was completed on the oil field wastewater. The results of this analysis are presented in **Attachment III.3.F**. Extractable Hexane is the only constituent detected which could have a negative impact on the properties of the HDPE liner. However, at the low concentration of 48 mg/l in the wastewater, there should be no impact to the performance of the HDPE liner. **Attachment III.3.A** includes recent research results that indicate the functional longevity of HDPE liners in similar installations is in the hundreds of years.

This section provides demonstrations, as required by 19.15.36.17.B, that the geosynthetic components are compatible with the fluids to be contained within the ponds. The attached compatibility documentation includes published reports and test results; and is further endorsed by industry experience and proven installations by the design engineer. For the performance criteria of both soil and geosynthetic components to be achieved, they must be constructed in strict accordance with the **Permit Plans** (**Volume III.1**) and the Liner Construction Quality Assurance (CQA) Plan, (**Volume III.2**) of this Application for Renewal. **Table III.3.1** provides an index of compatibility data provided for each of the geosynthetic materials and its function in the engineering design.

TABLE III.3.1 - Geosynthetic Applications and Compatibility Documentation

MATERIAL	FUNCTION	ATTACHED REFERENCE DOCUMENTATION	
HDPE Geomembrane	Primary and secondary barrier layer for liner	III.3.A	*Geomembrane Lifetime Prediction: Unexposed and Exposed Conditions - GRI*
			Cold Temperature and Free-Thaw Cycling Behavior of Geomembranes and Their Seams
			Chemical Compatibility of Poly-Flex Liners
			Chemical Resistance Table Low Density and High Density Polyethylene
			NSC, Contaminant Solutions for Industrial Waste; HDPE Geomembrane
			Liner Longevity Article: Geosynthetics Magazine, Oct/Nov 2008
Geotextile	Filter layer	III.3.B	*Amoco Technical Note No. 7, Chemical Resistance of Amoco Polypropylene Geotextiles*
			Amoco Technical Note No. 14, Geotextile Polymers for Waste Applications
Geonet	Drainage layer	III.3.C	*GSE TenDrain 275 mil Geocomposite*
			Evaluation on Stress Cracking Resistance of Various HDPE Drainage Geonets
GCL	Secondary layer in liner	III.3.D	*The Effects of Leachate on the Hydraulic Conductivity of Bentomat*
			Bench-scale Hydraulic Conductivity Tests of Bentonitic Blanket Materials for Liner and Cover Systems (Thesis by Paula Estornell)
HDPE Pipe	Solid and slotted piping (LDS)	III.3.E	*Chemical Resistance of Plastics and Elastomers Used in Pipeline Construction*
			Driscopipe Engineering Characteristics
			Plexco Chemical Resistance Information
Wastewater	Laboratory Results	III.3.F	*Basin Disposal Wastewater Laboratory Results*

Acronyms used:

GCL:	*Geosynthetic Clay Liner*	*HDPE:*	*High Density Polyethylene*
FML:	*Flexible Membrane Liner*	*NSC:*	*National Seal Company*
GSE:	*Gundle Schlegel Environmental*	*LDS:*	*Leak Detection System*

ATTACHMENT III.3.A

HDPE GEOMEMBRANES REFERENCE DOCUMENTATION

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FAX (610) 522-8441

GRI White Paper #6

- on -

Geomembrane Lifetime Prediction:
Unexposed and Exposed Conditions

by

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Updated: February 8, 2011

Geomembrane Lifetime Prediction: Unexposed and Exposed Conditions

1.0 Introduction

Without any hesitation the most frequently asked question we have had over the past thirty years' is "how long will a particular geomembrane last".* The two-part answer to the question, largely depends on whether the geomembrane is covered in a timely manner or left exposed to the site-specific environment. Before starting, however, recognize that the answer to either covered or exposed geomembrane lifetime prediction is neither easy, nor quick, to obtain. Further complicating the answer is the fact that all geomembranes are formulated materials consisting of (at the minimum), (i) the resin from which the name derives, (ii) carbon black or colorants, (iii) short-term processing stabilizers, and (iv) long-term antioxidants. If the formulation changes (particularly the additives), the predicted lifetime will also change. See Table 1 for the most common types of geomembranes and their approximate formulations.

Table 1 - Types of commonly used geomembranes and their approximate formulations (based on weight percentage)

Type	Resin	Plasticizer	Fillers	Carbon Black	Additives
HDPE	95-98	0	0	2-3	0.25-1
LLDPE	94-96	0	0	2-3	0.25-3
fPP	85-98	0	0-13	2-4	0.25-2
PVC	50-70	25-35	0-10	2-5	2-5
CSPE	40-60	0	40-50	5-10	5-15
EPDM	25-30	0	20-40	20-40	1-5

HDPE = high density polyethylene
LLDPE = linear low density polyethylene
fPP = flexible polypropylene
PVC = polyvinyl chloride (plasticized)
CSPE = chlorsulfonated polyethylene
EPDM = ethylene propylene diene terpolymer

* More recently, the same question has arisen but focused on geotextiles, geogrids, geopipe, turf reinforcement mats, fibers of GCLs, etc. This White Paper, however, is focused completely on geomembranes due to the tremendous time and expense of providing such information for all types of geosynthetics.

The possible variations being obvious, one must also address the degradation mechanisms which might occur. They are as follows accompanied by some generalized commentary.

- Ultraviolet Light - This occurs only when the geosynthetic is exposed; it will be the focus of the second part of this communication.
- Oxidation - This occurs in all polymers and is the major mechanism in polyolefins (polyethylene and polypropylene) under all conditions.
- Ozone - This occurs in all polymers that are exposed to the environment. The site-specific environment is critical in this regard.
- Hydrolysis - This is the primary mechanism in polyesters and polyamides.
- Chemical - Can occur in all polymers and can vary from water (least aggressive) to organic solvents (most aggressive).
- Radioactivity - This is not a factor unless the geomembrane is exposed to radioactive materials of sufficiently high intensity to cause chain scission, e.g., high level radioactive waste materials.
- Biological - This is generally not a factor unless biologically sensitive additives (such as low molecular weight plasticizers) are included in the formulation.
- Stress State – This is a complicating factor which is site-specific and should be appropriately modeled in the incubation process but, for long-term testing, is very difficult and expensive to acheive.
- Temperature - Clearly, the higher the temperature the more rapid the degradation of all of the above mechanisms; temperature is critical to lifetime and furthermore is the key to

time-temperature-superposition which is the basis of the laboratory incubation methods which will be followed.

2.0 Lifetime Prediction: Unexposed Conditions

Lifetime prediction studies at GRI began at Drexel University under U. S. EPA contract from 1991 to 1997 and was continued under GSI consortium funding until ca. 2002. Focus to date has been on HDPE geomembranes placed beneath solid waste landfills due to its common use in this particular challenging application. Incubation of the coupons has been in landfill simulation cells (see Figure 1) maintained at 85, 75, 65 and 55°C. The specific conditions within these cells are oxidation beneath, chemical (water) from above, and the equivalent of 50 m of solid waste mobilizing compressive stress. Results have been forthcoming over the years insofar as three distinct lifetime stages; see Figure 2.

Stage A - Antioxidant Depletion Time

Stage B - Induction Time to the Onset of Degradation

Stage C - Time to Reach 50% Degradation (i.e., the Halflife)

2.1 Stage A - Antioxidant Depletion Time

The dual purposes of antioxidants are to (i) prevent polymer degradation during processing, and (ii) prevent oxidation reactions from taking place during Stage A of service life, respectively. Obviously, there can only be a given amount of antioxidants in any formulation. Once the antioxidants are depleted, additional oxygen diffusing into the geomembrane will begin to attack the polymer chains, leading to subsequent stages as shown in Figure 2. The duration of the antioxidant depletion stage depends on both the type and amount of the various antioxidants, i.e., the precise formulation.

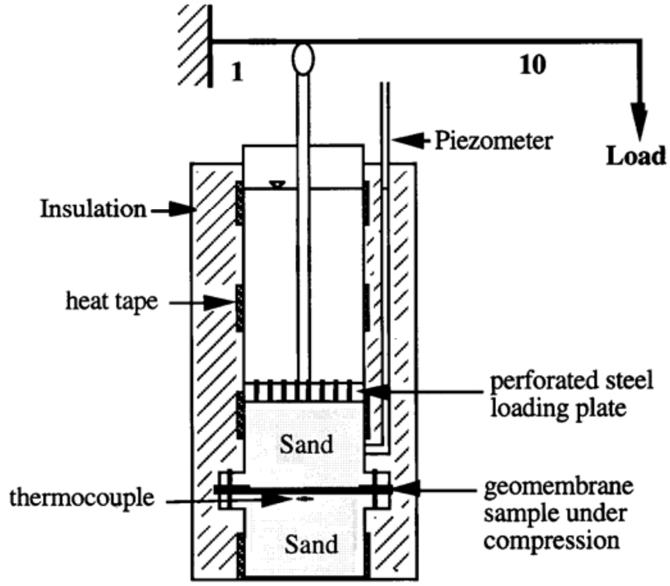


Figure 1. Incubation schematic and photograph of multiple cells maintained at various constant temperatures.

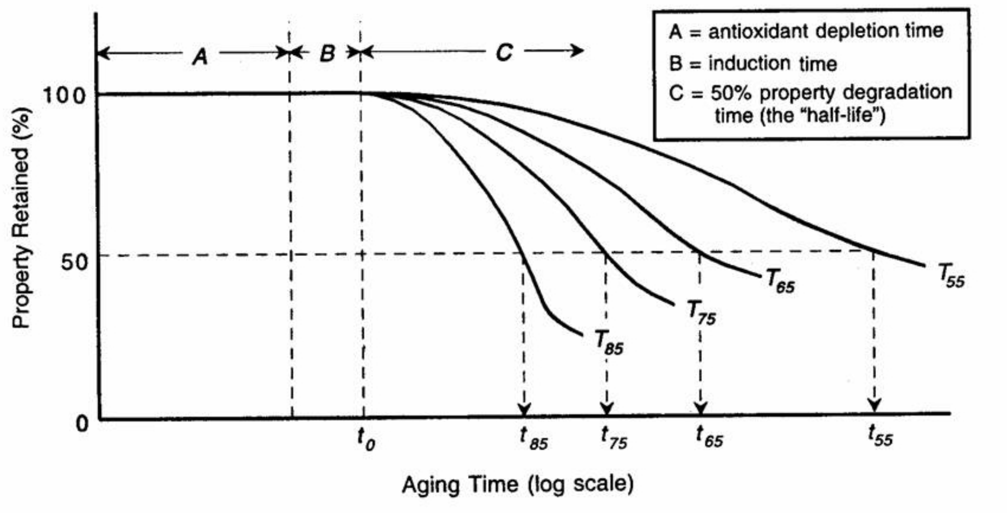


Figure 2. Three individual stages in the aging of most geomembranes.

The depletion of antioxidants is the consequence of two processes: (i) chemical reactions with the oxygen diffusing into the geomembrane, and (ii) physical loss of antioxidants from the geomembrane. The chemical process involves two main functions; the scavenging of free radicals converting them into stable molecules, and the reaction with unstable hydroperoxide (ROOH) forming a more stable substance. Regarding physical loss, the process involves the distribution of antioxidants in the geomembrane and their volatility and extractability to the site-specific environment.

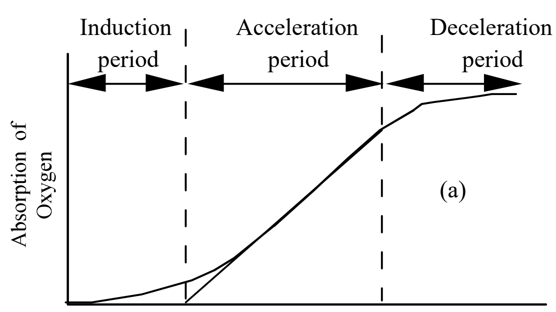
Hence, the rate of depletion of antioxidants is related to the type and amount of antioxidants, the service temperature, and the nature of the site-specific environment. See Hsuan and Koerner (1998) for additional details.

2.2 Stage B - Induction Time to Onset of Degradation

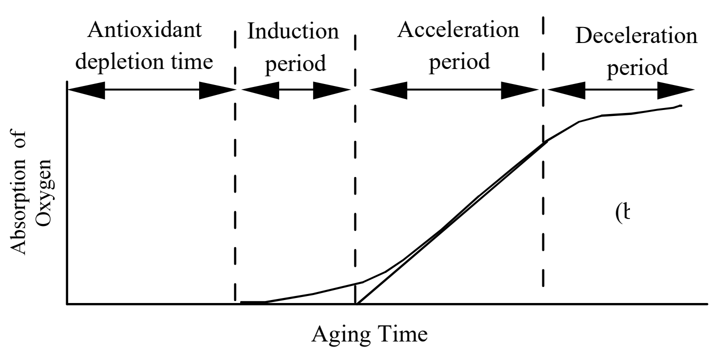
In a pure polyolefin resin, i.e., one without carbon black and antioxidants, oxidation occurs extremely slowly at the beginning, often at an immeasurable rate. Eventually, oxidation occurs more rapidly. The reaction eventually decelerates and once again becomes very slow.

This progression is illustrated by the S-shaped curve of Figure 3(a). The initial portion of the curve (before measurable degradation takes place) is called the induction period (or induction time) of the polymer. In the induction period, the polymer reacts with oxygen forming hydroperoxide (ROOH), as indicated in Equations (1)-(3). However, the amount of ROOH in this stage is very small and the hydroperoxide does not further decompose into other free radicals which inhibits the onset of the acceleration stage.

In a stabilized polymer such as one with antioxidants, the accelerated oxidation stage takes an even longer time to be reached. The antioxidants create an additional depletion time stage prior to the onset of the induction time, as shown in Figure 3(b).



(a) Pure unstabilized polyethylene



(b) Stabilized polyethylene

Figure 3. Curves illustrating various stages of oxidation.

$$RH \rightarrow R \bullet + H \bullet \quad (1)$$

(aided by energy or catalyst residues in the polymer)

$$R \bullet + O2 \rightarrow ROO \bullet \quad (2)$$

$$ROO \bullet + RH \rightarrow ROOH + R \bullet \quad (3)$$

In the above, RH represents the polyethylene polymer chains; and the symbol "•" represents free radicals, which are highly reactive molecules.

2.3 Stage C - Time to Reach 50% Degradation (Halflife)

As oxidation continues, additional ROOH molecules are being formed. Once the concentration of ROOH reaches a critical level, decomposition of ROOH begins, leading to a substantial increase in the amount of free radicals, as indicated in Equations (4) to (6). The additional free radicals rapidly attack other polymer chains, resulting in an accelerated chain reaction, signifying the end of the induction period, Rapopport and Zaikov (1986). This indicates that the concentration of ROOH has a critical control on the duration of the induction period.

$$ROOH \rightarrow RO \bullet OH \bullet \text{ (aided by energy)} \quad (4)$$

$$RO \bullet + RH \rightarrow ROH + R \bullet \quad (5)$$

$$OH \bullet + RH \rightarrow H2O + R \bullet \quad (6)$$

A series of oxidation reactions produces a substantial amount of free radical polymer chains (R•), called alkyl radicals, which can proceed to further reactions leading to either cross-linking or chain scission in the polymer. As the degradation of polymer continues, the physical and mechanical properties of the polymer start to change. The most noticeable change in physical properties is the melt index, since it relates to the molecular weight of the polymer. As for mechanical properties, both tensile break stress (strength) and break strain (elongation) decrease.

Ultimately, the degradation becomes so severe that all tensile properties start to change (tear, puncture, burst, etc.) and the engineering performance is jeopardized. This signifies the end of the so-called "service life" of the geomembrane.

Although quite arbitrary, the limit of service life of polymeric materials is often selected as a 50% reduction in a specific design property. This is commonly referred to as the halflife time, or simply the "halflife". It should be noted that even at halflife, the material still exists and can function, albeit at a decreased performance level with a factor-of-safety lower than the initial design value.

2.4 Summary of Lifetime Research-to-Date

Stage A, that of antioxidant depletion for HDPE geomembranes as required in the GRI-GM13 Specification, has been well established by our own research and corroborated by others, e.g., Sangram and Rowe (2004). The GRI data for standard and high pressure Oxidative Induction Time (OIT) is given in Table 2. The values are quite close to one another. Also, as expected, the lifetime is strongly dependent on the service temperature; with the higher the temperature the shorter the lifetime.

Table 2 - Lifetime prediction of HDPE (nonexposed) at various field temperatures

In Service Temperature (°C)	Stage "A" (years)			Stage "B" (years)	Stage "C" (years)	Total Prediction* (years)
	Standard OIT	High Press. OIT	Average OIT			
20	200	215	208	30	208	446
25	135	144	140	25	100	265
30	95	98	97	20	49	166
35	65	67	66	15	25	106
40	45	47	46	10	13	69

*Total = Stage A (average) + Stage B + Stage C

Stage "B", that of induction time, has been obtained by comparing 30-year old polyethylene water and milk containers (containing no long-term antioxidants) with currently produced containers. The data shows that degradation is just beginning to occur as evidenced by slight changes in break strength and elongation, but not in yield strength and elongation. The lifetime for this stage is also given in Table 2.

Stage "C", the time for 50% change of mechanical properties is given in Table 2 as well. The data depends on the activation energy, or slope of the Arrhenius curve, which is very sensitive to material and experimental techniques. The data is from Gedde, et al. (1994) which is typical of the HDPE resin used for gas pipelines and is similar to Martin and Gardner (1983).

Summarizing Stages A, B, and C, it is seen in Table 2 that the halflife of covered HDPE geomembranes (formulated according to the current GRI-GM13 Specification) is estimated to be 449-years at 20°C. This, of course, brings into question the actual temperature for a covered geomembrane such as beneath a solid waste landfill. Figure 4 presents multiple thermocouple monitoring data of a municipal waste landfill liner in Pennsylvania for over 10-years, Koerner and Koerner (2005). Note that for 6-years the temperature was approximately 20°C. At that time and for the subsequent 4-years the temperature increased to approximately 30°C. Thus, the halflife of this geomembrane is predicted to be from 166 to 446 years within this temperature range. The site is still being monitored, see Koerner and Koerner (2005).

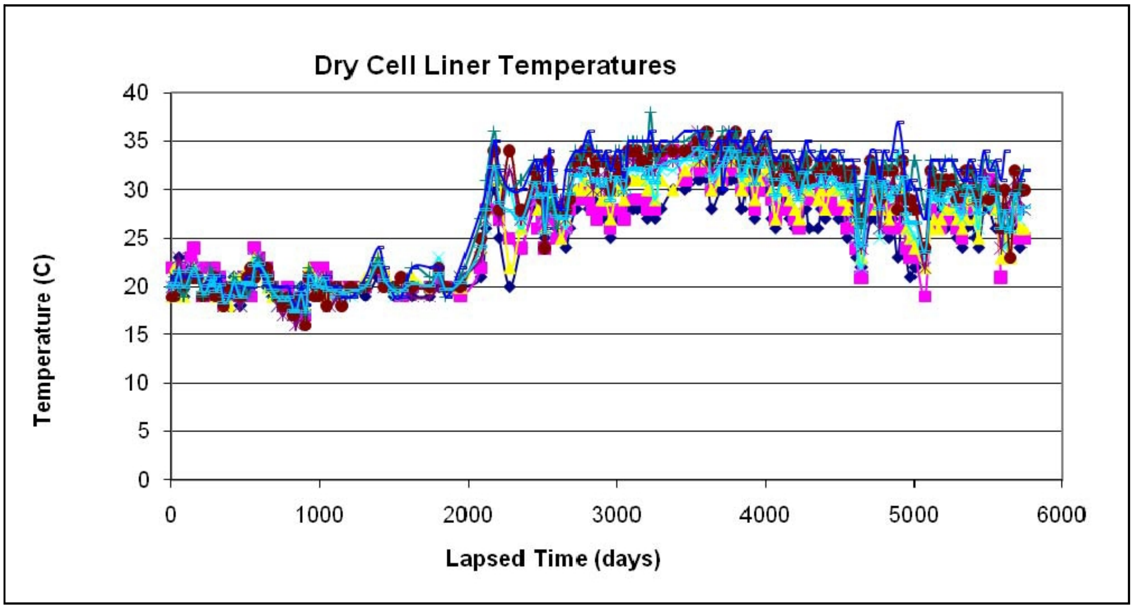


Figure 4. Long-term monitoring of an HDPE liner beneath a municipal solid waste landfill in Pennsylvania.

2.5 Lifetime of Other Covered Geomembranes

By virtue of its widespread use as liners for solid waste landfills, HDPE is by far the widest studied type of geomembrane. Note that in most countries (other than the U.S.), HDPE is the required geomembrane type for solid waste containment. Some commentary on other-than HDPE geomembranes (recall Table 1) follows:

2.5.1 Linear Low Density Polyethylene (LLDPE) geomembranes

The nature of the LLDPE resin and its formulation is very similar to HDPE. The fundamental difference is that LLDPE is a lower density, hence lower crystallinity, than HDPE; e.g., 10% versus 50%. This has the effect of allowing oxygen to diffuse into the polymer structure quicker, and likely decreases Stages A and C. How much is uncertain since no data is available, but it is felt that the lifetime of LLDPE will be somewhat reduced with respect to HDPE.

2.5.2 Plasticizer migration in PVC geomembranes

Since PVC geomembranes necessarily have plasticizers in their formulations so as to provide flexibility, the migration behavior must be addressed for this material. In PVC the plasticizer bonds to the resin and the strength of this bonding versus liquid-to-resin bonding is significant. One of the key parameters of a stable long-lasting plasticizer is its molecular weight. The higher the molecular weight of the plasticizer in a PVC formulation, the more durable will be the material. Conversely, low molecular weight plasticizers have resulted in field failures even under covered conditions. See Miller, et al. (1991), Hammon, et al. (1993), and Giroud and Tisinger (1994) for more detail in this regard. At present there is a considerable difference (and cost) between PVC geomembranes made in North America versus Europe. This will be apparent in the exposed study of durability in the second part of this White Paper.

2.5.3 Crosslinking in EPDM and CSPE geomembrnaes

The EPDM geomembranes mentioned in Table 1 are crosslinked thermoset materials. The oxidation degradation of EPDM takes place in either ethylene or propylene fraction of the co-polymer via free radical reactions, as expressed in Figure 5, which are described similarly by Equations (4) to (6).

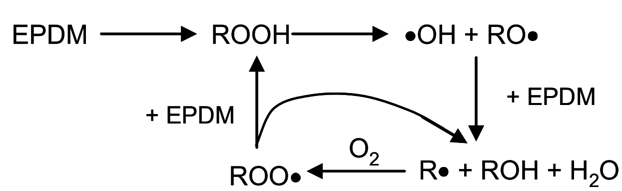


Figure 5. Oxidative degradation of crosslinked EPDM geomembranes, (Wang and Qu, 2003).

For CSPE geomembranes, the degradation mechanism is dehydrochlorination by losing chlorine and generating carbon-carbon double bonds in the main polymer chain, as shown in Figure 6.

The carbon-carbon double bonds become the preferred sites for further thermodegradation or cross-linking in the polymer, leading to eventual brittleness of the geomembrane.

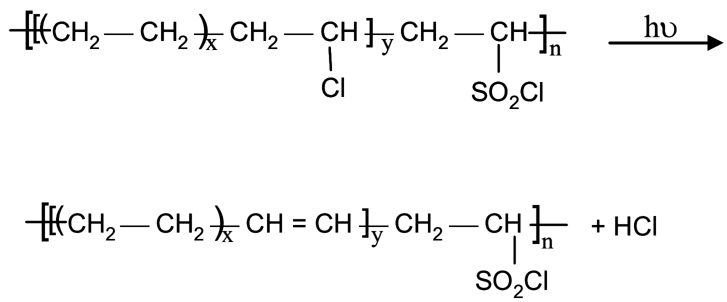


Figure 6. Dechlorination degradation of crosslinked CSPE geomembranes (Chailan, et al., 1995).

Neither EPDM nor CSPE has had a focused laboratory study of the type described for HDPE reported in the open literature. Most of lifetime data for these geomembranes is antidotal by virtue of actual field performance. Under covered conditions, as being considered in this section, there have been no reported failures by either of these thermoset polymers to our knowledge.

3.0 Lifetime Prediction: Exposed Conditions

Lifetime prediction of exposed geomembranes have taken two very different pathways; (i) prediction from anecdotal feedback and field performance, and (ii) from laboratory weathering device predictions.

3.1 Field Performance

There is a large body of anecdotal information available on field feedback of exposed geomembranes. It comes form two quite different sources, i.e., dams in Europe and flat roofs in the USA.

Regarding exposed geomembranes in dams in Europe, the original trials were using 2.0 mm thick polyisobutylene bonded directly to the face of the dam. There were numerous problems encountered as described by Scuero (1990). Similar experiences followed using PVC geomembranes. In 1980, a geocomposite was first used at Lago Nero which had a 200 g/m^2 nonwoven geotextile bonded to the PVC geomembrane. This proved quite successful and led to the now-accepted strategy of requiring drainage behind the geomembrane. In addition to thick nonwoven geotextiles, geonets, and geonet composites have been successful. Currently over 50 concrete and masonry dams have been rehabilitated in this manner and are proving successful for over 30-years of service life. The particular type of PVC plasticized geomembranes used for these dams is proving to be quite durable. Tests by the dam owners on residual properties show only nominal changes in properties, Cazzuffi (1998). As indicated in Miller, et al. (1991) and Hammond, et al. (1993), however, different PVC materials and formulations result in very different behavior; the choice of plasticizer and the material's thickness both being of paramount importance. An excellent overview of field performance is recently available in which 250 dams which have been waterproofed by geomembranes is available from ICOLD (2010).

Regarding exposed geomembranes in flat roofs, past practice in the USA is almost all with EPDM and CSPE and, more recently, with fPP. Manufacturers of these geomembranes regularly warranty their products for 20-years and such warrants appear to be justified. EPDM and CSPE, being thermoset or elastomeric polymers, can be used in dams without the necessity of having seams by using vertical attachments spaced at 2 to 4 m centers, see Scuero and Vaschetti (1996). Conversely, fPP can be seamed by a number of thermal fusion methods. All of these geomembrane types have good conformability to rough substrates as is typical of concrete and masonry dam rehabilitation. It appears as though experiences (both positive and negative) with geomembranes in flat roofs should be transferred to all types of waterproofing in civil engineering applications.

3.2 Laboratory Weatherometer Predictions

For an accelerated simulation of direct ultraviolet light, high temperature, and moisture using a laboratory weatherometer one usually considers a worst-case situation which is the solar maximum condition. This condition consists of global, noon sunlight, on the summer solstice, at normal incidence. It should be recognized that the UV-A range is the target spectrum for a laboratory device to simulate the naturally occurring phenomenon, see Hsuan and Koerner (1993), and Suits and Hsuan (2001).

The Xenon Arc weathering device (ASTM D4355) was introduced in Germany in 1954. There are two important features; the type of filters and the irradiance settings. Using a quartz inner and borosilicate outer filter (quartz/boro) results in excessive low frequency wavelength degradation. The more common borosilicate inner and outer filters (boro/boro) shows a good correlation with solar maximum conditions, although there is an excess of energy below 300 nm wavelength. Irradiance settings are important adjustments in shifting the response although they do not eliminate the portion of the spectrum below 300 nm frequency. Nevertheless, the Xenon Arc device is commonly used method for exposed lifetime prediction of all types of geosynthetics.

UV Fluorescent devices (ASTM D7238) are an alternative type of accelerated laboratory test device which became available in the early 1970's. They reproduce the ultraviolet portion of the sunlight spectrum but not the full spectrum as in Xenon Arc weatherometers. Earlier FS-40 and UVB-313 lamps give reasonable short wavelength output in comparison to solar maximum. The UVA-340 lamp was introduced in 1987 and its response is seen to reproduce ultraviolet light quite well. This device (as well as other types of weatherometers) can handle elevated temperature and programmed moisture on the test specimens.

Research at the Geosynthetic Institute (GSI) has actively pursued both Xenon and UV Fluorescent devices on a wide range of geomembranes. Table 3 gives the geomembranes that were incubated and the number of hours of exposure as of 12 July 2005.

Table 5 - Details of the GSI laboratory exposed weatherometer study on various types of geomembranes

Geomembrane Type	Thickness (mm)	UV Fluorescent Exposure*	Xenon Exposure*	Comment
1. HDPE (GM13)	1.50	8000 hrs.	6600 hrs.	Basis of GRI-GM13 Spec
2. LLDPE (GM17)	1.00	8000	6600	Basis of GRI-GM-17 Spec
3. PVC (No. Amer.)	0.75	8000	6600	Low Mol. Wt. Plasticizer
4. PVC (Europe)	2.50	7500	6600	High Mol. Wt. Plasticizer
5. fPP (BuRec)	1.00	2745**	4416**	Field Failure at 26 mos.
6. fPP-R (Texas)	0.91	100	100	Field Failure at 8 years
7. fPP (No. Amer.)	1.00	7500	6600	Expected Good Performance

*As of 12 July 2005 exposure is ongoing
**Light time to reach halflife of break and elongation

3.3 Laboratory Weatherometer Acceleration Factors

The key to validation of any laboratory study is to correlate results to actual field performance. For the nonexposed geomembranes of Section 2 such correlations will take hundreds of years for properly formulated products. For the exposed geomembranes of Section 3, however, the lifetimes are significantly shorter and such correlations are possible. In particular, Geomembrane #5 (flexible polypropylene) of Table 3 was an admittedly poor geomembrane formulation which failed in 26 months of exposure at El Paso, Texas, USA. The reporting of this failure is available in the literature, Comer, et al. (1998). Note that for both UV Fluorescent and Xenon Arc laboratory incubation of this material, failure (halflife to 50% reduction in strength and elongation) occurred at 2745 and 4416 hours, respectively. The comparative analysis of laboratory and field for this case history allows for the obtaining of acceleration factors for the two incubation devices.

3.3.1 Comparison between field and UV Fluorescent weathering

The light source used in the UV fluorescent weathering device is UVA with wavelengths from 295-400 nm. In addition, the intensity of the radiation is controlled by the Solar Eye irradiance control system. The UV energy output throughout the test is 68.25 W/m^2.

The time of exposure to reach 50% elongation at break was as follows:

= 2745 hr. of light
= 9,882,000 seconds

Total energy in MJ/m^2 = 68.25 W/m^2 × 9,882,000
= 674.4 MJ/m^2

The field site was located at El Paso, Texas. The UVA radiation energy (295-400 nm) at this site is estimated based on data collected by the South Florida Testing Lab in Arizona (which is a similar atmospheric location). For 26 months of exposure, the accumulated UV radiation energy is 724 MJ/m^2 which is very close to that generated from the UV fluorescent weatherometer. Therefore, direct comparison of the exposure time between field and UV fluorescent is acceptable.

Field time vs. Fluorescent UV light time: **Thus, the acceleration factor is 6.8.**
= 26 Months = 3.8 Months

3.3.2 Comparison between field and Xenon Arc weathering

The light source of the Xenon Arc weathering device simulates almost the entire sunlight spectrum from 250 to 800 nm. Depending of the age of the light source and filter, the solar energy ranges from 340.2 to 695.4 W/m^2, with the average value being 517.8 W/m^2.

The time of exposure to reach 50% elongation at break

= 4416 hr. of light
= 15,897,600 seconds

Total energy in MJ/m^2 = 517.8 W/m^2 × 15,897,600
= 8232 MJ/m^2

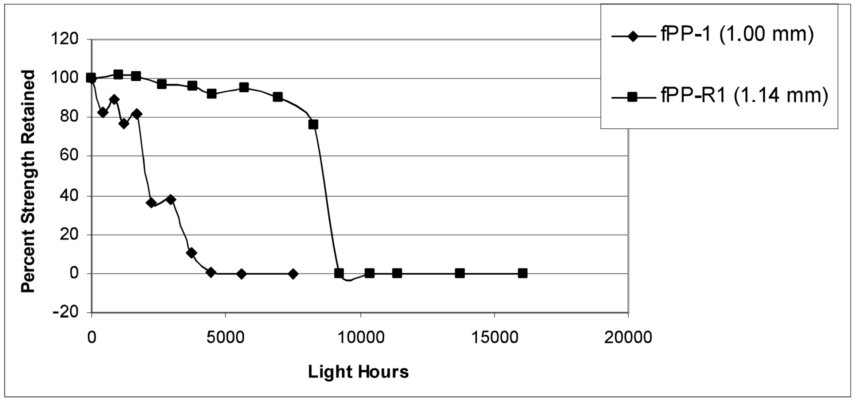
The solar energy in the field is again estimated based on data collected by the South Florida Testing Lab in Arizona. For 26 months of exposure, the accumulated solar energy (295-800 nm) is 15,800 MJ/m^2, which is much higher than that from the UV Fluorescent device. Therefore, direct comparison of halflives obtained from the field and Xenon Arc device is not anticipated to be very accurate. However, for illustration purposes the acceleration factor based on Xenon Arc device would be as follows:

Field = 26 Months	vs.	Xenon Arc = 6.1 Months	:	**Thus, the acceleration factor is 4.3.**

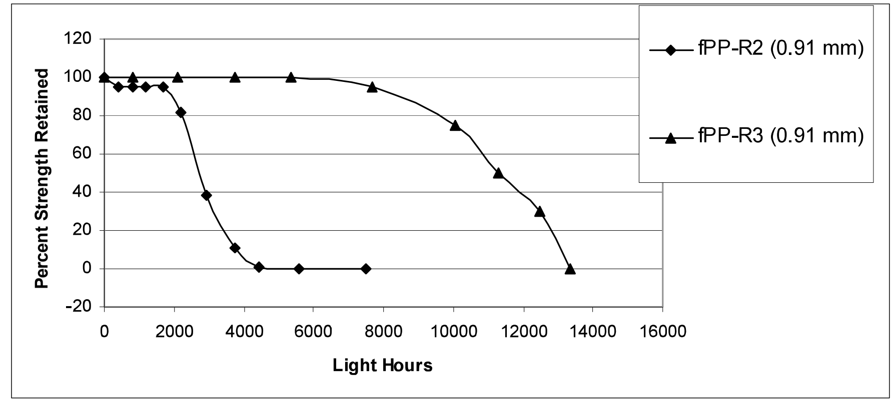
The resulting conclusion of this comparison of weathering devices is that the UV Fluorescent device is certainly reasonable to use for long-term incubations. When considering the low cost of the device, its low maintenance, its inexpensive bulbs, and ease of repair it (the UV Fluorescent device) will be used exclusively by GSI for long-term incubation studies.

3.3.3 Update of exposed lifetime predictions

There are presently (2011) four field failures of flexible polypropylene geomembranes and using unexposed archived samples from these sites their responses in laboratory UV Fluorescent devices per ASTM D7328 at 70°C are shown in Figure 5. From this information we deduce that the average correlation factor is approximately *1200 light hours ≃ one-year in a hot climate.* This value will be used accordingly for other geomembranes.



(a) Two Sites in West Texas



(b) Two Sites in So. Calif.

Lab-to-Field Correlation Factors
(ASTM D7238 @ 70°C)

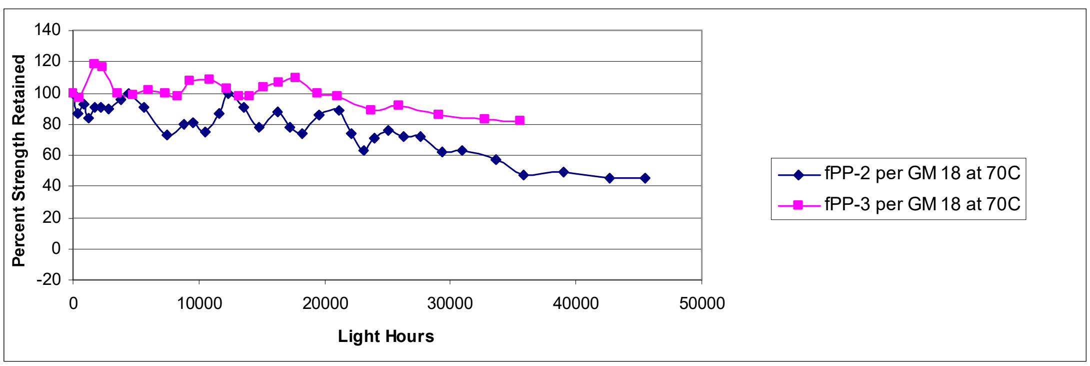
Method	Thickness (mm)	Field (yrs.)	Location	Lab (lt. hr.)	Factor (lt. hrs./1.0 yr.)
fPP-1	1.00	$\simeq$ 2	W. Texas	1800	900
fPP-R1	1.14	$\simeq$ 8	W. Texas	8200	1025
fPP-R2	0.91	$\simeq$ 2	So. Calif.	2500	1250
fPP-R3	0.91	$\simeq$ 8	So. Calif.	11200	1400
					1140*

*Use 1200 lt. hr. = 1.0 year in hot climates

Figure 5. Four field failures of fPP and fPP-R exposed geomembranes.

Exposure of a number of different types of geomembranes in laboratory UV Fluorescent devices per ASTM D7238 at 70°C has been ongoing for the six years (between 2005 and 2011) since this White Paper was first released. Included are the following geomembranes:

- Two black 1.0 mm (4.0 mil) unreinforced flexible polypropylene geomembranes formulated per GRI-GM18 Specification; see Figure 6a.
- Two black unreinforced polyethylene geomembranes, one 1.5 mm (60 mil) high density per GRI-GM13 Specification and the other 1.0 mm (40 mil) linear low density per GRI-GM17 Specification; see Figure 6b.
- One 1.0 (40 mil) black ethylene polypropylene diene terpolymer geomembrane per GRI-GM21 Specification; see Figure 6c.
- Two polyvinyl chloride geomembranes, one black 1.0 mm (40 mil) formulated in North America and the other grey 1.5 mm (60 mil) formulated in Europe; see Figure 6d.



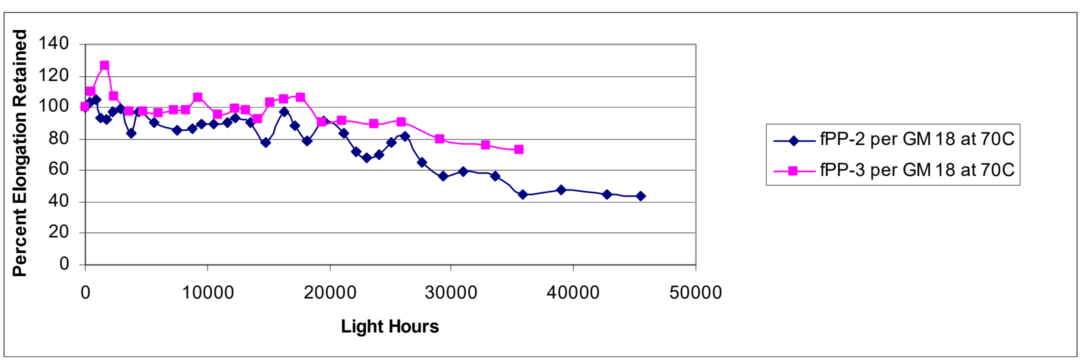
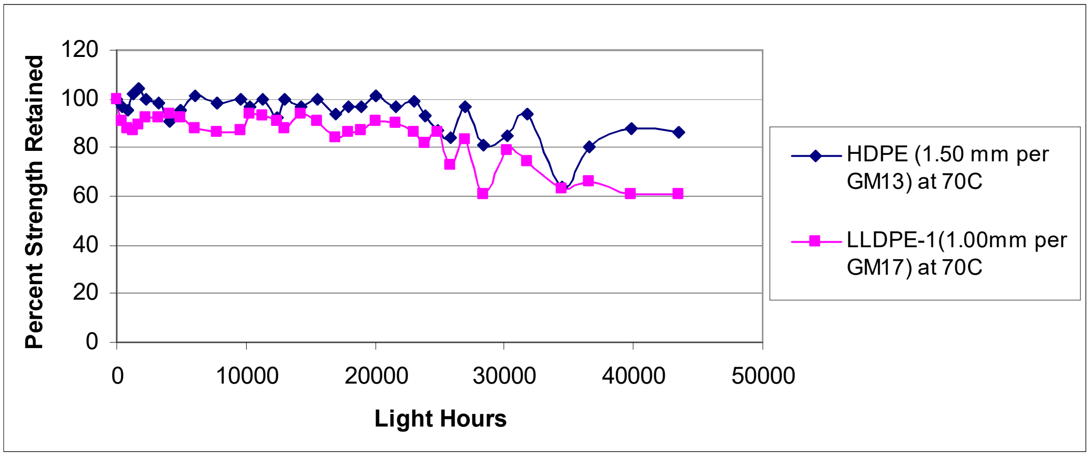


Figure 6a. Flexible polyethylene (fPP) geomembrane behavior.



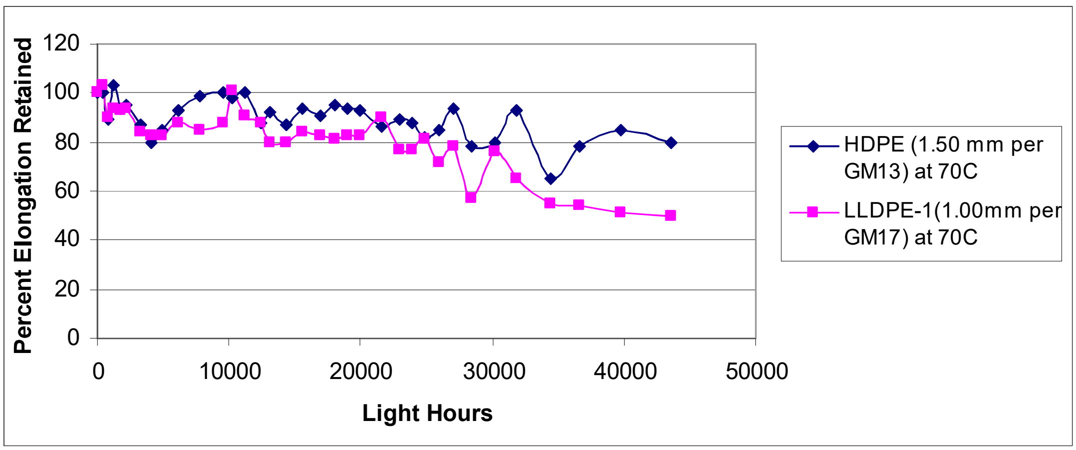
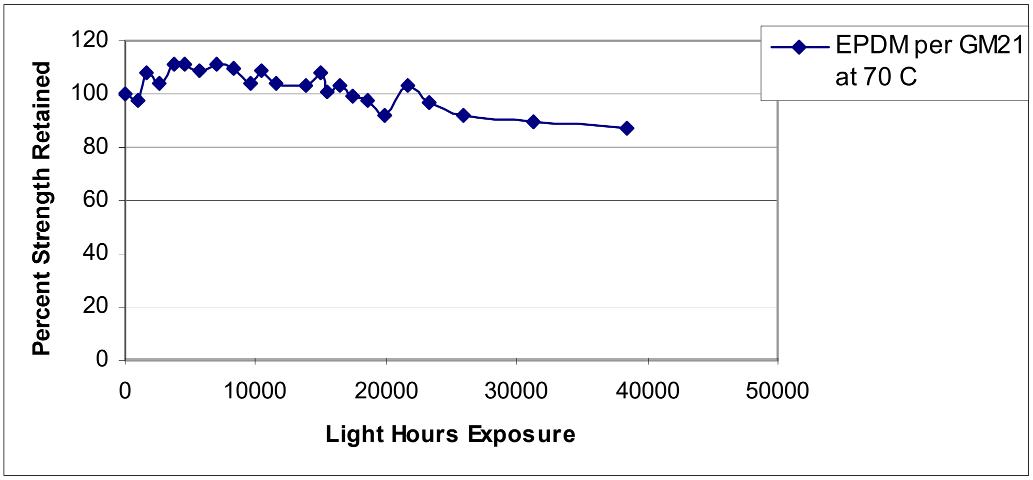


Figure 6b. Polyethylene (HDPE and LLDPE) geomembrane behavior.



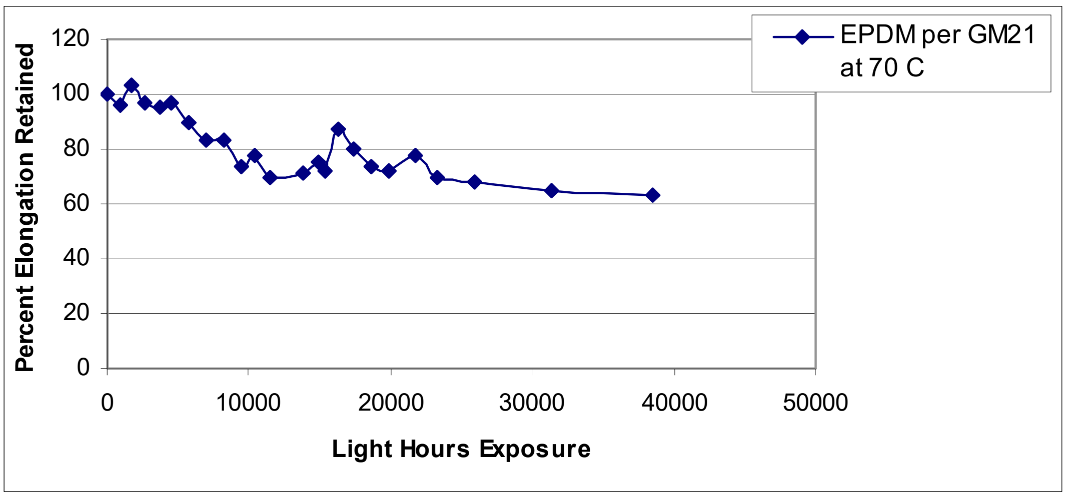


Figure 6c. Ethylene polypropylene diene terpolymer (EPDM) geomembrane.

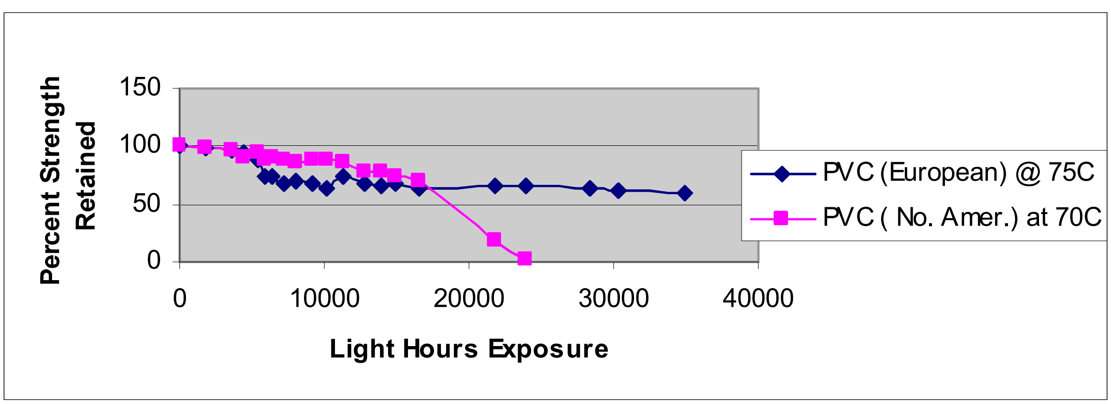


Figure 6d. Polyvinyl chloride (PVC) geomembranes.

From the response curves of the various geomembranes shown in Figure 6a-d, the 50% reduction value in strength or elongation (usually elongation) was taken as being the "halflife". This value is customarily used by the polymer industry as being the materials lifetime prediction value. We have done likewise to develop Table 6 which is our predicted values for the designated exposed geomembrane lifetimes to date.

Table 6 – Exposed lifetime prediction results of selected geomembranes to date

Type	Specification	Prediction Lifetime in a Dry and Arid Climate
HDPE	GRI-GM13	> 36 years (ongoing)
LLDPE	GRI-GM17	$\simeq$ 36 years (halflife)
EPDM	GRI-GM21	> 27 years (ongoing)
fPP-2	GRI-GM18	$\simeq$ 30 years (halflife)
fPP-3	GRI-GM18	> 27 years (ongoing)
PVC-N.A.	(see FGI)	$\simeq$ 18 years (halflife)
PVC-Eur.	proprietary	> 32 years (ongoing)

4.0 Conclusions and Recommendations

This White Paper is bifurcated into two very different parts; covered (or buried) lifetime prediction of HDPE geomembranes and exposed (to the atmosphere) lifetime prediction of a number of geomembrane types. In the covered geomembrane study we chose the geomembrane type which has had the majority of usage, that being HDPE as typically used in waste containment applications. Invariably whether used in landfill liner or cover applications *the geomembrane is covered.* After ten-years of research Table 2 (repeated here) was developed which is the conclusion of the covered geomembrane research program. Here it is seen that HDPE decreases its predicted lifetime (as measured by its halflife) from 446-years at 20°C, to 69-years at 40°C. Other geomembrane types (LLDPE, fPP, EPDM and PVC) have had essentially no focused effort on their covered lifetime prediction of the type described herein. That said, all are candidates for additional research in this regard.

Table 2 - Lifetime prediction of HDPE (nonexposed) at various field temperatures

In Service Temperature (°C)	Stage "A" (years)			Stage "B" (years)	Stage "C" (years)	Total Prediction* (years)
	Standard OIT	High Press. OIT	Average OIT			
20	200	215	208	30	208	446
25	135	144	140	25	100	265
30	95	98	97	20	49	166
35	65	67	66	15	25	106
40	45	47	46	10	13	69

*Total = Stage A (average) + Stage B + Stage C

Exposed geomembrane lifetime was addressed from the perspective of field performance which is very unequivocal. Experience in Europe, mainly with relatively thick PVC containing high molecular weight plasticizers, has given 25-years of service and the geomembranes are still in use. Experience in the USA with exposed geomembranes on flat roofs, mainly with EPDM and CSPE, has given 20^{+}-years of service. The newest geomembrane type in such applications is fPP which currently carries similar warranties.

Rather than using the intricate laboratory setups of Figure 1 which are necessary for covered geomembranes, exposed geomembrane lifetime can be addressed by using accelerating laboratory weathering devices. Here it was shown that the UV fluorescent device (per ASTM D7238 settings) versus the Xenon Arc device (per ASTM D 4355) is equally if not slightly more intense in its degradation capabilities. As a result, all further incubation has been using the UV fluorescent devices per D7238 at 70°C.

Archived flexible polypropylene geomembranes at four field failure sites resulted in a correlation factor of 1200 light hours equaling one-year performance in a hot climate. Using this value on the incubation behavior of seven commonly used geomembranes has resulted in the following conclusions (recall Figure 6 and Table 6);

- HDPE geomembranes (per GRI-GM13) are predicted to have lifetimes greater than 36-years; testing is ongoing.
- LLDPE geomembranes (per GRI-GM17) are predicted to have lifetimes of approximately 36-years.
- EPDM geomembranes (per GRI-GM21) are predicted to have lifetimes of greater than 27-years; testing is ongoing.
- fPP geomembranes (per GRI-GM18) are predicted to have lifetimes of approximately 30-years.
- PVC geomembranes are very dependent on their plascitizer types and amounts, and probably thicknesses as well. The North American formulation has a lifetime of approximately 18-years, while the European formulation is still ongoing after 32-years.

Regarding continued and future recommendations with respect to lifetime prediction, GSI is currently providing the following:

(i) Continuing the exposed lifetime incubations of HDPE, EPDM and PVC (European) geomembranes at 70°C.

(ii) Beginning the exposed lifetime incubations of HDPE, LLDPE, fPP, EPDM and both PVC's at 60°C and 80°C incubations.

(iii) With data from these three incubation temperatures (60, 70 and 80°C), time-temperature-superposition plots followed by Arrhenius modeling will eventually provide information such as Table 2 for covered geomembranes. This is our ultimate goal.

(iv) Parallel lifetime studies are ongoing at GSI for four types of geogrids and three types of turf reinforcement mats at 60, 70 and 80°C.

(v) GSI does not plan to duplicate the covered geomembrane study to other than the HDPE provided herein. In this regard, the time and expense that would be necessary is prohibitive.

(vi) The above said, GSI is always interested in field lifetime behavior of geomembranes (and other geosynthetics as well) whether covered or exposed.

Acknowledgements

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References

Cazzuffi, D., "Long-Term Performance of Exposed Geomembranes on Dams in the Italian Alps," Proc. 6th Intl. Conf. on Geosynthetics, IFAI, 1998, pp. 1107-1114.

Chailan, J.-F., Boiteux, C., Chauchard, J., Pinel, B. and Seytre, G., "Effect of Thermal Degradation on the Viscoelastic and Dielectric Properties of Chlorosulfonated Polyethylene (CSPE) Compounds," Journal of Polymer Degradation and Stability, Vol. 48, 1995, pp. 61-65.

Comer, A. I., Hsuan, Y. G. and Konrath, L., "The Performance of Flexible Polypropylene Geomembranes in Covered and Exposed Environments," 6th International Conference on Geosynthetics, Atlanta, Georgia, USA, March, 1998, pp. 359-364.

Gedde, U. W., Viebke, J., Leijstrom, H. and Ifwarson, M., "Long-Term Properties of Hot-Water Polyolefin Pipes - A Review," Polymer Engineering and Science, Vol. 34, No. 24, 1994, pp. 1773-1787.

Giroud, J.-P. and Tisinger, L. G., "The Influence of Plasticizers on the Performance of PVC Geomembranes," PVC GRI-17 Conference, IFAI, Roseville, MN, 1994, pp. 169-196.

Hammon, M., Hsuan, G., Levin, S. B. and Mackey, R. E., "The Re-examination of a Nine-Year-Old PVC Geomembrane Used in a Top Cap Application," 31st Annual SWANA Conference, San Jose, CA, 1993, pp. 93-108.

Hsuan, Y. G. and Guan, Z., "Evaluation of the Oxidation Behavior of Polyethylene Geomembranes Using Oxidative Induction Time Tests," ASTM STP 1326, Riga and Patterson, Eds., ASTM, 1997, pp. 138-149.

Hsuan, Y. G. and Koerner, R. M., "Can Outdoor Degradation be Predicted by Laboratory Acceleration Weathering?," GFR, November, 1993, pp. 12-16.

Hsuan, Y. G. and Koerner, R. M., "Antioxidant Depletion Lifetime in High Density Polyethylene Geomembranes," Jour. Geotech. and Geoenviron. Engr., ASCE, Vol. 124, No. 6, 1998, pp. 532-541.

ICOLD (2010), "Geomembrane Sealing Systems for Dams: Design Principles and Return of Experience," Intl. Committee on Large Dams, Bulletin 135, Paris, France.

Koerner, G. R. and Koerner. R. M., "In-Situ Temperature Monitoring of Geomembranes," Proc. GRI-18 Conf. at GeoFrontiers, Austin, TX, 2005, 6 pgs.

Martin, J. R. and Gardner, R. J. (1983), "Use of Plastics in Corrosion Resistant Instrumentation," 1983 Plastics Seminar, NACE, October 24-27.

Miller, L. V., Koerner, R. M., Dewyea, J. and Mackey, R. E., "Evaluation of a 30 mil PVC Liner and Leachate Collection System," Proc. 29th Annual GRCDA/SWANA Conf., Cincinnati, OH, 1991.

Müeller, W. and Jakob, I., "Oxidative Resistance of High-Density Polyethylene Geomembranes," Jour. Polymer Degradation and Stability," Elsevier Publ. Co., No. 79, 2003, pp. 161-172.

Rapoport, N. Y. and Zaikov, G. E., "Kinetics and Mechanisms of the Oxidation of Stressed Polymer," Developments in Polymer Stabilization—4, G. Scott, Ed., Applied Science Publishers Ltd., London, U.K., 1986, pp. 207-258.

Sangam, H. P. and Rowe, R. K., "Effects of Exposure Conditions on the Depletion of Antioxidants from HDPE Geomembranes", Canadian Geotechnical Journal, Vol. 39, 2002, pp. 1221-1230.

Scuero, A., "The Use of Geocomposites for the Rehabilitation of Concrete Dams," Proc. 4th Intl. Conf. on Geosynthetics, The Hague, Balkema Publ. Co., 1990, pg. 474.

Scuero, A. M. and Vaschetti, G. L., "Geomembranes for Masonry and Concrete Dams: State-of-the-Art Report," Proc. Geosynthetics Applications, Design and Construction, M. B. deGroot, et al., Eds., A. A. Balkema, 1996, pp. 889-898.

Suits, L. D. and Hsuan, Y. G., "Assessing the Photo Degradation of Geosynthetics by Outdoor Exposure and Laboratory Weatherometers," Proc. GRI-15 Conference, Hot Topics in Geosynthetics II, GII Publ., Folsom, PA, 2001, pp. 267-279.

Wang, W. and Qu, B., "Photo and Thermo-Oxidative Degradation of Photocrosslinked Ethylene-Propylene-Diene Terpolymer," Journal of Polymer Degradation and Stability, Vol. 81, 2003, pp. 531-537.

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GSI White Paper #28

"Cold Temperature and Free-Thaw Cycling Behavior of Geomembranes and Their Seams"

by

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"Cold Temperature and Free-Thaw Cycling Behavior of Geomembranes and Their Seams"

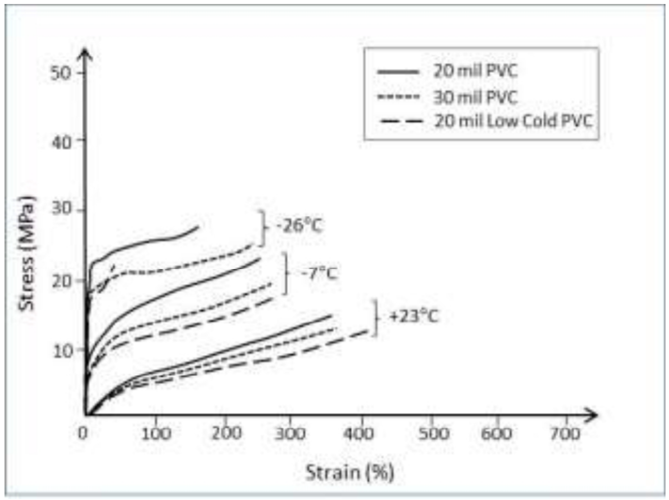
Introduction

It is common knowledge that materials in general, and polymeric materials in particular, will somewhat soften and increase in flexibility under high temperatures and will conversely somewhat harden and decrease in flexibility under cold temperatures. While there are indeed circumstances where high ambient temperatures are important, this white paper focuses entirely on cold ambient temperatures. Even further, it addresses cold temperature behavior of the various geomembranes by themselves and, most importantly, the freeze-thaw cycling behavior of a large number of geomembrane sheets and their seams.

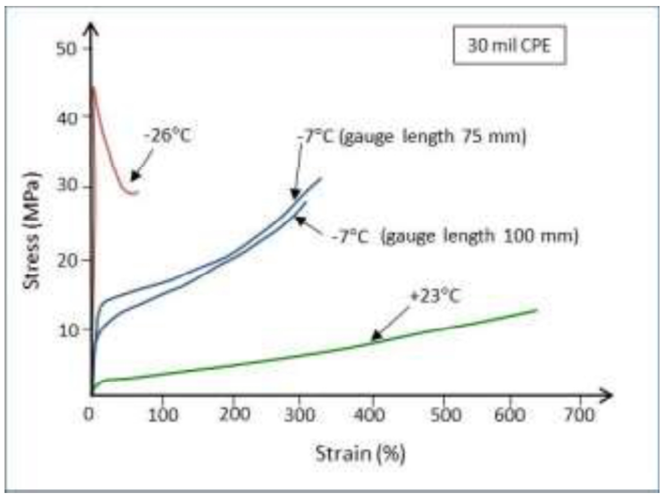
The stimulus for writing the white paper is the myriad questions that regularly come to GSI as to the potential negative effects on the tensile strength of geomembranes and their seams under cold temperature and cyclic freeze-thaw field conditions. As will be seen, the primary source for the information to be presented herein is a joint U.S. EPA/U.S. BuRec study conducted by Alice Comer and Grace Hsuan in 1996. Other companion technical information will also be presented.

Cold Temperature Behavior of Geomembranes

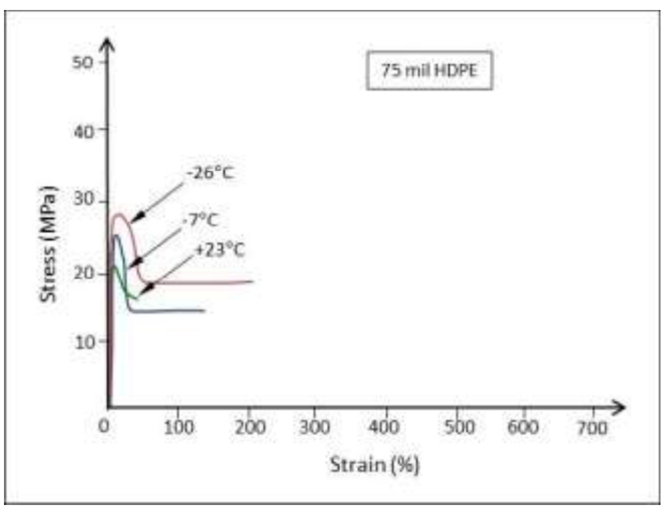
A report by Thornton and Blackall (1976) appears to be the first in describing Canadian experiences with geomembranes in cold regions. Subsequently, Rollin, et al. (1984) conducted a laboratory study on 21 types of geomembranes at temperatures down to - 35°C. They found increasing tensile strength with decreasing temperature. Richards, et al. (1985) did similar studies which also resulted in an increase in strength and a decrease in elongation with decreasing temperatures. They evaluated PVC, CPE and HDPE geomembranes and presented the stress-versus-strain curves at +23°C, -7°C and -26°C temperatures; see Figures 1a, 1b, and



(a) Tensile test results for PVC geomembranes



(b) Tensile test results for CPE geomembranes



(c) Tensile test results for HDPE geomembranes

Figure 1 – Stress-versus-strain behavior of three geomembrane types under progressively colder testing environments, Richards, et al. (1985)

1c. Here one can readily observe how the sets of curves transition from relatively ductile behavior at +23°C, to relatively brittle behavior at -26°C, with the intermediate behavior at -7°C. There are a few outliers, but the trends are undeniable. This general behavior was confirmed by Peggs, et al. (1990) and Giroud, et al. (1993), the latter working with both smooth and textured HDPE geomembranes.

While this type of thermal behavior is of interest, such information for a specific type of geomembrane must be obtained by performing or commissioning individual tests so as to obtain actual design information. Such individual testing is required due to the uniqueness of each polymer type and its specific formulation. Additives such as plasticizers, fillers, antioxidants, carbon black, colorants, etc., can influence the results to varying degrees. Even the resins themselves have behavioral differences at different temperatures. For example, the glass transition temperature of propylene is -7°C, below which the polymer is glassy and above which it is characterized as rubbery. In such a case the tensile properties are greatly influenced, as well as the material's creep and stress relaxation behavior.

There are other aspects of cold temperatures on geomembranes that go beyond the scope of this white paper. In particular are cases of impact shuttering failures in cold climates and installation concerns such as frozen subgrade, bridging, snow and ice removal and worker discomfort, Burns, et al. (1990).

Freeze-Thaw Cycling of Geomembrane Sheets and Seams

Budiman (1994) reported on both cold temperature behavior but also appears to be the first to include freeze-thaw cycling for up to 150 repetitions. He focused entirely on HDPE sheet (of different thicknesses) but not on seams. There was no degradation observed during his tests but he suggested that more cycles would be appropriate. At approximately the same time a much larger freeze-thaw study was ongoing. The final report by Comer and Hsuan was released by the U.S. Bureau of Reclamation in 1996. Related papers leading up to this final report are Hsuan, et al. (1993), Comer, et al. (1995), and Hsuan, et al. (1997). Their combined study involved 19 different geomembrane sheet materials and 31 different seam types. Furthermore, seven different resin types were evaluated. The resin types were the following:

- polyvinyl chloride (PVC)
- linear low density polyethylene (LLDPE)
- high density polyethylene (HDPE)
- flexible polypropylene (fPP)
- chlorosulfonated polyethylene (CSPE)
- fully crosslinked elastomeric alloy (FCEA)

All except FCEA are currently available, however, changes in additives and formulations have occurred and will likely to do so in the future. The entire study was conducted in four discrete parts although the fourth part was focused on induced tensile stress and stress relaxation and is not the specific purpose of this white paper. See Table 1 for the relevant three parts of their study.

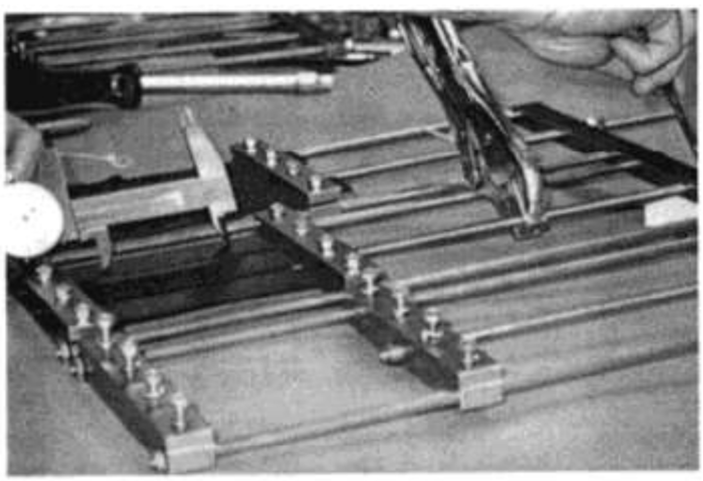
Table 1 – Experimental Design of Different Parts of Comer and Hsuan (1996) Study

Part	Cyclic Temperature Range	Maximum Cycles	Incubation Condition	Tensile Test Temperature
I	+20°C to -20°C	200	relaxed	+20°C
II	+20°C to -20°C	200	relaxed	-20°C
III	+30°C to -20°C	500	constrained	+20°C

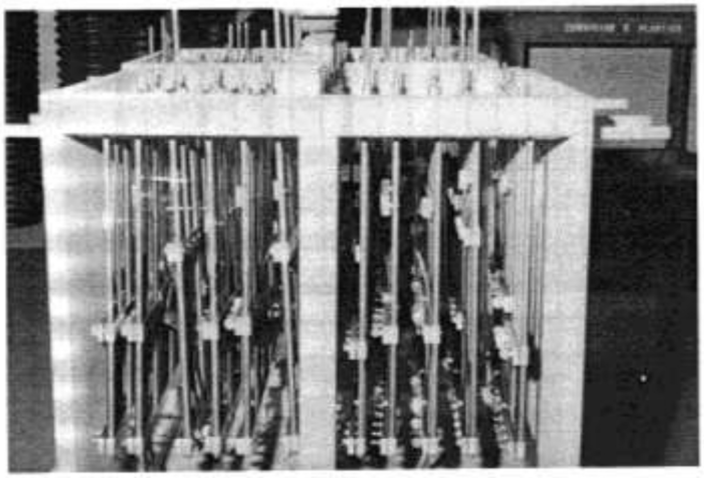
Part I consisted of 19 sheet materials and 27 seams. They underwent freeze-thaw cycles at +20°C for 8 hours and then -20°C for 16 hours. Tensile tests were then conducted at +20°C after 1, 5, 10, 20 50, 100 and 200 cycles.

Part II consisted of 6 sheet materials and 13 seams. They also underwent freeze-thaw cycling at +20°C for 8 hours and then -20°C for 16 hours. Different in this regard was that tensile tests were then conducted at -20°C after 1, 5, 10, 20, 50, 100 and 200 cycles. The -20°C tests were conducted in an environmental chamber (both specimens and their grips) cooled by liquid nitrogen and set at -20°C temperature.

Part III consisted of the same set of 19 sheet materials and 27 seams as in Part I but were now tensioned at a constant strain during the freeze-thaw cycling. The rack used for the tensioning is shown in Figure 2a and the assembly within the environmental chamber is shown in Figure 2b. After the targeted number of freeze-thaw cycles at +20°C for 8 hours and -20°C for 16 hours, specimens were removed and tested at +20°C after 1, 10, 50, 100, 200 and 500 cycles.



(a) Method of applying tensile load to test specimens in Part III tests



(b) Geomembrane racks in holding frame used in Part III series

Figure 2 – Method used for tensioning samples during incubation; Comer and Hsuan (1996)

Rather than showing the graphic results of the above freeze-thaw cycling study (it is available in full in the Comer and Hsuan report by the Bureau of Reclamation and the related papers by these authors) only the concluding comments will be reproduced here. They follow verbatim from the report.

Part I – Results on 200 Freeze-Thaw Cycles Tested at +20°C

- Tensile tests on geomembrane sheets: "The results show no change in either the peak strength or peak elongation of any of the tested materials".
- Shear tests on the geomembrane seams: "The results show no change in shear strength of any of the tested seam materials".
- Peel tests on the geomembrane seams: "The results show no change in peel strength of any of the tested seam materials.

Part II – Results on 200 Freeze-Thaw Cycles Tested at -20°C

- Tensile tests on geomembrane sheets: "The results show no change in either the peak strength or peak elongation of any of the tested materials".
- Shear tests on the geomembrane seams: "The results show no change in shear strength of any of the tested seam materials".
- Peel tests on the geomembrane seams: "The results show no change in peel strength of any of the tested seam materials.

Part III – Results on 500 Freeze-Thaw Cycles Tested at +20°C in a Constrained Condition

- Tensile tests on geomembrane sheets: "The results show no change in either the peak strength or peak elongation of any of the tested materials".
- Shear tests on the geomembrane seams: "The results show no change in shear strength of any of the tested seam materials".
- Peel tests on the geomembrane seams: "The results show no change in peel strength of any of the tested seam materials.

Conclusion and Recommendations

This two-part white paper focused initially on the cold temperature tensile behavior of the stress- versus-strain curves of several different types of geomembranes. As expected, the colder the temperature the more brittle, hence less ductile, were the response curves. Geomembranes made from PVC, CPE and HDPE were illustrated in this regard. The recommendation reached for this part of the white paper is that if a formulation-specific geomembrane under site-specific conditions is to be evaluated for its stress-versus-strain response, actual tests must be commissioned accordingly. The literature can only give general trends in this regard.

The second (and more important) part of this white paper focused entirely on freeze-thaw behavior of geomembranes and their different seam types. The U.S. Bureau of Reclamation report is extremely revealing in this regard. *The conclusion that the authors reached is that there is simply "no change" in tensile behavior of geomembrane sheets or their seams after freeze-thaw cycling.* It is felt that this conclusion in the context of their study is so impressive that it has essentially "closed the door" to further research on this specific topic. The essential question often raised in this regard, i.e., "will freeze-thaw conditions affect geomembrane sheets or their seam behavior," is answered with a resounding "NO".

References

Budiman, J. (1994), "Effects of Temperature on Physical Behavior of Geomembranes," Proc. 5th Intl. Conf. on Geosynthetics, Singapore, SEAC-IGS Publication, pp. 1093-1100.

Burns, D. E. and Pierce, S. V. (1990), "Technical Note on Cold Weather Installation of HDPE," Jour. Geotextiles and Geomembranes, Vol. 9, Nos. 4-6, pp. 457-459.

Comer, A. I. and Hsuan, Y. G. (1996), "Freeze-Thaw Cycling and Cold Temperature Effects on Geomembrane Sheets and Seams," U. S. Bureau of Reclamation Report R-96-03, March, 136 pgs.

Comer, A. I., Sculli, M. L. and Hsuan, Y. G. (1995), "Effects of Freeze-Thaw Cycling on Geomembrane Sheets and Their Seams," Proc. of Geosynthetics '95, Nashville, TN, pp. 853-866.

Giroud, J. P., Soderman, K. L. and Monroe, M. (1993), "Mechanical Design of Geomembrane Applications," Proc. of Geosynthetics '93, Vancouver, Canada, pp. 1455-1468.

Hsuan, Y. G., Sculli, M. L. and Comer, A. I. (1997), "Effects of Freeze-Thaw Cycling on Geomembranes Sheets and Their Seams – Part II Cold Temperature Tensile Behavior and

Thermal Induced Cyclic Stress," Geosynthetics '97 Conference Proceedings, Long Beach, CA, published by IFAI, pp. 201-216.

Hsuan, Y. G., Sculli, M. L. and Koerner, R. M. (1993), "Effects of Freeze-Thaw Cycling on Geomembranes and Their Seams," Proc. GRI-7 Conference on Geosynthetic Liner Systems: Innovations, Concerns and Designs, IFAI, Rosewell, IN, pp. 209-224.

Koerner, R. M. (20120, Designing With Geosynthetics, 6th Edition, Xlibris Publ. Co., 914 pgs.

Lord, Jr., A.E., Soong, T. Y. and Koerner, R. M. (1995), "Relaxation Behavior of Thermally-Induced Stress in HDPE Geomembranes," Geosynthetics International, Vol. 2, No. 3, pp. 626-634.

Peggs, I. D., Carlson, D. S. and Peggs, S. J. (1990), "Understanding and Preventing 'Shattering' Failures of Polyethylene Geomembranes," Geotextiles, Geomembranes and Related Products, Rotterdam, Balkema.

Richards, E. A., Scott, J. D. and Chalaturnyk (1985), "Cold Temperature Properties of Geomembranes," Proc. 2nd Conf. on Geotextiles and Geomembranes, Canadian Geotechnical Society, Edmonton, Alberta, pp. 121-132.

Rollin, A. L., Lafleur, J., Marcotte, M., Dascal, O. and Akber, Z. (1984), "Selection Criteria for the Use of Geomembranes in Dams and Dykes in Northern Climate," Proc. of the Intl. Conf. on Geomembranes, Denver, CO, pp. 493-499.

Thornton, D. E. and Blackall, P. (1976), "Field Evaluation of Plastic Film Liners for Petroleum Storage Areas in the Mackenzie Delta," Canadian Environmental Protection Service, Economic and Technical Review Report EPA-3-76-13.

CHEMICAL COMPATIBILITY OF POLY-FLEX LINERS

Chemical compatibility or resistance as applied to geomembranes is a relative term. Actually compatibility would mean that one material will dissolve in the other such as alcohol in water or grease in gasoline. An example of incompatibility would be oil and water. In liners it is undesirable to have the chemicals dissolve in the liner hence the term compatibility is the reverse of what is normally meant in the chemical industry. In the strictest sense and from a laboratory prospective, chemical compatibility, as the term applies to this industry, would imply that the chemical has no effect on the liner. On the other hand, from an engineering prospective, chemical compatibility means that a liner will survive the exposure to a given chemical even though the chemical could have some effect on the performance of the liner, but not enough to cause failure. Therefore, one must understand and define chemical compatibility for a specific project.

Generally polyethylene will be effected by chemicals in one of three ways.

1. No effect—This means that the chemical in question and the polyethylene do not interact. The polyethylene does not gain (lose) weight, swell, and the physical properties are not significantly altered.
2. Oxidizes (cross linking)—Chemicals classed as oxidizing agents will cause the polyethylene molecules to cross link and cause irreversible changes to the physical properties of the liner. Basically it makes the liner brittle.
3. Plasticizes—Chemicals in this classification are soluble in the polyethylene structure. They do not change the structure of the polyethylene itself but will act as a plasticizer. In doing so, the liner will experience weight gain of 3-15%, may swell by up to 10%, and will have measurable changes in physical properties (i.e. the tensile strength at yield may decrease by up to 20%). Even under these conditions the liner will maintain its integrity and will not be breached by liquids, provided the liner has not been subjected to any stress. These effects are reversible once the chemicals are removed and the liner has time to dry out.

Aside from the effect that chemicals have on a liner is the issue of vapor permeation through the liner. Vapor permeation is molecular diffusion of chemicals through the liner. Vapor transmission for a given chemical is dependent primarily on liner type, contact time, chemical solubility, temperature, thickness, and concentration gradient, but not on hydraulic head or pressure. Transmission through the liner can occur in as little as 1-2 days. Normally, a small amount of chemical is transmitted. Generally HDPE has the lowest permeation rate of the liners that are commercially available.

As stated above chemical compatibility is a relative term. For example, the use of HDPE as a primary containment of chlorinated hydrocarbons at a concentration of 100% may not be recommended, but it may be acceptable at 0.1% concentration for a limited time period or may be acceptable for secondary containment. Factors that go into assessment of chemical compatibility are type of chemical(s), concentration, temperature and the type of application. No hard and fast rules are available to make decisions on chemical compatibility. Even the EPA 9090 test is just a method to generate data so that an opinion on chemical compatibility can be more reliably reached.

A simplified table on chemical resistance is provided to act as a screening process for chemical containment applications.

Poly-Flex, Inc. • 2000 W. Marshall Dr. • Grand Prairie, TX 75051 U.S.A. • 888-765-9359

CHEMICAL RESISTANCE INFORMATION

CHEMICAL CLASS	CHEMICAL EFFECT	PRIMARY CONTAINMENT (LONG TERM CONTACT) HDPE	PRIMARY CONTAINMENT (LONG TERM CONTACT) LLDPE	SECONDARY CONTAINMENT (SHORT TERM CONTACT) HDPE	SECONDARY CONTAINMENT (SHORT TERM CONTACT) LLDPE
CARBOXYLIC ACID	1				
- Unsubstituted (e.g. Acetic acid)		B	C	A	C
- Substituted (e.g. Lactic acid)		A	B	A	A
- Aromatic (e.g. Benzoic acid)		A	B	A	A
ALDEHYDES	3				
- Aliphatic (e.g. Acetaldehyde)		B	C	B	C
- Hetrocyclic (e.g. Furfural)		C	C	B	C
AMINE	3				
- Primary (e.g. Ethylamine)		B	C	B	C
- Secondary (e.g. Diethylamine)		C	C	B	C
- Aromatic (e.g. Aniline)		B	C	B	C
CYANIDES (e.g. Sodium Cyanide)	1	A	A	A	A
ESTER (e.g. Ethyl acetate)	3	B	C	B	C
ETHER (e.g. Ethyl ether)		C	C	B	C
HYDROCARBONS	3				
- Aliphatic (e.g. Hexane)		C	C	B	C
- Aromatic (e.g. Benzene)		C	C	B	C
- Mixed (e.g. Crude oil)		C	C	B	C
HALOGENATED HYDROCARBONS	3				
- Aliphatic (e.g. Dichloroethane) +A4		C	C	B	C
- Aromatic (e.g. Chlorobenzene)		C	C	B	C
ALCOHOLS	1				
- Aliphatic (e.g. Ethyl alcohol)		A	A	A	A
- Aromatic (e.g. Phenol)		A	C	A	B
INORGANIC ACID					
- Non-Oxidizers (e.g. Hydrocloric acid)	1	A	A	A	A
- Oxidizers (e.g. Nitric Acid)	2	C	C	B	C
INORGANIC BASES (e.g. Sodium hydroxide)	1	A	A	A	A
SALTS (e.g. Calcium chloride)	1	A	A	A	A
METALS (e.g. Cadmium)	1	A	A	A	A
KETONES (e.g. Methyl ethyl ketone)	3	C	C	B	C
OXIDIZERS (e.g. Hydrogen Peroxide)	2	C	C	C	C

Chemical effect (see discussion on Chemical Resistance)

1. No Effect--Most chemicals of this class have no or minor effect.
2. Oxidizer--Chemicals of this class will cause irreversible degradaton.

3. Plasticizer--Chemicals of this class will cause a reversible change in physical properties.

Chart Rating

A. Most chemicals of this class have little or no effect on the liner.
   Recommended regardless of concentration or temperature (below 150° F).

B. Chemicals of this class will effect the liner to various degrees.
   Recommendations are based on the specific chemical, concentration and temperature.
   Consult with Poly-Flex, Inc.

C. Chemicals of this class at high concentrations will have significant effect on the physical properties of the liner.
   Generally not recommended but may be acceptable at low concentrations and with special design considerations.
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This data is provided for informational purposes only and is not intended as a warranty or guarantee. Poly-Flex, Inc. assumes no responsibility in connection with the use of this data. Consult with Poly-Flex, Inc. for specific chemical resistance information and liner selection.

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POLY-FLEX
POLYETHYLENE GEOMEMBRANES

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A simplified table on chemical resistance is provided to act as a screening process for chemical containment applications.

CHEMICAL RESISTANCE INFORMATION

POLY-FLEX
POLYETHYLENE GEOMEMBRANES

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HYDROCARBONS	3				
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- Aromatic (e.g. Benzene)		C	C	B	C
- Mixed (e.g. Crude oil)		C	C	B	C
HALOGENATED HYDROCARBONS	3				
- Aliphatic (e.g. Dichloroethane) +A4		C	C	B	C
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- Aliphatic (e.g. Ethyl alcohol)		A	A	A	A
- Aromatic (e.g. Phenol)		A	C	A	B
INORGANIC ACID					
- Non-oxidizers (e.g. Hydrochloric acid)	1	A	A	A	A
- Oxidizers (e.g. Nitric Acid)	2	C	C	B	C
INORGANIC BASES (e.g. Sodium hydroxide)	1	A	A	A	A
SALTS (e.g. Calcium chloride)	1	A	A	A	A
METALS (e.g. Cadmium)	1	A	A	A	A
KETONES (e.g. Methyl ethyl ketone)	3	C	C	B	C
OXIDIZERS (e.g. Hydrogen peroxide)	2	C	C	C	C

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Chart Rating

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Recommended regardless of concentration or temperature (below 150° F).

B. Chemicals of this class will affect the liner to various degrees.
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Consult with Poly-Flex, Inc.

C. Chemicals of this class at high concentrations will have significant effect on the physical properties of the liner.
Generally not recommended but may be acceptable at low concentrations and with special design considerations.
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POLYETHYLENE

ART 254 10.12.1999 Ed. 2

Chemicals Resistance Table
Low Density and High Density Polyethylene

INTRODUCTION

The table in this document summarises the data given in a number of chemical resistance tables at present in use in various countries, derived from both practical experience and test results.

Source: ISO/TR 7472, 7474; Carlowitz: "Kunststofftabellen-3. Auflage".

The table contains an evaluation of the chemical resistance of a number of fluids judged to be either aggressive or not towards low and high density polyethylene. This evaluation is based on values obtained by immersion of low and high density polyethylene test specimens in the fluid concerned at 20 and 60°C and atmospheric pressure, followed in certain cases by the determination of tensile characteristics.

A subsequent classification will be established with respect to a restricted number of fluids deemed to be technically or commercially more important, using equipment which permits testing under pressure and the determination of the ìcoefficient of chemical resistanceî for each fluid. These tests will thus furnish more complete indications on the use of low and high density polyethylene products for the transport of stated fluids, including their use under pressure.

SCOPE AND FIELD APPLICATION

This document establishes a provisional classification of the chemical resistance of low and high density polyethylene with respect to about 300 fluids. It is intended to provide general guidelines on the possible utilisation of low and high density polyethylene:

- at temperatures up to 20 och 60°C
- in the absence of internal pressure and external mechanical stress (for example flexural stresses, stresses due to thrust, rolling loads etc).

DEFINITIONS, SYMBOLS AND ABBREVIATIONS

The criteria of classification, definitions, symbols and abbreviations adopted in this document are as follows:

S = Satisfactory

The chemical resistance of low or high density polyethylene exposed to the action of a fluid is classified as "satisfactory" when the results of test are acknowledged to be ìsatisfactoryî by the majority of the countries participating in the evaluation.

L = Limited

The chemical resistance of low or high density polyethylene exposed to the action of a fluid is classified as "limited" when the results of tests are acknowledged to be "limited" by the majority of the countries participating in the evaluation.

Also classified as "limited" are the resistance to the action of chemical fluids for which judgements "S" and "NS" or "L" are pronounced to an equal extent.

NS = Not satisfactory

The chemical resistance of low or high density polyethylene exposed to the action of a fluid is classified as "not satisfactory" when the results of tests are acknowledged to be "not satisfactory" by the majority of the countries participating in the evaluation.

Also classified as "not satisfactory" are materials for which judgements "L" and "NS" are pronounced to an equal extent.

Sat.sol Saturated aqueous solution, prepared at 20°C

Sol Aqueous solution at a concentration higher than 10 %, but not saturated

Dil.sol Dilute aqueous solution at a concentration equel to or lower than 10 %

Work.sol Aqueous solution having the usual concentration for industrial use

Solution concentrations reported in the text are expressed as a percentage by mass.
The aqueous solutions of sparingly soluble chemicals are considered, as far as chemical action towards low or high density polyethylene is concerned, as saturated solutions.

In general, common chemical names are used in this document.

The table is made as a first guideline for user of polyethylene. If a chemical compound is not to be found or if there is an uncertainty on the chemical resistance in an application, please contact Borealis for advise and proposal on testing.

Chemical resistance of low density and high density polyethylene, not subjected to mechanical stress, to various fluids at 20 and 60°C

Chemical or product	Concentration	LD 20	°C 60	HD 20	°C 60
Acetaldehyde	100 %	L	NS	S	L
Acetanilide	–			S	S
Acetic acid	10 %	S	S	S	S
Acetic acid	60 %	S	L	S	S
Acetic acid, glacial	Greater than 96 %	L	NS	S	L
Acetic anhydride	100 %	L	NS	S	L
Acetone	100 %	L	NS	L	L
Acrylnitrile	–	S	S	S	S
Acetylsilicacid	–	S	S	S	S
Adipic acid	Sat.sol	S	S	S	S
After shave	–	NS	NS	NS	NS
Aliphatic hydocarbons	–	L	NS	L	L
Allyl acetate	–	S	L	S	L
Allyl alcohol	100 %	L	NS	–	–
Allyl alcohol	96 %	–	–	S	S
Allyl chloride	–	L	NS	L	NS
Aluminium chloride	Sat.sol	S	S	S	S
Aluminium fluoride	Sat.sol	S	S	S	S
Aluminium hydroxide	Sat.sol	S	S	S	S
Aluminium nitrate	Sat.sol	S	S	S	S
Aluminium oxychloride	Sat.sol	S	S	S	S
Al/potassium sulphate	Sat.sol	S	S	S	S
Aluminium sulphate	Sat.sol	S	S	S	S
Alums	Sol	S	S	S	S
Aminobenzoic acid	–	S	S	S	S
Ammonia, dry gas	100 %	S	S	S	S
Ammonia, liquid	100 %	L	L	S	S
Ammonia, aqueous	Dil.sol	S	S	S	S
Ammonium acetate	–	S	S	S	S
Ammonium carbonate	Sat.sol	S	S	S	S
Ammonium chloride	Sat.sol	S	S	S	S
Ammonium fluoride	Sol	S	–	S	S
Ammonium hexafluorosilicate	Sat.sol	S	S	S	S
Ammonium hydrogen carbonate	Sat.sol	S	S	S	S
Ammonium hydroxide	10 %	S	S	S	S
Ammonium hydroxide	30 %	S	S	S	S

Chemical or product	Concentration	LD °C 20	60	HD °C 20	60
Ammonium metaphosphate	Sat.sol	S	S	S	S
Ammonium nitrate	Sat.sol	S	S	S	S
Ammonium oxalate	Sat.sol	S	S	S	S
Ammonium phosphate	Sat.sol	S	S	S	S
Ammonium persulphate	Sat.sol	S	S	S	S
Ammonium sulphate	Sat.sol	S	S	S	S
Ammonium sulphide	Sol	S	S	S	S
Ammonium thiocyanate	Sat.sol	S	S	S	S
Amyl acetate	100 %	NS	NS	L	L
Amyl alcohol	100 %	L	L	S	L
Amyl chloride	100 %	NS	NS	–	–
Amyl phthalate	–	L	L	S	L
Aniline	100 %	NS	NS	S	L
Anilinchlorohydrate	–	L	–	–	–
Antimony (III) chloride	90 %	–	–	S	S
Antimony (III) chloride	Sat.sol	S	S	S	S
Antimony trichloride	Sol	S	S	S	S
Apple juice	Sol	–	–	S	L
Aqua regia	$HCl/HNO_3 = 3/1$	NS	NS	NS	NS
Aromaitic hydrocarbons	–	NS	NS	NS	NS
Arsenic acid	Sat.sol	S	S	S	S
Asorbic acid	10 %	S	S	S	S
Barium bromide	Sat.sol	S	S	S	S
Barium carbonate	Sat.sol	S	S	S	S
Barium chloride	Sat.sol	S	S	S	S
Barium hydroxide	Sat.sol	S	S	S	S
Barium sulphate	Sat.sol	S	S	S	S
Barium sulphide	Sat.sol	S	S	S	S
Beer	–	S	S	S	S
Benzaldehyde	100 %	L	NS	S	L
Benzene	100 %	NS	NS	L	L
Benzoic acid	Sat.sol	S	S	S	S
Benzoylchloride	–	S	L	S	L
Benzyl alcohol	–	S	L	S	S
Benzylsulphonic acid	10 %	S	S	S	S
Bismuth carbonate	Sat.sol	S	S	S	S
Bitumen	–	S	L	S	S
Bleach lye	10 %	S	S	S	S

Chemical or product	Concentration	LD 20	°C 60	HD 20	°C 60
Borax	Sat.sol	S	S	S	S
Boric acid	Sat.sol	S	S	S	S
Boron trifluoride	–	L	NS	L	NS
Brake fluid	–	L	NS	L	NS
Brine	–	S	S	S	S
Bromine, dry gas	100 %	NS	NS	NS	NS
Bromine, liquid	100 %	NS	NS	NS	NS
Bromoform	100 %	NS	NS	NS	NS
Butandiol	10 %	S	S	S	S
Butandiol	60 %	S	S	S	S
Butandiol	100 %	S	S	S	S
Butane, gas	100 %	–	–	S	S
Butanol	100 %	S	L	S	S
Butter	–	S	S	S	S
Butyl acetate	100 %	S	L	S	L
Butyl alcohol	100 %	S	S	S	S
Butyl chloride	–	S	–	S	–
Butylene glycol	10 %	S	S	S	S
Butylene glycol	60 %	S	S	S	S
Butylene glycol	100 %	S	S	S	S
Butyraldehyde	–	–	–	S	L
Butyric acid	100 %	L	L	S	L
Calcium arsenate	–	S	S	S	S
Calcium benzoate	–	S	S	S	S
Calcium bisulphide	–	S	S	S	S
Calcium bromate	10 %	S	S	S	S
Calcium bromide	Sat.sol	S	S	S	S
Calcium carbonate	Sat.sol	S	S	S	S
Calcium chlorate	Sat.sol	S	S	S	S
Calcium chloride	Sat.sol	S	S	S	S
Calcium chromate	40 %	S	S	S	S
Calcium cyanide	–	S	S	S	S
Calcium hydrosulphide	Sol	S	S	S	S
Calcium hydroxide	Sat.sol	S	S	S	S
Calcium hypochlorite	Sol	S	S	S	S
Calcium nitrate	Sat.sol	S	S	S	S
Calcium oxide	Sat.sol	S	S	S	S
Calcium perchlorate	1 %	S	–	S	S

Chemical or product	Concentration	LD 20	°C 60	HD 20	°C 60
Calcium permanganate	20 %	S	S	S	S
Calcium persulphate	Sol	S	S	S	S
Calcium sulphate	Sat.sol	S	S	S	S
Calcium sulphide	Dil.sol	–	–	L	L
Camphor oil	–	NS	NS	L	L
Carbon dioxide, dry gas	100 %	–	–	S	S
Carbon dioxide, wet	–	S	S	S	S
Carbon disulphide	100 %	NS	NS	L	NS
Carbon monoxide	100 %	S	S	S	S
Carbon tetrachloride	100 %	NS	NS	L	NS
Carbonic acid		S	S	S	S
Castor oil	Sol	S	S	S	S
Chlorine, water	2 % Sat.sol	L	L	S	S
Chlorine, aqueous	Sat.sol	NS	NS	L	NS
Chlorine, dry gas	100 %	NS	NS	L	NS
Chloroacetic acid	Sol	–	–	S	S
Chlorobenzene	100 %	NS	NS	NS	NS
Chloroethanol	100 %	S	S	S	S
Chloroform	100 %	NS	NS	NS	NS
Chloromethane, gas	100 %	L	–	L	–
Chlorosulphonic acid	100 %	NS	NS	NS	NS
Chloropropene	–	NS	–	L	–
Chrome alum	Sol	S	S	S	S
Chromic acid	Sat.sol	S	S	–	–
Chromic acid	20 %	–	–	S	L
Chromic acid	50 %	–	–	S	L
Chromium VI oxide	Sat.sol	S	S	S	S
Cider	–	S	S	S	S
Citric acid	Sat.sol	S	S	S	S
Citric acid	10 %	S	S	S	S
Citric acid	25 %	S	S	S	S
Coconut oil alcoholic	–	S	S	S	S
Coffee	–	S	S	S	S
Copper (II) chloride	Sat.sol	S	S	S	S
Copper cyanide	Sat.sol	S	S	S	S
Copper (II) fluoride	Sat.sol	S	S	S	S
Copper (II) fluoride	2 %	S	S	S	S
Copper (II) nitrate	Sat.sol	S	S	S	S
Copper (II) sulphate	Sat.sol	S	S	S	S

Chemical or product	Concentration	LD 20	°C 60	HD 20	°C 60
Corn oil	–	S	S	S	S
Cottonseed oil	–	S	S	S	S
Cresylic acid	Sat.sol	–	–	L	–
Crotonaldehyde	Sat.sol	L	–	–	–
Cyclanone	–	S	S	S	S
Cyclohexane	–	NS	NS	NS	NS
Cyclohexanol	Sat.sol	L	NS	–	–
Cyclohexanol	100 %	–	–	S	S
Cyclohexanone	100 %	NS	NS	S	L
Decahydronaphthalene	100 %	L	NS	S	L
Decane	–	NS	NS	L	NS
Decalin	100 %	–	–	S	L
Detergents, synthetic	–	S	S	S	S
Developers (photographic)	Work.conc	–	–	S	S
Dextrin	Sol	S	S	S	S
Dextrose	Sol	S	S	S	S
Diacetone alcohol	–	L	L	L	L
Diazo salts	–	S	S	S	S
Dibutyl amine	–	NS	NS	L	NS
Dibuthyl ether	–	NS	NS	L	–
Dibutylphthalate	–	L	L	S	L
Dichlorobenzene	–	NS	NS	NS	NS
Dichloroethylene	–	NS	NS	NS	NS
Dichloropropylene	–	NS	NS	NS	NS
Diesel oil	–	S	NS	S	L
Diethyl ether	100 %	NS	NS	L	–
Diethyl ketone	–	L	NS	L	L
Diethylene glycol	–	S	S	S	S
Diglycolic acid	–	S	S	S	S
Diisobutylketone	100 %	S	L	S	L
Dimethyl amine	100 %	NS	NS	–	–
Dimethyl formamid	–	S	L	S	S
Dioctyl phthalate	100 %	L	NS	S	L
Dioxan	100 %	–	–	S	S
Dipentene	–	NS	NS	NS	NS
Disodium phosphate	–	S	S	S	S
Drano, plumbing cleaner	–	S	S	S	S

Chemical or product	Concentration	LD °C 20	60	HD °C 20	60
Emulsions, photographic	–	S	S	S	S
Ethandiol	100 %	S	S	S	S
Ethanol	40 %	S	L	S	L
Ethanol	96 %	L	L	–	–
Ethyl acetate	100 %	L	NS	S	NS
Ethyl acrylate	100 %	NS	NS	L	NS
Ethyl alcohol	35 %	S	S	S	S
Ethyl alcohol	100 %	S	S	S	S
Ethyl benzene	–	NS	NS	NS	NS
Ethyl chloride	100 %	NS	NS	NS	NS
Ethylene chloride	100 %	NS	NS	NS	NS
Ethylene diamine	100 %	S	L	S	S
Ethyl ether	–	NS	NS	NS	NS
Ethylene glycol	100 %	S	S	S	S
Ethyl mercaptan	–	NS	NS	NS	NS
Ferric chloride	Sat.sol	S	S	S	S
Ferric nitrate	Sat.sol	S	S	S	S
Ferric sulphate	Sat.sol	S	S	S	S
Ferrous chloride	Sat.sol	S	S	S	S
Ferrous sulphate	Sat.sol	S	S	S	S
Fish solubles	Sol	S	S	S	S
Fluoboric acid	–	S	S	S	S
Fluorine gas	100 %	L	NS	NS	NS
Fluorine gas, dry	100 %	NS	NS	NS	NS
Fluorine gas, wet	100 %	NS	NS	NS	NS
Fluorosilic acid	Conc	S	L	S	L
Fluorosilic acid	40 %	S	S	S	S
Formaldehyde	40 %	S	S	S	S
Formic acid	40 %	S	S	S	S
Formic acid	98 to 100 %	S	S	S	S
Fructose	Sat.sol	S	S	S	S
Fruit pulps	Sol	S	S	S	S
Furfural	100 %	NS	NS	NS	NS
Furfuryl alcohol	100 %	L	NS	S	L
Gallic acid	Sat.sol	S	S	S	S
Gasoline, petrol	–	L	NS	L	L
Gelatine	–	S	S	S	S

Chemical or product	Concentration	LD °C 20	LD °C 60	HD °C 20	HD °C 60
Glucose	Sat.sol	S	S	S	S
Glycerine	100 %	S	S	S	S
Glycerol	100 %	S	S	S	S
Glycolic acid	30 %	S	L	–	–
Glycolic acid	Sol	–	–	S	S
n-Heptane	100 %	NS	NS	L	NS
Hexachlorobenzene	–	S	S	S	L
Hexachlorophene	–	NS	NS	L	L
Hexamethylenetriamine	40 %	S	–	S	–
Hexane	–	S	L	S	L
Hexanol, tertiary	–	S	S	S	S
Hydrobromic acid	50 %	S	S	S	S
Hydrobromic acid	Up to 100 %	S	S	S	S
Hydrochloric acid	Up to 36 %	S	S	S	S
Hydrochloric acid	Conc	S	S	S	S
Hydrochlorous acid	Conc	S	S	S	S
Hydrocyanic acid	10 %	S	S	S	S
Hydrocyanic acid	Sat.sol	S	S	S	S
Hydrofluoric acid	40 %	S	S	S	S
Hydrofluoric acid	60 %	S	L	S	L
Hydrogen	100 %	S	S	S	S
Hydrogen chloride	Dry gas	S	S	S	S
Hydrogen peroxide	30 %	S	L	S	S
Hydrogen peroxide	90 %	S	NS	S	NS
Hydrogen sulphide gas	100 %	S	S	S	S
Hydroquinone	Sat.sol	S	S	–	–
Hydroxylamine	up to 12 %	S	S	S	S
Inks	–	S	S	S	S
Iodine (in potassium sol)	–	L	NS	NS	NS
Iodine (in alcohol)	–	NS	NS	NS	NS
Iron (II) chloride	Sat.sol	S	S	S	S
Iron (II) sulphate	Sat.sol	S	S	S	S
Iron (III) chloride	Sat.sol	S	S	S	S
Iron (III) nitrate	Sol	S	S	S	S
Iron (III) sulphate	Sat.sol	S	S	S	S
Iso octane	100 %	S	NS	S	L
Iso pentane	–	NS	NS	NS	NS

Chemical or product	Concentration	LD °C 20	LD °C 60	HD °C 20	HD °C 60
Isopropanol	–	S	S	S	S
Isopropyl amine	–	NS	NS	NS	NS
Isopropyl ether	100 %	L	NS	S	NS
Kerosene	–	NS	NS	NS	NS
Lactic acid	10 %	S	S	S	S
Lactic acid	28 %	S	S	S	S
Lactic acid	up to 100 %	S	S	S	S
Latex	–	S	S	S	S
Lead acetate	Dil.sol	S	S	S	S
Lead acetate	Sat.sol	S	S	S	S
Lead arsenate	–	S	S	S	S
Lubricating oil	–	S	S	S	S
Lysol	–	NS	NS	L	NS
Magnesium carbonate	Sat.sol	S	S	S	S
Magnesium chloride	Sat.sol	S	S	S	S
Magnesium hydroxide	Sat.sol	S	S	S	S
Magnesium nitrate	Sat.sol	S	S	S	S
Magnesium sulphate	Sat.sol	S	S	S	S
Maleic acid	Sat.sol	S	S	S	S
Mercury	–	S	S	S	S
Mercury (I) nitrate	Sol	S	S	S	S
Mercury (II) chloride	Sat.sol	S	S	S	S
Mecury (II) cyanide	Sat.sol	S	S	S	S
Mercury	100 %	S	S	S	S
Methanol	100 %	S	L	S	S
Methyl alcohol	100 %	S	L	S	S
Methyl benzoic acid	Sat.sol	NS	NS	L	–
Methyl bromide	100 %	NS	NS	NS	NS
Methyl chloride	100 %	NS	NS	NS	NS
Methylcyclohexane	–	L	NS	L	NS
Methyl ethyl ketone	100 %	–	–	S	L
Methylene chloride	–	NS	NS	NS	NS
Methoxybutanol	100 %	S	L	S	L
Milk	–	S	S	S	S
Milk of Magnesia	–	S	L	S	L
Mineral oils	–	L	NS	S	L

Chemical or product	Concentration	LD °C 20	LD °C 60	HD °C 20	HD °C 60
Molasses	Work.conc	S	S	S	S
Motor oil	–	S	L	S	S
Naphtha	–	L	NS	L	NS
Naphtahalene	–	NS	NS	L	–
Nickel chloride	Sat.sol	S	S	S	S
Nickel nitrate	Sat.sol	S	S	S	S
Nickel sulphate	Sat.sol	S	S	S	–
Nicotine	Dil.sol	S	S	S	S
Nicotinic acid	Dil.sol	L	L	S	–
Nitric acid	25 %	S	S	S	S
Nitric acid	50 %	S	L	S	L
Nitric acid	70 %	S	L	S	L
Nitric acid	95 %	NS	NS	NS	NS
Nitric acid	100 %	NS	NS	NS	NS
Nitrobenzene	100 %	NS	NS	NS	NS
Nitroethane	100 %	S	NS	S	NS
Nitromethane	100 %	S	–	S	–
Nitrotoluene	–	NS	NS	NS	NS
n-Octane	–	S	S	S	S
Octyl alcohol	–	S	NS	S	NS
Oil and fats		L	NS	S	L
Oleic acid	100 %	L	NS	S	S
Oleum (H2SO4 + 10 % SO3)		NS	NS	NS	NS
Oleum (H2SO4 + 50 % SO3)		NS	NS	NS	NS
Olive oil	–	S	NS	S	NS
Orthophosphoric acid	50 %	S	S	S	S
Orthophosphoric acid	95 %	S	L	S	L
Oxalic acid	Sat.sol	S	S	S	S
Oxygen	100 %	S	–	S	L
Ozone	100 %	NS	NS	L	NS
Paraffin oil	–	S	L	S	S
n-Pentane	–	NS	NS	NS	NS
Pentane-2	–	NS	NS	NS	NS
Perchloric acid	20 %	S	S	S	S
Perchloric acid	50 %	S	L	S	L
Perchloric acid	70 %	S	NS	S	NS

Chemical or product	Concentration	LD °C 20	LD °C 60	HD °C 20	HD °C 60
Perchloroethylene	–	NS	NS	NS	NS
Phenol	Sol	L	NS	S	S
Phosphine	100 %	S	S	S	S
Phosphoric acid	up to 25 %	S	S	S	S
Phosphoric acid	25 to 50 %	S	S	S	S
Phosphoric (III) chloride	100 %	S	L	S	L
Phosphorous (II) chloride	100 %	–	–	S	L
Phosphorous pentoxide	100 %	S	S	S	S
Phosphorous trichloride	100 %	S	L	S	L
Photographic solutions	–	S	S	S	S
Phtalic acid	50 %	S	S	S	S
Picric acid	Sat.sol	S	L	S	–
Plating solutions	–	S	S	S	S
Potassium acetate	–	S	S	S	S
Potassium aluminium sulphate	Sat.sol	S	S	S	S
Potassium benzoate	–	S	S	S	S
Potassium bicarbonate	Sat.sol	S	S	S	S
Potassium borate	Sat.sol	S	S	S	S
Potassium bromate	Sat.sol	S	S	S	S
Potassium bromide	Sat.sol	S	S	S	S
Potassium carbonate	Sat.sol	S	S	S	S
Potassium chlorate	Sat.sol	S	S	S	S
Potassium chloride	Sat.sol	S	S	S	S
Potassium chromate	Sat.sol	S	S	S	S
Potassium cyanide	Sol	S	S	S	S
Potassium dichromate	Sat.sol	S	S	S	S
Potassium fluoride	Sat.sol	S	S	S	S
Potassium hexacyanoferrate (III)	Sat.sol	S	S	S	S
Potassium hexacyanoferrate (II)	Sat.sol	S	S	S	S
Potassium hexafluorosilicate	Sat.sol	S	S	S	S
Potassium hydrogen carbonate	Sat.sol	S	S	S	S
Potassium hydrogen sulphate	Sat.sol	S	S	S	S
Potassium hydrogen sulphide	Sol	–	–	S	S
Potassium hydroxide	10 %	S	S	S	S
Potassium hydroxide	Sol	S	S	S	S
Potassium hypochlorite	Sol	S	L	S	L
Potassium iodate	10 %	S	S	S	S
Potassium iodide	Sat.sol	S	S	S	S
Potassium nitrate	Sat.sol	S	S	S	S

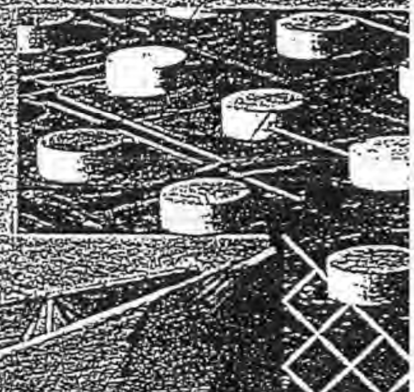
Chemical or product	Concentration	LD °C 20	LD °C 60	HD °C 20	HD °C 60
Potassium orthophosphate	Sat.sol	S	S	S	S
Potassium oxalate	Sat.sol	S	S	S	S
Potassium perchlorate	Sat.sol	S	S	S	S
Potassium permanganate	20 %	S	S	S	S
Potassium persulphate	Sat.sol	S	S	S	S
Potassium phosphate	Sat.sol	S	S	S	S
Potassium sulphate	Sat.sol	S	S	S	S
Potassium sulphide	Sol	S	S	S	S
Potassium sulphite	Sat.sol	S	S	–	–
Potassium thiocyanate	Sat.sol	S	S	S	S
Potassium thiosulphate	Sat.sol	S	S	S	S
Propargul alcohol	–	S	S	S	S
n-Propyl alcohol	–	S	S	S	S
Propionic acid	50 %	–	–	S	S
Propionic acid	100 %	–	–	S	L
Propylene dichloride	100 %	NS	NS	NS	NS
Propylene glycol	–	S	S	S	S
Pyridine	100 %	–	–	S	L
Quinol (hydroquinone)	Sat.sol	S	S	S	S
Resorcinol	Sat.sol	S	S	S	S
Salicylic acid	Sat.sol	S	S	S	S
Sea water	–	S	S	S	S
Selenic acid	–	S	S	S	S
Silicon oil	–	S	S	S	S
Silver acetate	Sat.sol	S	S	S	S
Silver cyanide	Sat.sol	S	S	S	S
Silver nitrate	Sat.sol	S	S	–	–
Soap solution	100 %	S	S	S	S
Sodium acetate	Sat.sol	S	S	–	–
Sodium antimonate	Sat.sol	S	S	S	S
Sodium arsenite	Sat.sol	S	S	S	S
Sodium benzoate	Sat.sol	S	S	S	S
Sodium bicarbonate	Sat.sol	S	S	S	S
Sodium bisulphate	Sat.sol	S	S	S	S
Sodium bisulphite	Sat.sol	S	S	S	S
Sodium borate	–	S	S	S	S
Sodium bromide	Sat.sol	S	S	S	S
Sodium carbonate	Sat.sol	S	S	S	S

Chemical or product	Concentration	LD °C 20	60	HD °C 20	60
Sodium chlorate	Sat.sol	S	S	S	S
Sodium chloride	Sat.sol	S	S	S	S
Sodium chlorite	Sat.sol	L	–	–	–
Sodium cyanide	Sat.sol	S	S	S	S
Sodium dichromate	Sat.sol	S	S	S	S
Sodium fluoride	Sat.sol	S	S	S	S
Sodium hexacyanoferrate (III)	Sat.sol	–	–	S	S
Sodium hexacyanoferrate (II)	Sat.sol	–	–	S	S
Sodium hexafluorosilicate	Sat.sol	S	S	S	S
Sodium hydrogen carbonate	Sat.sol	S	S	S	S
Sodium hydrogen sulphate	Sat.sol	S	S	S	S
Sodium hydrogen sulphite	Sol	S	S	S	S
Sodium hydroxide	40 %	S	S	S	S
Sodium hydroxide	Sol	–	–	S	S
Sodium hypochloride	–	L	NS	S	S
Sodium hypochlorite	15 %	–	–	S	S
	available Cl	–	–	S	S
Sodium iodate	10 %	S	S	S	S
Sodium iodide	Sat.sol	S	S	S	S
Sodium nitrate	Sat.sol	S	S	S	S
Sodium nitrite	Sat.sol	S	S	S	S
Sodium ortophosphate	Sat.sol	S	S	S	S
Sodium oxalate	Sat.sol	S	S	S	S
Sodium phosphate	Sat.sol	S	S	S	S
Sodium silicate	Sol	S	S	S	S
Sodium sulphate	Sat.sol	S	S	S	S
Sodium sulphide	Sat.sol	S	S	S	S
Sodium sulphite	Sat.sol	S	S	S	S
Sodium thiocyanate	Sat.sol	S	S	S	S
Stannic chloride	Sat.sol	S	S	S	S
Stannous chloride	Sat.sol	S	S	S	S
Starch solution	Sat.sol	S	S	S	S
Stearic acid	Sat.sol	S	L	S	–
Styrene	Sol	L	NS	L	NS
Sulphur dioxide, dry	100 %	S	S	S	S
Sulphur trioxide	100 %	NS	NS	NS	NS
Sulphur acid	10 to 50 %	S	S	S	S
Sulphuric acid	10 %	S	S	S	S
Sulphuric acid	50 %	S	S	S	S

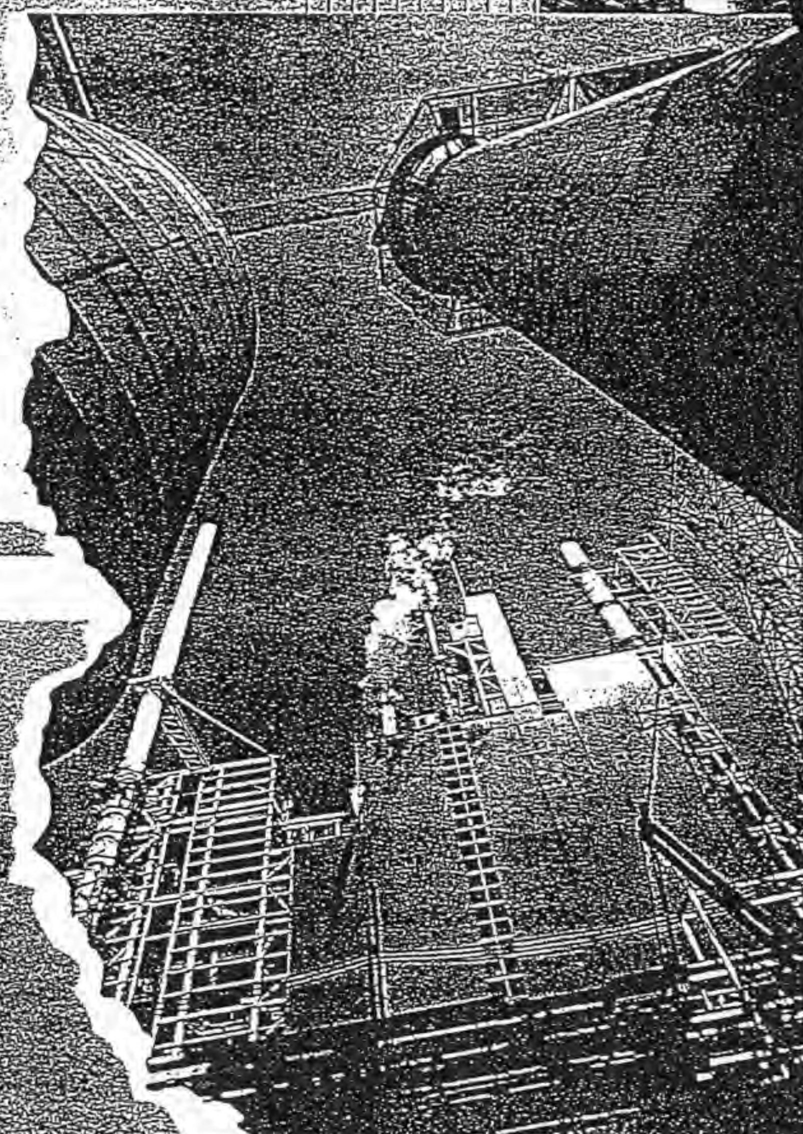
Chemical or product	Concentration	LD 20	°C 60	HD 20	°C 60
Sulphuric acid	70 %	S	L	S	L
Sulphuric acid	80 %	S	NS	S	NS
Sulphuric acid	98 %	L	NS	S	NS
Sulphuric acid	Fuming	NS	NS	NS	NS
Sulphurous acid	30 %	S	S	S	S
Sulphurous acid	Sol	S	S	S	S
Tallow	–	S	L	S	L
Tannic acid	Sol	S	S	S	S
Tartaric acid	Sat.sol	S	S	S	S
Tartaric acid	Sol	–	–	S	S
Tetrachloroethylene	100 %	NS	NS	NS	NS
Tetrachloromethane	100 %	NS	NS	L	NS
Tetradecane		NS	NS	NS	NS
Tetrahydrofuran	–	NS	NS	NS	NS
Tetrahydronaphthalene	100 %	L	NS	S	L
Thionyl chloride	100 %	NS	NS	NS	NS
Tin (II) chloride	Sat.sol	S	S	S	S
Tin (IV) chloride	Sol	S	S	S	S
Tin (IV) chloride	Sat.sol	–	–	S	S
Titanium tetrachloride	Sat.sol	NS	NS	NS	NS
Toluene	100 %	NS	NS	L	NS
Tribromomethane	–	NS	NS	NS	NS
Trichloroacetaldehyde	–	S	–	S	–
Trichlorobenzene	–	NS	NS	–	–
Trichloroethylene	100 %	NS	NS	NS	NS
Triethanolamine	100 %	S	–	S	–
Triethanolamine	Sol	–	–	S	L
Triethylene glycol	–	S	S	S	S
Trisodium phosphate	Sat.sol	S	S	–	–
Turpentine	–	NS	NS	NS	NS
Urea	up to 30 %	S	S	S	S
Urea	Sol	S	S	S	S
Urine	-	S	S	S	S
Vanilla extract	–	S	S	S	S
Vaseline	–	S	L	S	S
Vegetables oils		S	L	S	S
Vinegar		S	S	S	S
Water		S	S	S	S
Wetting agents	–	S	S	S	S
Wines and spirits		S	S	S	S
Chemical or product	Concentration	LD 20	°C 60	HD 20	°C 60

Xylene	100 %	NS	NS	L	NS
Yeast	Sol	S	S	S	S
Zinc bromide	Sat.sol	S	S	S	S
Zinc carbonate	Sat.sol	–	–	S	S
Zinc chloride	Sat.sol	S	S	S	S
Zinc oxide	Sat.sol	S	S	S	S
Zinc stearate	–	S	S	S	S
Zinc sulphate	Sat.sol	S	S	S	S
o-Zylene		NS	NS	NS	NS
p-Zylene	–	NS	NS	NS	NS

CONTAINMENT SOLUTIONS FOR INDUSTRIAL WASTE



- Dike raising
- Sludge caps
- Sludge ponds
- Secondary containment
- Landfill linings
- Landfill caps
- Floating covers



NSC

NSC

HIGH DENSITY POLYETHYLENE (HDPE) GEOMEMBRANE

Over the past five years, the geomembrane industry has experienced numerous changes. Factors such as the increased concern for the environment; new products in the marketplace; and the push for tighter governmental control over the environment have all played a significant role in revolutionizing the geosynthetic industry.

Today, the most widely used geomembrane in the waste management industry is High Density Polyethylene (HDPE). HDPE offers superior performance by maintaining the highest standards of durability.

FEATURES AND BENEFITS

National Seal Company's HDPE geomembrane is manufactured on a computer controlled, flat sheet extruder using virgin, first quality, high molecular weight polyethylene. This process guarantees a material thickness of ±5% from target, the most stringent quality control available in the industry. NSC also guarantees the minimum average thickness of our liner will be greater than or equal to the nominal thickness. HDPE is available in 40 (1.0mm), 50 (1.25mm), 60 (1.5mm), 80 (2.0mm), and 100 (2.5mm) mil thicknesses.

* Chemical Resistance - Often the chemical resistance of the liner is the most critical aspect of the design process. HDPE is the most chemically resistant of all geomembranes. Typical landfill leachates pose no threat to a liner made of HDPE.

Low Permeability - The low permeability of HDPE provides assurance that groundwater will not penetrate the liner; rainwater will not infiltrate a cap; and methane gas will not migrate away from the gas venting system.

Ultraviolet Resistance - HDPE has excellent resistance to ultraviolet degradation. NSC adds carbon black which provides UV protection. Plasticizers are never used in NSC's geomembranes so there is never a concern about volatilization of the plasticizer which can be caused by UV exposure.

APPLICATIONS:

Landfill (primary and secondary containment)
Landfill caps
Lagoon liners
Pond liners
Floating covers
Secondary containment for above ground storage tanks
Retention ponds for mining applications
Wastewater treatment facilities
Potable water reservoirs
Tank linings
Canal linings
Heap leach pads

HDPE GEOMEMBRANE
PHYSICAL PROPERTIES

60 mil

The properties on this page are not part of NSC's Manufacturing Quality Control program and are not included on the material certifications. Seam testing is the responsibility of the installer and/or CQA personnel.

PROPERTIES	METHOD	UNITS	MINIMUM[1]	TYPICAL
Multi-Axial Tensile Elongation	GRI, GM-4	percent	20.0	28.0
Critical Cone Height	GRI, GM-3, NSC mod.	cm	1.0	1.5
Wide Width Tensile	ASTM D 4885			
Stress at Yield		psi	2000	2110
Strain at Yield		%	15.0	20.0
Brittleness Temp. by Impact[2]	ASTM D 746	°C	-75	<-90
Coef. of Linear Thermal Exp.[2]	ASTM D 696	$°C^{-1}$	1.5×10^{-4}	1.2×10^{-4}
ESCR, Bent Strip	ASTM D 1693	hours	1500	>10,000
Hydrostatic Resistance	ASTM D 751	psi	450	510
Modulus of Elasticity	ASTM D 638	psi	80,000	135,000
Ozone Resistance	ASTM D 1149, 168 hrs	P/F	P	P
Permeability[2]	ASTM E 96	cm/sec · Pa	2.3×10^{-14}	8.1×10^{-15}
Puncture Resistance	FTMS 101, method 2065	ppi	1300	1700
		lbs	78	105
Soil Burial Resistance[2]	ASTM D 3083, NSF mod.	% change	10	0
Tensile Impact	ASTM D 1822	ft lbs/in^2	250	420
Volatile Loss[2]	ASTM D 1203, A	percent	0.10	0.06
Water Absorption[2]	ASTM D 570, 23°C	percent	0.10	0.04
Water Vapor Transmission[2]	ASTM E 96	g/day · m^2	0.024	0.009

SEAM PROPERTIES	METHOD	UNITS	MINIMUM[1]	TYPICAL
Shear Strength	ASTM D 4437, NSF mod.	psi	2000	2700
		ppi	120	166
Peel Strength	ASTM D 4437, NSF mod.	psi	1500	1870
(hot wedge fusion)		ppi	90	115
Peel Strength	ASTM D 4437, NSF mod.	psi	1300	1590
(fillet extrusion)		ppi	78	98

STANDARD ROLL DIMENSIONS

Length	1110 feet	Area	16,650 ft^2
Width	15 feet	Weight	5,000 lbs

This information contained herein has been compiled by National Seal Company and is, to the best of our knowledge, true and accurate. All suggestions and recommendations are offered without guarantee. Final determination of suitability for use based on any information provided, is the sole responsibility of the user. There is no implied or expressed warranty of merchantability of fitness of the product for the contemplated use.

NSC reserves the right to update the information contained herein in accordance with technological advances in the material properties.

6H-0893

NSC

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81-9/93-5M

HDPE GEOMEMBRANE
QUALITY CONTROL SPECIFICATIONS

60 mil

National Seal Company's High Density Polyethylene (HDPE) Geomembranes are produced from virgin, first quality, high molecular weight resins and are manufactured specifically for containment in hydraulic structures. NSC HDPE geomembranes have been formulated to be chemically resistant, free of leachable additives and resistant to ultraviolet degradation.

The following properties are tested as a part of NSC's quality control program. Certified test results for properties on this page are available upon request. Refer to NSC's Quality Control Manual for exact test methods and frequencies.

All properties meet or exceed NSF Standard Number 54.

RESIN PROPERTIES	METHOD	UNITS	MINIMUM[1]	TYPICAL
Melt Flow Index[2]	ASTM D 1238	g/10 min	0.50	0.25
Oxidative Induction Time	ASTM D 3895, Al pan, 200°C, 1 atm O_2	minutes	100	120

SHEET PROPERTIES	METHOD	UNITS	MINIMUM[1]	TYPICAL
Thickness	ASTM D 751, NSF mod.			
Average		mils	60.0	61.5
Individual		mils	57.0	59.7
Density	ASTM D 1505	g/cm^3	0.940	0.948
Carbon Black Content	ASTM D 1603	percent	2.0-3.0	2.35
Carbon Black Dispersion	ASTM D 3015, NSF mod.	rating	A1, A2, B1	A1
Tensile Properties	ASTM D 638			
Stress at Yield		psi	2200	2550
		ppi	132	157
Stress at Break		psi	3800	4850
		ppi	228	298
Strain at Yield	1.3" gage length (NSF)	percent	13.0	16.9
Strain at Break	2.0" gage or extensometer	percent	700	890
	2.5" gage length (NSF)	percent	560	710
Dimensional Stability[2]	ASTM D 1204, NSF mod.	percent	1.5	0.4
Tear Resistance	ASTM D 1004	ppi	750	860
		lbs	45	53
Puncture Resistance	ASTM D 4833	ppi	1800	2130
		lbs	108	131
Constant Load ESCR, Single Point	GRI, GM-5a	hours	200	>400

[1] This value represents the minimum acceptable test value for a roll as tested according to NSC's Manufacturing Quality Control Manual. Individual test specimen values are not addressed in this specification except thickness.

[2] Indicates Maximum Value

NSC

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How long will my liner last?

| What is the remaining service life of my HDPE geomembrane?

By Ian D. Peggs, P.E., P.Eng., Ph.D.

Introduction

In his keynote lecture at the GeoAmericas-2008 conference last March, Dr. Robert Koerner (et al., 2008) of the Geosynthetic Institute (GSI) reported the ongoing Geosynthetic Research Institute (GRI) work to make the first real stab at assessing the service lives of high-density polyethylene (HDPE), linear low-density polyethylene (LLDPE), reinforced PE, ethylene propylene diene terpolymer (EPDM), and flexible polypropylene (fPP) exposed geomembranes.

The selected environment simulated that of Texas, USA, in sunny ambient temperatures between ~7°C (45°F) and 35°C (95°F). Of course, an exposed black HDPE geomembrane in the sun will achieve much higher temperatures, probably in excess of 80°C (176°F).

I do not know what the temperature would be at 150-300mm above the liner (for those still specifying this parameter), but it is quite immaterial. The only temperature of concern is the actual geomembrane temperature.

The lifetimes are shown in **Table 1**, but it must be recognized that these data are for specific manufactured products with specific formulations. The "greater than" notation indicates that laboratory exposures (incubations) are still on-going, not that some samples have failed after the indicated time period. The PE-R-1 material is a thin LLDPE, so it might be expected to be the first to reach the defined end of life; the half-life—the time to loss of 50% of uniaxial tensile properties.

It is interesting to note that HDPE-1 and LLDPE-1 are proceeding apace, but it would be expected that the LLDPE-1 would reach its half-life earlier than HDPE-1. However, this does not automatically follow. With adequate additive formulations, perhaps LLDPE could be left exposed and demonstrate more weathering resistance than some HDPEs. This demonstrates the fact that all PEs, whether HD or LLD, are not identical—they can have different long-term performances dependent on the PE resin used and the formulation of the stabilizer package. However, such differences are not evident in the conventional mechanical properties such as tensile strength/elongation, puncture and tear resistances, and so on.

The two fPPs are performing well. However, there had also been an fPP-1, one of the first PP geomembranes that did not perform well. This was due to a totally inappropriate stabilizer formulation. That particular product lasted 1.5 years in service. In

Final Inspection continued on page 44

Type	Specification	Predicted Lifetime in Texas, USA
HDPE-1	GRI-GM13	>28 years (Incubation ongoing)
LLDPEE-1	GRI-GM17	>28 years (Incubation ongoing)
EPDM-1	GRI-GM21	>20 years (Incubation ongoing)
PE-R-1	GRI-GM22	≈17 years (reached halflife)
fPP-2	GRI-GM18 (temp. susp.)	>27 years (Incubation ongoing)
fPP-3	GRI-GM18 (temp. susp.)	>17 years (Incubation ongoing)

Table 1 | Estimated exposed geomembrane lifetimes

| Ian Peggs is president of I-CORP International Inc. and is a member of *Geosynthetics* magazine's Editorial Advisory Committee.

Final Inspection continued from page 56

the QUV weatherometer, it lasted 1,800 light hours at 70°C (158°F). Therefore, the lab/field correlation is that 1,000 QUV light hours is equivalent to a 0.83yr service life under those specific environmental conditions.

At another location in Texas, Koerner/GRI found 1,000hr of QUV exposure was equivalent to 1.1 year actual field exposure. Consequently, for Texas exposures GRI is using a correlation of 1000hr QUV exposure as equivalent to Iyr of in-service exposure. Clearly, the correlation would be different in less sunny and colder environments.

The failed fPP-1 liner was replaced with a correctly stabilized fPP that, subsequently, performed well.

So how can we evaluate the condition of our exposed liners in a simple and practical manner to ensure they will continue to provide adequate service lifetimes and to get sufficient warning of impending expiration?

For each installation, a baseline needs to be established, and changes from that baseline need to be monitored.

A liner lifetime evaluation program

Rather than be taken by surprise when a liner fails or simply expires, it should be possible to monitor the condition of the liner to obtain a few years of notice for impending expiration. One can then plan for a timely replacement without the potential for accidental environmental damage and undesirable publicity. A program of periodic liner-condition assessment is proposed.

... it should be possible to monitor the condition of the liner to obtain a few years of notice for impending expiration.

While estimated correlations might be made for other locations using historical weather station sunshine and temperature data, there is no question that the best remaining lifetime assessments will be obtained using samples removed from the field installation of interest.

A lifetime in excess of 28yr, demonstrated for a recently-made HDPE geomembrane, is comparable to the present actual service periods of as long as 30-35yr. However, actual lifetimes of as low as ~15yr have also been experienced.

Do service lifetimes now exceeding 30yr mean that we might expect to see another round of stress cracking failures as exposed liners finally oxidize sufficiently on the surface to initiate stress cracking?

This would be frustrating after resolving the early 1980s problems with stress cracking failures at welds and stone protrusions when the liners contracted at low temperatures, but it is the way end-of-life will become apparent. And will that be soon or in another 5-20 years? It would be useful to know.

For baseline data, it would be useful to have some archive material to test, but that is not usually available. Manufacturers often discard retained samples after about 5 years. Perhaps facility owners should be encouraged to keep retained samples at room temperature and out of sunlight. The next best thing is to use material from the anchor trench or elsewhere that has not experienced extremes in temperature and that has not been exposed to UV radiation or to expansion/contraction stresses.

Less satisfactory options are to use the original NSF 54 specifications, the manufacturer's specifications, or the GRI-GM13 specifications at the appropriate time of liner manufacturing. The concern with using these specifications is that while aged material may meet them, there is no indication of whether the measured values have significantly decreased from the actual as-manufactured values that generally significantly exceed the specification.

A final option for the baseline would be to use the values at the time of the first liner assessment.

The first liner condition assessment would consist of a site visit during which a general visual examination would be done together with a mechanical probing of the edges of welds. A visual examination would include the black/gray shades of different panels that might indicate low carbon contents.

A closer examination should be done using a loupe (small magnifier) on suspect areas such as wrinkle peaks, the tops and edges of multiple extrusion weld beads, and the apex-down creases of round die-manufactured sheet.

The last detail is significant because the combination of oxidizing surface and exposed surface tension when the liner contracts at low temperatures and the crease is pulled flat can be one of the first locations to crack. The apex-up creases do not fail at the same time because the oxidized exposed surface is under compression (or less tension) when the crease is flattened out.

Appropriate samples for detailed laboratory testing will be removed.

It may be appropriate to do a water lance electrical integrity survey on the exposed sideslopes, but this would only be effective on single liners, and on double liners with a composite primary liner, a conductive geomembrane, or a geocomposite with a conductive geotextile on top.

A sampling and testing regime

A liner lifetime evaluation program should be simple, meaningful, and cost-effective.

While it will initially require expert polymer materials science/engineering input to analyze the test data and to define the critical parameters, it should ultimately be possible to use an expert system to automatically make predictions using the input test data.

Small samples will be taken from deep in the anchor trench and from appropriate

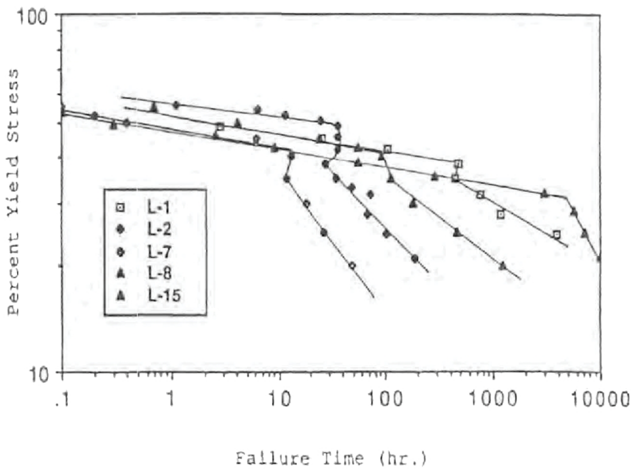

Figure 1 | Standard stress rupture curves for five HDPE geomembranes (Hsuan, et al. 1992)

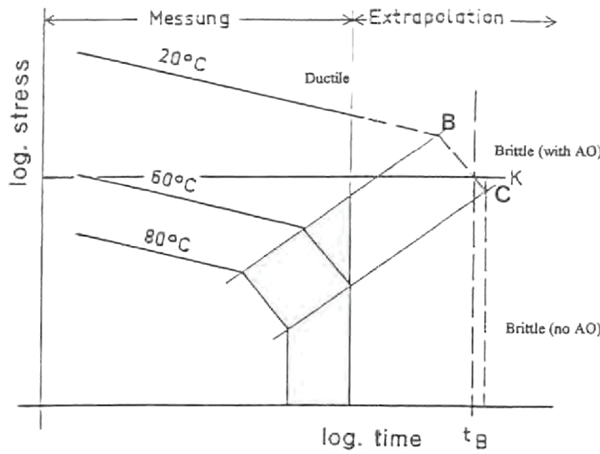

Figure 2 | Stress rupture curves showing third stage (Brittle no AO) oxidized limit. (Gaube, et al. 1985)

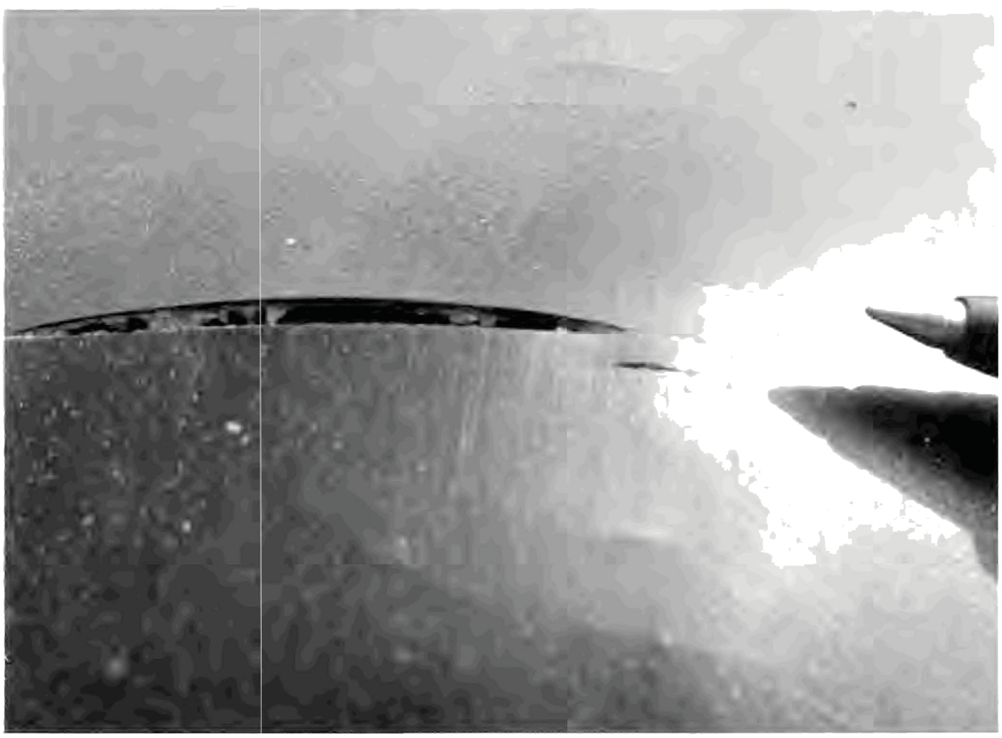

Figure 3 | Stress crack initiated by extruder die line at stone protrusion

exposed locations. Potential sites for future sample removal by the facility owner for future testing will be identified and marked by the expert during the first site visit.

The baseline sample(s) will be tested as follows:

- Single-point stress cracking resistance (SCR) on a molded plaque by ASTM D5397
- High-pressure oxidative induction time (HP-OIT) by ASTM D5885
- Fourier transform infrared spectroscopy (FTIR-ATR) on upper surface to determine carbonyl index (CI) on nonarchive samples only
- Oven aging/HP-OIT (GRI-GM13)
- UV resistance/HP-OIT (GRI-GM13)

The exposed samples will be tested as follows:

- Carbon content (ASTM D1603)
- Carbon dispersion (ASTM D5596)
- Single-point SCR on molded plaque (ASTM D5397)
- Light microscopy of exposed surface, through-thickness cross sections, and thin microsections (~15 µm thick) as necessary
- HP-OIT on 0.5-mm-thick exposed surface layers from basic sheet and from sheet at edge of extruded weld bead (ASTM D5885), preferably at a double-weld bead
- FTIR-ATR on exposed surface to determine CI
- Oven aging/HP-OIT on 0.5mm surface layer (GRI-GM13)
- UV resistance/HP-OIT on 0.5 mm surface layer (GRI-GM13)

Carbon content is done to ensure adequate basic UV protection. Carbon dispersion is done to ensure uniform surface UV protection and to evaluate agglomerates that might act as initiation sites for stress cracking.

HP-OIT is used to assess the remaining amount of stabilizer additives, both in the liner panels and in the sheet adjacent to an extrusion weld. Most stress cracking is observed at the edges of extrusion weld beads in the lower sheet, so it is important to monitor this location.

While standard OIT (ASTM D3895 at 200°C) better assesses the relevant stabilizers effective at processing (melting) and welding temperatures, the relevant changes in effective stabilizer content during continued service, including in the weld zone, will be provided by measurement of HP-OIT. There will be no future high temperature transient where knowledge of S-OIT will be useful. It is expected that the liner adjacent to the weld bead will be more deficient in stabilizer than the panel itself. Therefore, S-OIT is not considered in this program.

Note that HP-OIT is measured on a thin surface layer because the surface layer may be oxidized while the body of the geomembrane may not. If material from the full thickness of the geomembrane is used it could show a significant value of OIT, implying that there is still stabilizer present and that oxidation is far from occurring. However, the surface layer could be fully oxidized with stress cracks already initiated and propagating. A crack will then propagate more easily through unoxidized material than would initiation and propagation occur in unoxidized material.

The fact that the HP-OIT meets a certain specification value in the as-manufactured condition provides no guarantee that thermo- and photo-oxidation protection will be provided for a long time. Stabilizers might be consumed quickly or slowly while providing protection. They may also be consumed quickly to begin with, then more slowly, or vice versa.

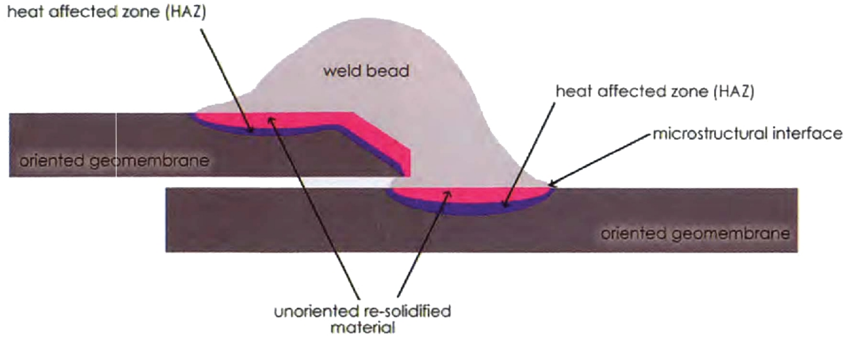

Figure 4 | Schematic of microstructure at extrusion weld

Hence, the need for continuing oven (thermal) aging and UV resistance tests. These two parameters, assessed by measuring retained HP- OIT, are critical to the assessment of remaining service life.

Oven (thermal) aging and UV resistance tests performed in this program will provide an extremely valuable data base that relates laboratory testing to in-service performance and that will further aid in more accurately projecting in-service performance from laboratory testing results.

Special considerations

Because we do not know, by OIT measurements alone, whether the surface layer is or is not oxidized (unless OIT is zero), and since we do not yet know at what level of OIT loss there might be an oxidized surface layer (the database has not yet been generated), FTIR directly on the surface of the geomembrane is performed using the attenuated total reflectance (ATR) technique to deny or confirm the presence of oxidation products (carbonyl groups).

Following the practice of Broutman, et al. (1989) and Duvall (2002) on HDPE pipes, if the ratio of the carbonyl peak at wave number 1760 cm-1 and the C-H stretching (PE) peak at wave number 1410 cm -1 is more than 0.10, there is a sufficiently oxidized surface layer that stress cracking might be initiated. For those familiar with the two slope stress rupture curve (**Figure 1**) where the brittle stress cracking region is the steeper segment below the knee, there is a third vertical part of the curve (**Figure 2**) where the material is fully oxidized and fracture occurs at the slightest stress. This is what will happen at the end of service life. But first note the times to initiation of stress cracking (the knees in the curves) in **Figure 1**—they range from ~10/hr to ~5,000/hr—clearly confirming that all HDPEs are not the same. Some are far more durable than others.

At the end of service life, at some level of OIT, there will be a critically oxidized surface layer that when stressed, such as at low temperatures by an upwards protruding stone, or by flexing due to wind uplift, will initiate a stress crack on the surface that will propagate downward through the geomembrane, as shown by the crack in **Figure 3**.

This crack, initiated at a stress concentrating surface die mark, occurred when the liner contracted at low temperatures, and tightened over an upwardly protruding stone. The straight morphology of the crack, and the ductile break at the bottom surface as the stress in the remaining ligament rose above the knee in the stress rupture curve, are typical of a stress crack. Note the shorter stress cracks initiated along other nearby die marks.

Stress cracks are preferentially initiated along the edges of welds because the adjacent geomembrane has been more depleted of stabilizers during the high temperature welding process. Thus, under further oxidizing service conditions, it will become the first location to

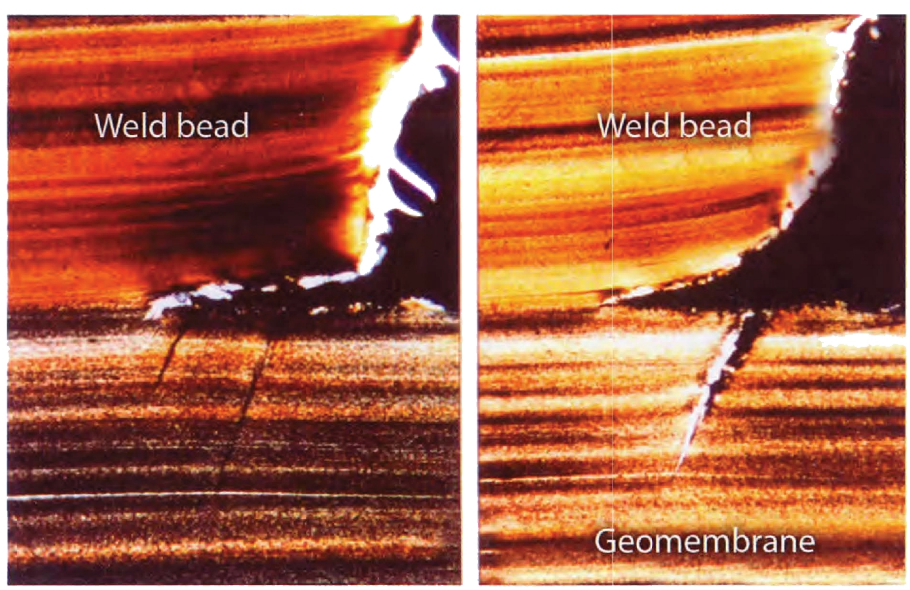

Figure 5 | Typical off-normal angle of precursor crazes (left) and stress crack (right) at edge of extrusion weld.

Type	Specification	Predicted Lifetime in Texas, USA
Side wall exposed	54	5
Side wall concrete side	81	71
Lower launder exposed	16	3
Lower launder concrete side	145	1

Table 2 | S-OIT values on solution and concrete liner surfaces (Peggs, 2008).

be oxidized to the critical level at which stress cracks will be initiated under any applied stress. In addition, the geometrical notches at grinding gouges and at the edges of the bead increase local stresses to critical levels for SC to occur.

I also believe that an internal microstructural flaw exists between the originally oriented geomembrane structure and the pool of more isotropic melted and resolidified material at the edge of the weld zone, as shown schematically in **Figure 4**. Most stress cracks occur at an off-normal angle at the edge of the weld bead that may be related to the angle of this molten-pool to oriented-structure interface (**Figure 5**). It is also known that stress increases the extraction of stabilizers from polyolefin materials.

With all of these agencies acting synergistically, it is not surprising that stress cracking often first occurs adjacent to extrusion welds.

Looking ahead

With the first field assessment test results available to us, and the extent of changes from the baseline sample known, removal of a second set of samples by the facility owner (at locations previously identified and marked by the initial surveyor), will be planned for a future time, probably in 2 or 3 years.

Why 2 or 3 years? In an extreme chemical environment, extensive reductions in S-OIT of studded HDPE concrete protection liners in mine solvent extraction facilities using kerosene/aromatic hydrocarbon/sulfuric acid process solutions at 55°C (131°F) have been observed on the solution and concrete sides of the liner (**Table 2**) within 1 year (Peggs 2008). But it is unlikely that such rapid decreases will be observed in air-exposed material.

With this second set of field samples, and with three sets of data points, practically reliable extrapolations of remaining lifetime can start to be made.

It is expected that a few years of notice for impending failures will be possible.

The key point to note in making these condition assessments is that, while all HDPE geomembranes have very similar conventional index properties, they can have widely variable photo-oxidation, thermal-oxidation, and stress-cracking resistances. Therefore, some HDPEs are more durable than others.

Thus, while one HDPE geomembrane manufactured in 1990 failed after 15 years in 2005, another HDPE geomembrane made in 1990 from a different HDPE resin (or more correctly a medium-density polyethylene [MDPE] resin), and with a better stabilizer additive package, could still have a remaining lifetime of 5, 20, or 30 years.

So, keep a close eye on those exposed liners and we'll learn a great deal more about liner performance and get notice of the end of service lifetime. And if owners can retain some archive material from new installations, so much the better.

References

Broutman L.J., Duvall, D.E., So, P.K. (1989). "Fractographic Study of a Polyethylene Sewer Pipe Failure." SPE Antec, pp 1599-1602.

Duvall, D.E. (2002). "Analyses of Large Diameter Polyethylene Piping Failures." Proceedings of the Society of Plastics Engineers, 60th Annual Technical Conference.

Gaube, E., Gebler, H., Müller, W., and Gondro, C. (1985). "Creep Rupture Strength and Aging of HDPE Pipes 30 Years Experience in Testing of Pipes." Kunststoffe 74 7, pp 412-415.

Koerner, R.M., Hsuan, Y.G., Koerner, G. (2008). "Freshwater and Geosynthetics: A Perfect Marriage." Keynote Lecture at GeoAmericas 2008, IFAI, Roseville, Minn., USA.

Hsuan, Y.G., Koerner, R.M., Lord, A.E., Jr., (1992). "The Notched Constant Tensile Load (NCTL) Test to Evaluate Stress Cracking Resistance." 6th GRI Seminar, MQC/MQA and CQC/CQA of Geosynthetics, Folsom, Pa., USA, pp 244-256.

Peggs, I.D., (2008). "The Performance of Concrete Protection liners in Mine SX/EW Mixers and Settlers: The Need for Chemical Resistance Testing." Proceedings of GeoAmericas 2008, IFAI, Roseville, Minn., USA.

ATTACHMENT III.3.B

GEOTEXTILES REFERENCE DOCUMENTATION

Technical Note No. 7

Chemical Resistance of Amoco Polypropylene Geotextiles

Amoco woven and nonwoven geotextiles are manufactured from polypropylene with ultra violet stabilizing additives. The excellent chemical resistance of Amoco polypropylene geotextiles is one of the qualities which has established Amoco as a leading producer of geotextiles for use in the waste containment industry. This technical note addresses the chemical resistance of polypropylene with a focus on recent testing programs which have clearly demonstrated the durability of Amoco fabrics in a variety of chemical environments.

Are polypropylene geotextiles durable in the chemical environment of landfill leachates?

Yes. Of the polymers used to manufacture geotextiles, polypropylene exhibits the greatest resistance to chemical attack. In fact, polypropylene is the polymer of choice for such commonly used products as landfill liners, synthetic grass for athletic fields, outdoor carpeting, battery cases, bleach bottles, antifreeze jugs, washing machine agitators, and thousands of other commonly used items that are routinely exposed to chemical environments. Polypropylene is stable within a pH range of 2 to 13, making one of the most stable polymers.

Polypropylene geotextiles have been found to be durable in a wide range of chemical environments (Bell, et. al., 1980; Haxo, 1978, 1983; Pucetas, et.al., 1991; Tisinger, et. al., 1989). Research has found both woven and nonwoven polypropylene geotextiles to be non-biodegradable and resistant to commonly encountered soil-bound chemicals, landfill achates, mildew, and insects.

How is the chemical resistance of polypropylene geotextiles determined?

Numerous laboratory test programs have subjected polypropylene to severe chemical environments such as solutions of organic solvents, oils, organic acids, and inorganic acids. The laboratory tests are generally performed in accordance with ASTM D 543, "Standard Test Method for Resistance of Plastics to Chemical Reagents." These test programs have found polypropylene to exhibit superb chemical resistance.

In the ASTM D 543 procedure, the specimens are immersed in a concentrated chemical solution at a specified temperature for a specified exposure period. This test method exposes the polypropylene to etremely harsh conditions which are considerably more severe than those encountered in most civil engineering applications.

The chemical compatibility of geotextiles with leachates is determined by EPA Test Method 9090 (EPA 9090), *"Compatibility Test for Wastes and Membrane Liners."* This was the laboratory method used in the Amoco geotextile test programs reported in this technical note. Geotextile samples are immersed in a constant temperature leachate bath for four months. At the end of each month samples of the fabric are removed and subjected to physical testing. Changes in properties may indicate chemically imposed degradation.

Have Amoco geotextiles been proven to be chemically resistant?

Four laboratory testing programs have been performed to evaluate the chemical compatibility of Amoco geotextiles with landfill leachates. The tests exposed both Amoco woven and nonwoven products to hazardous and municipal waste leachates.

In all testing programs there was no indication of geotextile degradation due to exposure to landfill leachates. The test results are summarized in the remainder of this technical note.

Hazardous waste leachate

A laboratory testing program was performed in 1989 to evaluate the chemical compatibility of Amoco geotextiles with a hazardous waste leachate. The program included EPA 9090 testing of 4 oz/yd² and 8 oz/yd² nonwoven specimens. The testing exposed the geotextiles to leachate in both the laboratory and in a leachate collection sump at a hazardous waste landfill. Test evaluation incorporated detailed microstructural analyses which are not typically incorporated into chemical resistance testing programs. Methods included differential scanning calorimetry, thermal gravimetric analysis, and infrared spectrophotometry. These analyses were performed to identify any changes in the microstructure of the geotextile due to immersion in the leachate.
The results of this testing program found the geotextile microstructure remained intact, stable, and unchanged (Tisinger, et. al., 1989).

Municipal waste leachate

The chemical resistance of Amoco geotextiles to municipal solid waste leachate was evaluated in three laboratory testing programs. The first program, completed in 1990, included EPA 9090 testing of 16 oz/yd² nonwoven geotextile specimens. The second test program, performed in 1992, tested specimens of 8 oz/yd² nonwoven geotextile. The third program, completed in 1993, evaluated the chemical resistance of a high strength woven geotextile. The testing programs evaluated changes in physical properties of the specimens, including specimen dimensions, thickness, grab tensile strength and elongation, puncture resistance, burst strength, and tear strength. In all cases there were no measurable changes in physical properties of the specimens after exposure to the leachate.

Are the results of these tests applicable to Amoco geotextiles which have not been similarly tested?

Yes. All Amoco geotextiles are equally resistant to chemical degradation because they are all manufactured using the same polymer and additives. This conclusion is supported by the test results, which demonstrated no difference in chemical resistance for different types of Amoco geotextiles. The information in this technical note, therefore, is considered to be applicable to all Amoco geotextiles regardless of weight, thickness, or strength.

References

Bell, J.R., et. al., "*Evaluation of Test Methods and Use Criteria for Geotechnical Fabrics in Highway Applications,*" Federal Highway Administration, FHWA/RD-80-021, 1980, 202 p.

EPA Method 9090, "Compatibility Test for Wastes and Membrane Liners,"
Test Methods for Evaluating Solid Waste, Physical/Chemical Methods. US Environmental Protection Agency, EPA 530/SW-846, 1988.

Haxo, R.S., "Chemical Resistance of Lining Materials with Different Waste Fluids," *Proceedings of the Colloque sur l'Etanche'ite' Superficielle des Bassins, Barrages* et Canaux, Paris, France, 1983, pp. 13-20.

Haxo, R.S., "Interaction of Selected Lining Materials with Various Hazardous Wastes," *Proceedings of the Fourth Annual Research Symposium on Land Disposal of Hazardous Wastes,* EPA-600/9-78-016, Southwest Research Institute, US Environmental Protection Agency, Solid and Hazardous Waste Research Division, San Antonio, TX, 1978, pp. 256-273.

Pucetas, R.C., Verschoor, K.L., Allen, S.R., and Sprague, C.J., "The Chemical Resistance of Geotextiles to be Used in Secondary Containment Systems for Underground Storage Tanks," *Geosynthetics '91 Conference Proceedings,* Atlanta, GA, published by the Industrial Fabrics Association International,
St. Paul, MN, 1991, pp. 311-314.

Tisinger, L.G. and Dudzik, B.E., "An Evaluation of Chemical Resistance Test Results of Nonwoven, Needle-Punched Polypropylene Geotextile Exposed to Hazardous Waste Landfill Leachate," *Sardinia '89 2nd International Landfill Symposium,* 1989.

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Technical Note No. 14

Amoco Fabrics and Fibers Company

AMOCO GEOTEXTILES

Geotextile Polymers for Waste Applications

What types of polymers are used to manufacture geotextiles?

Virtually all geotextile fibers are made from either polypropylene or polyester polymers.

Are these polymers used in a 100% pure form?

The manufacture of geosynthetics usually includes the addition of stabilizers and other additives that are blended with the base polymer. The additives constitute a minor fraction of the polymer mixture.

Additives are used primarily to counteract the effects of oxidation, to which many synthetic polymers are sensitive. Oxidation can cause a reduction in material properties such as strength and elasticity. The main sources of oxidation are heat/temperature (thermal oxidation) and ultra violet (UV) radiation from sunlight (photo-oxidation). Manufacturers of geosynthetics add a variety of proprietary additives during production to make the polymers more stable against thermal and UV degradation (see Amoco Technical Note No. 9).

Should the designer specify polypropylene or polyester for geotextiles to be used in waste applications?

The type of polymer used in the fabrication of the geotextile is not a relevant design parameter. The specifications should be developed to focus on the required physical properties of the geotextile relative to strength, hydraulic performance, and chemical compatibility and durability. These elements are addressed in detail in the Amoco Waste-Related Geotextile Guide Specifications.

Does the type of base polymer affect the chemical resistance of geotextiles used in landfills?

Geotextiles in landfills are exposed to leachates, which are generally dilute solutions of chemicals. The geotextile must be resistant to degrading in this chemical environment. Chemical resistance of geotextiles to leachates is evaluated in the laboratory using EPA Test Method 9090 (EPA 9090). The results of such testing on polypropylene and polyester have proved both polymers to be relatively inert and durable in various chemical environments of hazardous and nonhazardous waste landfills (refer to Amoco Technical Note No. 7).

Of the polymers used to manufacture geotextiles, polypropylene exhibits the greatest resistance to chemical attack. Polypropylene is inert to most chemicals except for some highly concentrated solvents. Geotextiles are not expected to be exposed to such solvents in waste applications, where the associated leachates typically contain only trace to very low concentrations of solvent constituents.

Polyester exhibits comparable chemical compatibility. However, unlike polypropylene, polyester is subject to hydrolysis in aqueous environments such as landfill leachates. Hydrolysis is a process in which water-based solvents or water alone causes the polymer chains to break. This can result in a reduction in the mechanical properties of the polymer. Despite this characteristic, the results of EPA 9090 testing on polyester do not show an impact from hydrolysis.

What effect does polymer type have on the UV resistance of geotextiles used in landfills?

There are only slight differences in the UV stability of various geotextile polymers. From a construction perspective, these differences have no impact on the selection of geotextiles for landfill applications. Regardless of the polymer type, it is important to limit exposure of the geotextile to potentially damaging UV radiation.

In landfill applications, geotextiles are usually covered by soil layers and waste soon after construction. Their exposure to UV radiation therefore generally occurs only during construction. Regardless of polymer type, exposure of the fabrics to sunlight during installation should be limited in accordance with the project specifications (see Amoco Waste-Related Geotextile Guide Specifications).

On some landfill side slopes, the geotextile might be left exposed for an extended time before being covered with soil. In these cases, the geotextile must be protected from UV radiation by alternative methods, regardless of whether the fabric is manufactured of polypropylene or polyester. Alternatives include covering the geotextile with a sacrificial geotextile layer or opaque plastic sheet. The sacrificial layer would be removed prior to placing soil cover.

Has the performance of Amoco geotextiles in landfill applications been verified?

Yes. In fact, the excellent chemical resistance of Amoco polypropylene geotextiles is one of the qualities that has established Amoco as a leading supplier of fabrics to the waste containment industry.

Laboratory testing programs have been performed specifically to evaluate the chemical compatibility of Amoco polypropylene geotextiles with landfill leachates. In all test cases there were no measurable changes in the physical properties of the Amoco geotextiles after exposure to leachates. Also, unlike polyester, polypropylene does not undergo hydrolysis. Amoco Technical Note No. 7 provides detailed information regarding the chemical compatibility test conditions, procedures, and results.

References

Amoco Fabrics and Fibers Company, *Technical Note No. 7, Chemical Resistance of Amoco Polypropylene Geotextiles.*

Amoco Fabrics and Fibers Company, *Technical Note No. 9, Ultra Violet Light Degradation.*

Amoco Fabrics and Fibers Company, *Technical Note No. 12, Staple Fiber and Continuous Filament Polypropylene Geotextiles: A Comparison.*

Amoco Fabrics and Fibers Company, *Waste-Related Geotextile Guide Specifications.*

EPA Method 9090, "Compatibility Test for Wastes and Membrane Liners," *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, Environmental Protection Agency,* EPA 530/SW-846, 1988.

GeoSyntec Consultants, Correspondence to Amoco Fabrics and Fibers Company, Atlanta, GA, July 1993.

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Code 94-014/3000/12-97

ATTACHMENT III.3.C

GEONET REFERENCE DOCUMENTATION

PRODUCT DATA SHEET

GSE TenDrain 275 mil Geocomposite

GSE TenDrain geocomposite consists of a 275 mil thick GSE TenDrain geonet heat-laminated on one or both sides with a GSE nonwoven needle-punched geotextile. TenDrain 275 is comprised of a tri-planar structure consisting of middle ribs that provide direct channelized flow, with diagonally placed top and bottom ribs. The geotextile is available in mass per unit area range of 6 oz/yd² to 16 oz/yd². TenDrain 275 geocomposite provides high transmissivity under high and low loads.

[*]

AT THE CORE:
A 275 mil thick TenDrain geonet heat-laminated on one or both sides with a nonwoven needlepunched geotextile.

Product Specifications

Tested Property	Test Method	Frequency	Minimum Average Roll Value[1]	
Geocomposite			6 oz/yd²	8 oz/yd²
Transmissivity[2], gal/min/ft, (m²/sec) Double-Sided Composite	ASTM D 4716	1/540,000 ft²	24.2 (5x10⁻³)	24.2 (5x10⁻³)
Ply Adhesion, lb/in	ASTM D 7005	1/50,000 ft²	0.5	0.5
Geonet Core[1,3] – GSE TenDrain				
Geonet Core Thickness, mi	ASTM D 5199	1/50,000 ft²	275	275
Density, g/cm³	ASTM D 1505	1/50,000 ft²	0.94	0.94
Tensile Strength (MD), lb/in	ASTM D 7179	1/50,000 ft²	75	75
Carbon Black Content, %	ASTM D 4218	1/50,000 ft²	2.0	2.0
Creep Reduction Factor[4]	GRI-GC8	per formulation	1.2	1.2
Compressive Strength, psf	ASTM D 6364	1/540,000 ft²	60,000	60,000
Geotextile[1,3]				
Mass per Unit Area, oz/yd²	ASTM D 5261	1/90,000 ft²	6	8
Grab Tensile Strength, lb	ASTM D 4632	1/90,000 ft²	160	220
Grab Elongation	ASTM D 4632	1/90,000 ft²	50%	50%
CBR Puncture Strength, lb	ASTM D 6241	1/90,000 ft²	435	575
Trapezoidal Tear Strength, lb	ASTM D 4533	1/90,000 ft²	65	90
AOS, US sieve[1], (mm)	ASTM D 4751	1/540,000 ft²	70 (0.212)	80 (0.180)
Permittivity, sec⁻¹	ASTM D 4491	1/540,000 ft²	1.5	1.3
Water Flow Rate, gpm/ft²	ASTM D 4491	1/540,000 ft²	110	95
UV Resistance, % retained	ASTM D 4355 (after 500 hours)	per formulation	70	70
NOMINAL ROLL DIMENSIONS[5]				
Roll Width, ft			12.75	12.75
Roll Length, ft	Double-Sided Composite		200	200
Roll Area, ft²	Double-Sided Composite		2,550	2,550

NOTES:
- [1] All geotextile properties are minimum average roll values except AOS which is maximum average roll value and UV resistance is typical value. Geonet core thickness is minimum average value.
- [2] Gradient of 0.02, normal load of 7,000 psf, boundary condition: plate/sand/geocomposite/geomembrane/plate, water at 70°F for 1 hour.
- [3] Component properties prior to lamination.
- [4] 10,000 hour creep test under 10,000 psf at 70°F temperature.
- [5] Roll widths and lengths have a tolerance of ±1%.

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Proceedings of the 4th Asian Regional Conference on Geosynthetics
June 17 - 20, 2008 Shanghai, China

EVALUATION ON STRESS CRACKING RESISTANCES OF VARIOUS HDPE DRAINAGE GEONETS

M.S. Mok[1], E. Blond[2], J. Mlynarek[3] and H. Y. Jeon[4]

ABSTRACT: Specimens from each geonet were placed under various compressive loads in a vessel containing a solution of 10% surface-active agent and 90% water at a temperature of 50°C. Then the surface morphology study of the specimen was performed after 500 hours test duration. The results show that all of these geonets did not appear any kind of stress cracking in the condition of 400 kPa, which is a typical landfill's loading condition. However, in the case of bi-planar geonet there were some deposits on the surface of geonet's strand and it is expected that this phenomena is due to the results of chemical clogging. On the other hand, in the case of the tri-planar and circular type bi-planar geonets, it maintained very clean flow channels until the end of the test. For high normal pressure some environmental stress cracks were detected for the circular type bi-planar geonet. The results show that the resistance to the environmental stress cracking is related to its polymer density, crystallinity and also rigidity not its mechanical properties.

KEYWORDS: geonet, compressive loads, surface morphology, stress cracking, chemical clogging, flow channels

INTRODUCTION

Land filling, by all indications, will continue to be the predominant method of solid waste disposal. As the use of high density polyethylene (HDPE) geonets increase in landfill applications, it is required to evaluate their long-term properties in several chemical conditions. (Ward and Brown 1990; Carlson 1993)

Typically, the high crystallinity of polyethylene geonets provides an excellent chemical resistance to harsh chemical leachate, however can be problematic with regard to environmental stress cracking. (Qian and Brown 1993; Thomas 1998) Under low stresses in the circumstance of room temperature polyethylenes will fracture by slow crack growth. This mode of failure limits the lifetime of polyethylenes used in critical applications as drainage materials, lining under landfills. (Lagaron, Pastor, Kip 1999; Bobsein 1999)

Geomembranes and geonets are used as a barrier and drainage component in this system, respectively. With addition of carbon black which is an anti-oxidation material HDPE geomembranes and geonets are normally used in hazardous landfill system as a barrier and drainage respectively.

Many researchers and a lot of work about environmental stress cracking resistance for the geomembranes were done and many beneficial reports have already been published. (Peggs and Kannien 1995; Thomas and Deschepper 1993) However a few research results on the environmental stress cracking resistance for the geonet drainage material were performed. Therefore, in this study the resistance to environmental stress cracking (ESCR) was examined mainly in morphological issues for various geonets (bi-planar, tri-planar and circular type of bi-planar geonet) under condition of various normal pressures.

SPECIMEN & TEST METHODS

Total three types of geonets were test in this study. Sample A has 5.6 mm mean value of thickness and two layers which means bi-planar geonet. The cross sectional shape of strand of Sample A is more likely to a square. Sample B has average of 8.6 mm thickness and has 3 layers (tri-planar). Sample C is also bi-planar geonet however has circular type cross sectional shape and thicker than sample A. The raw material of all these samples is high density polyethylene (HDPE). Typical specifications of the samples are provided in Table 1.

Fig. 1 shows these samples. Short-term compressive deformation test was performed using the procedures set forth in Standard Test Method for Determining Short-term Compression Behavior of Geosynthetics (ASTM

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D6364) to evaluate basic mechanical properties of samples. Specimen is positioned between two rigid steel platens and compressed at a constant rate of 1.0 mm/min. To control an accurate temperature of specimen of 23°C heating platens were manufactured and its heating is 14°C/min. Also special test equipment for ESCR under compression was manufactured and this equipment is shown Fig. 2.

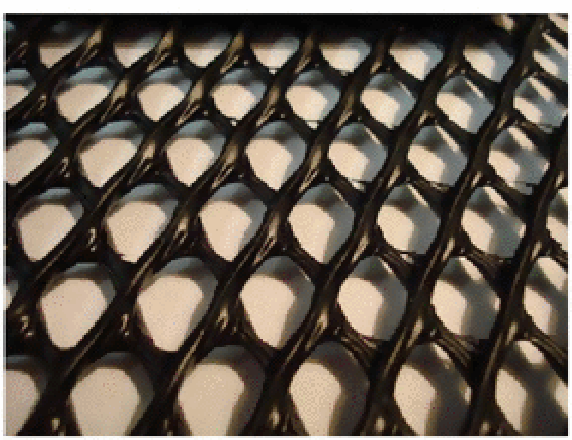
The specimens were immersed in a solution of 90% water and 10% I-gepal CO630 at a temperature of 50°C. The solution level was checked daily and de-ionized water used to keep the bath at a constant level.

And the solution was replaced every 2 weeks. 200, 400 and 700 kPa for sample A, 600, 1,000 and 1,200 kPa for sample B and 400, 600 and 800 kPa for C of load were subjected as compressive load using 6:1 arm lever loading system within considering their compressive strengths.

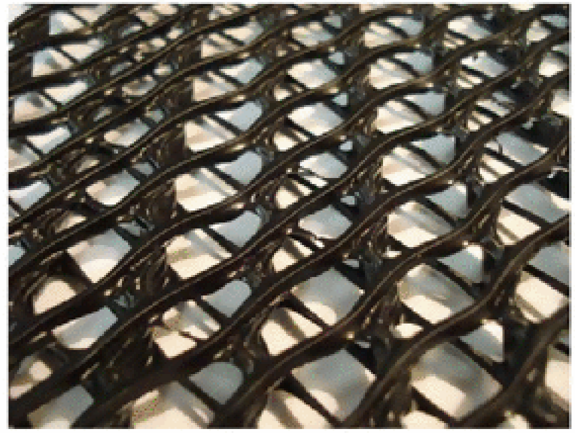
The immersion duration was 500 hours and during and after the test apparent observation and microscopic morphology was evaluated for the specimen.

Table 1 Typical specification of the samples

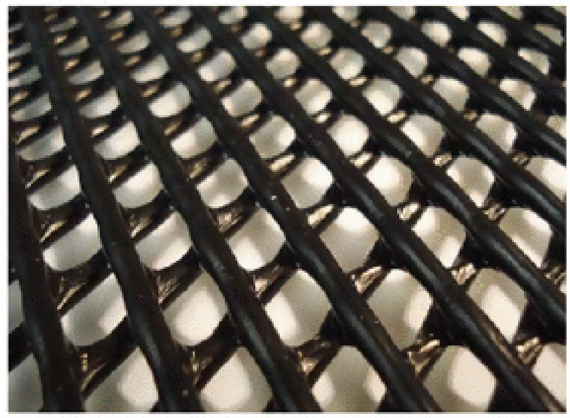
Property	Test method	Unit	Sample		
			A	B	C
Thickness	ASTM D5199	mm	5.6	8.6	8.2
Mass per unit area	ASTM D5261	g/m^2	920	1700	2300
Carbon black	ASTM D4218	%	2.3	2.2	2.3
Density	ASTM D1505	g/cm^3	0.942	0.944	0.940
Crystallinity	ASTM D2910	%	56	55	61



(a) Sample A



(b) Sample B



(c) Sample C

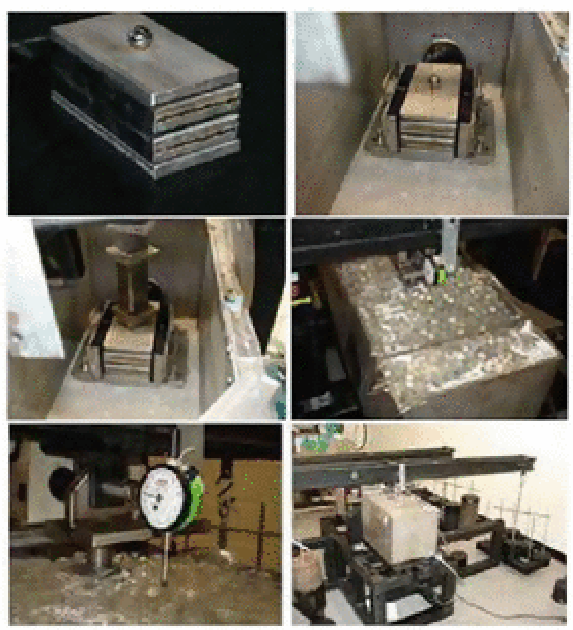


Fig. 2 Compressive environmental stress cracking test equipment

RESULTS & DISCUSSION

Considering the compressive strength and strain properties, the sample C has the stiffest behavior in these three Samples. Initial 5% elastic modulus is much higher than other samples. From this behavior of Sample C it is expected that sample C has rigid structure and has high crystallinity of over 60%. Table 1 confirms this phenomenon. In the other hand Sample A and C have more flexible behavior and low initial elastic modulus.

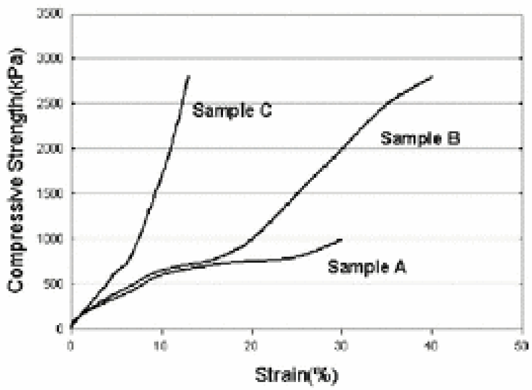


Fig. 3 Short-term compression test results

Figs. 4—9 exhibit the results of apparent observations and microscopic morphologies. Some kind of chemical clogging due to the I-gepal solution is expected for the Sample A because of its flow channel and thickness. This chemical clogging for the Sample A was confirmed by the apparent observation. Fig. 4 shows the results of apparent observations for Sample A. In this figure many deposits on the surface of the specimens were detected during and end of the test and it seems that these deposits which were induced from the chemical solution may occur clogging and therefore affect geonet's in-plane flow capacity. Also there is no chemical clogging on the surface of the specimen for Sample B and this fact was confirmed by apparent observation (Fig. 5).

Considering flowing pattern of the I-gepal solution through out the specimen, the I-gepal has zig-zag flow pattern and this courses some frictions with strands of sample A, therefore the chance of clogging is higher than the Sample B which has straight flow pattern. Also thin thickness compared to other samples can increase chance of any clogging. For the Sample C, the initial creep deformation was very low which means the initial modulus is higher than the other samples and therefore high modulus indicate more rigid than others. High rigidity has brittle failure pattern rather than ductile failure and this can induce a stress crack during the compressive creep test. Also it seems that the chemical act a stress cracking accelerator.

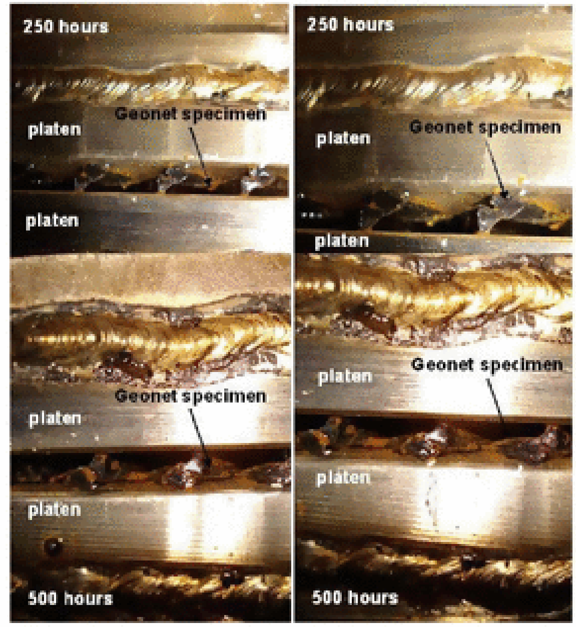


Fig. 4 Apparent observation during and end of the test for sample A (200kPa)

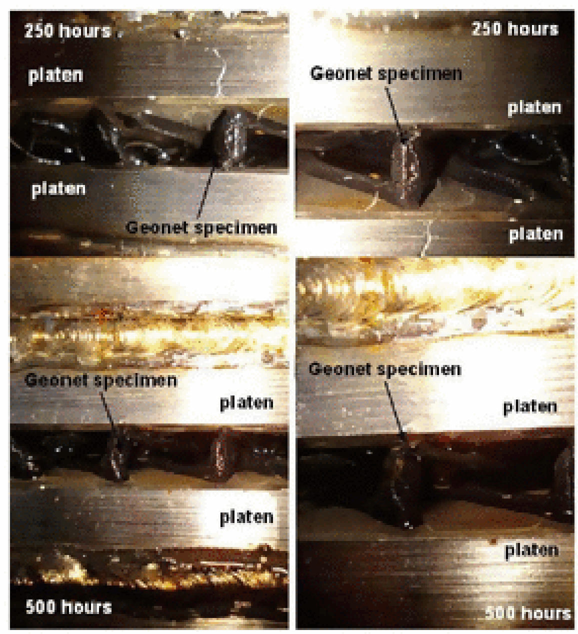


Fig. 5 Apparent observation during and end of the test for sample B (700 kPa)

Figs. 6—9 confirm this environmental stress cracking phenomenon. From these exhibitions it is clear that Sample A and Sample B which have relatively more flexible HDPE strand than Sample C didn't experience any kind of environmental stress cracking. For the Sample C which is more rigid and has high crystallinity (Table 1) likely has to chance of stress cracking. The microscopic morphologies indicate that the extent of environmental stress cracking observed in the Sample C is related to its flexibility and crystallinity. And from the morphologies it seems that the stress cracks occurred at the junction point of the strands first and then propagate to strands with increasing normal pressure.

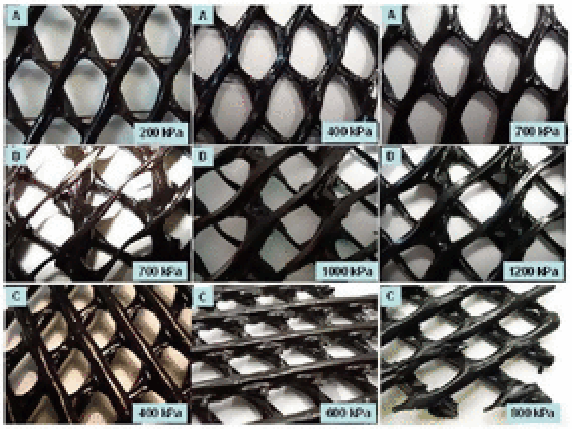


Fig. 6 Apparent observations end of the test for samples under various normal pressures

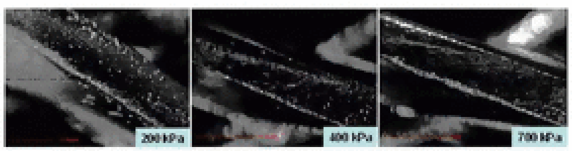


Fig. 7 Microscopic morphologies of Sample A after the test for various normal pressures

Fig. 8 Microscopic morphologies of Sample B after the test for various normal pressures

Fig. 9 Microscopic morphologies of Sample C after the test for various normal pressures

CONCLUSIONS

In this study long-term (500 hours) environmental stress cracking resistance for various geonets under various normal pressures were evaluated. The conclusions are as follows:

1. ESCR property is one of the most critical parameters for evaluating long-term chemical resistance of HDPE geonets which used in hazardous landfill systems.

2. Traditional bi-planar geonets which have square type strand and tri-planar geonet have very strong chemical and stress cracking resistance even high normal pressure.

3. Cylindrical type bi-planar geonets is more rigid material than other samples and it is very week to environmental stress cracking with increasing normal pressure

REFERENCES

Bobsein RL (1999) factors influencing SP-NCTL test results, Proceedings of the 13th GRI Seminar: 46-57

Carlson, DS, etc. (1993) laboratory evaluation of HDPE geomembrane seams, Geosyntheitcs 93, Vancouver, Canada: 1543

Lagaron JM, Pastor JM, Kip BJ (1999) Polymer 40: 1629-1636

Peggs ID, Kannien MF (1995) Geosynthetics International 2(1)

Qian R, Lu X, Brown N (1993) Polymer 34(22)

Thomas, RW (1998) evaluating the stress crack resistance of HDPE seams, 6th International Conference on Geosynthetics

Thomas RW, Deschepper BW (1993) stress crack testing of unnotched HDPE geomembrane and seams, Proceedings of the 7th GRI seminar Dec. 14-15

Ward AL, Lu X, Brown N (1990) Polymer Engineering and Science, Sep 30(18)

ATTACHMENT III.3.D

GEOSYNTHETIC CLAY LINER REFERENCE DOCUMENTATION

THE EFFECTS OF LEACHATE ON THE HYDRAULIC CONDUCTIVITY OF BENTOMAT®

Compatibility testing was performed to determine the effects of solid waste landfill leachate on the permeability of Bentomat over a prescribed time period. Testing was performed in accordance with United States Environmental Protection Agency (USEPA) Method 9100, as provided in SW846.

Hydration of specimens was conducted using de-aired tap water for approximately 48 hours. Saturation was also conducted using de-aired tap water until a minimum B value of 0.95 was achieved. Following hydration and saturation, baseline hydraulic conductivity was performed using water. After the baseline hydraulic conductivity was established, the permeant was switched to leachate. Testing continued for an additional 30 days to allow a sufficient number of pore volumes to permeate the specimen to establish a hydraulic conductivity with leachate.

Results show that the hydraulic conductivity of Bentomat was unaffected when permeated with this leachate.

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FINAL REPORT

LABORATORY TESTING OF BENTOMAT

Prepared for

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GeoSyntec Consultants Project Number: GL1614

31 July 1991

2. TEST PROCEDURES

2.1 Task 1: EPA 9100 Compatibility Testing

Compatibility testing on the Bentomat was performed to measure the effect of leachate on the hydraulic conductivity of the mat product over a prescribed period of time. Testing was performed in accordance with the United States Environmental Protection Agency (USEPA) Method 9100 SW-846, Revision 1, 1987. The test conditions for Task 1 were as follows:

- Testing was conducted using flexible-wall triaxial permeameters, as shown in Photograph 2.1-1.
- Three replicate samples of the Bentomat were tested.
- Each sample was trimmed to a diameter of 2.8 in. (70 mm) and assembled in the following test configuration (from bottom to top): porous stone/filter paper/sand layer/Bentomat/sand layer/filter paper/porous stone.
- Hydration and saturation of the samples using de-aired tap water was conducted at an effective stress of 2.0 psi (14 kPa) for a time period of approximately 48 hours. Saturation was defined as a minimum Skempton's B-parameter of 0.95.
- Consolidation of the saturated test samples was performed at an effective stress of 5.0 psi (35 kPa). Pore-water displacement was monitored until primary consolidation was complete.
- To determine the baseline hydraulic conductivity, the samples were permeated using de-aired tap water. The average hydraulic gradient used for baseline permeation was approximately 50. For this testing program, initial hydration and saturation was

conducted using de-aired tap water. Hydration with leachate may or may not yield different results.

- After establishing the baseline hydraulic conductivity, the permeant was switched to the leachate. Because of the slow permeation rates and the objective to increase the volume of leachate in contact with the Bentomat, the sand layer was replaced on all samples by an Amoco 4516 geotextile after approximately three weeks of testing. Permeation of the samples with the leachate continued for an additional 30 days. The hydraulic conductivity of the sample was monitored and reported daily during this period.

- Permeation of the test specimens with the leachate was initially conducted at an average hydraulic gradient of approximately 50. In order to increase flow through the Bentomat during the prescribed time period, the average hydraulic gradient was increased to approximately 160.

- Because the final hydrated thickness of the Bentomat is unknown until the completion of testing and for comparison of the test data, the hydraulic conductivity was calculated using 0.4 in. (1.0 cm) for the Bentomat. These values were used in all calculations of hydraulic conductivity in Tasks 1 through 7.

TABLE 3.1-1

EPA 9100 COMPATIBILITY TESTING
BENTOMAT SPECIMEN CONDITIONS

American Colloid Company

Parameters	Specimen No. 1		Specimen No. 2		Specimen No. 3	
	Initial	Final	Initial	Final	Initial	Final
Thickness, in.	0.29	0.39	0.33	0.43	0.28	0.36
Diameter, in.	3.01	3.14	3.19	3.30	3.11	3.18
[1]Dry Mass, g	30.8	24.4	38.3	31.4	34.4	26.1
[2]Mass/Area, lb/ft^2	1.37	1.00	1.54	1.16	1.44	1.05
Water Content, %	18.8	170.1	15.7	169.4	10.9	167.4

Notes: 1 The dry mass includes the dry weight of the bentonite and the geotextiles bonded to the specimen.

2 The mass/area is determined using the dry mass of the material normalized with respect to the cross-sectional area of the test specimen before drying.

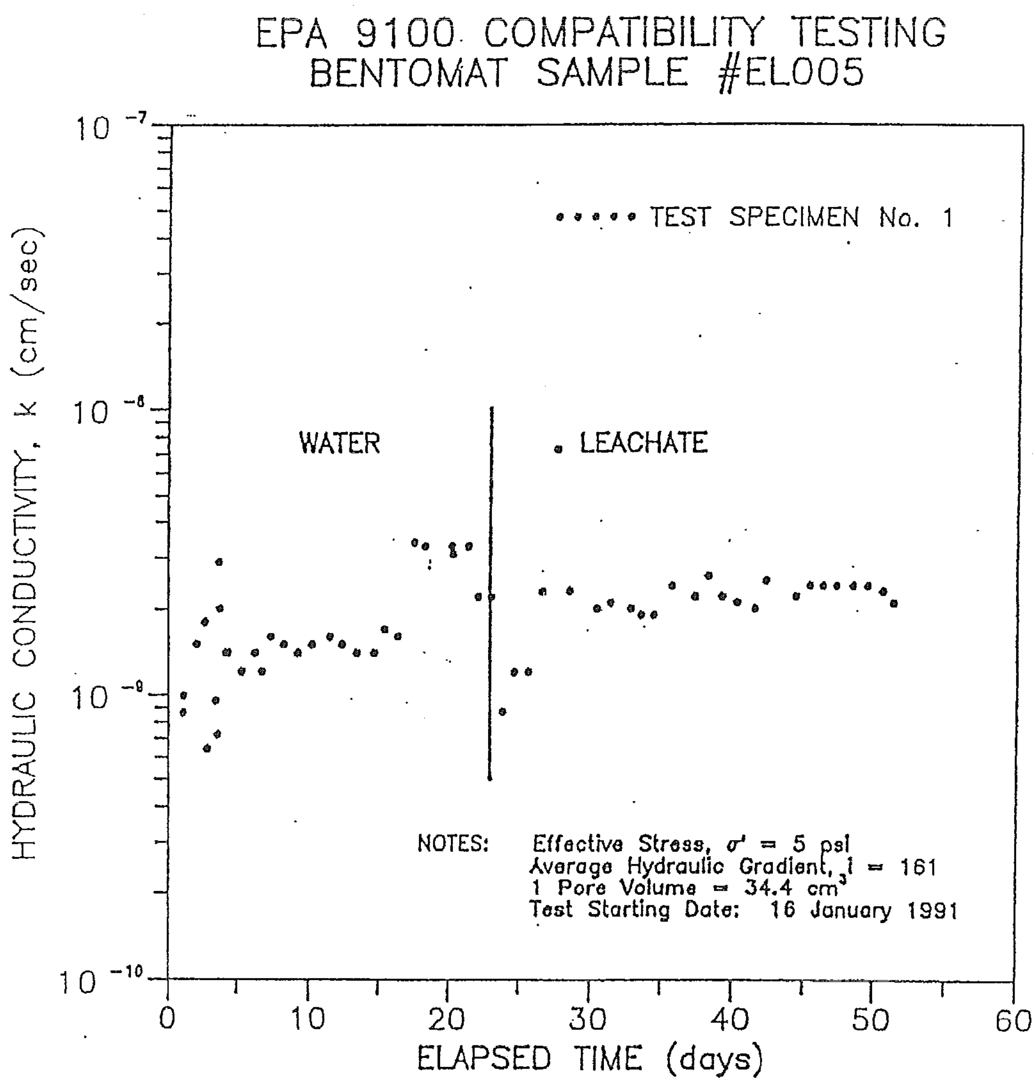

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FIGURE NO.	3.1-1
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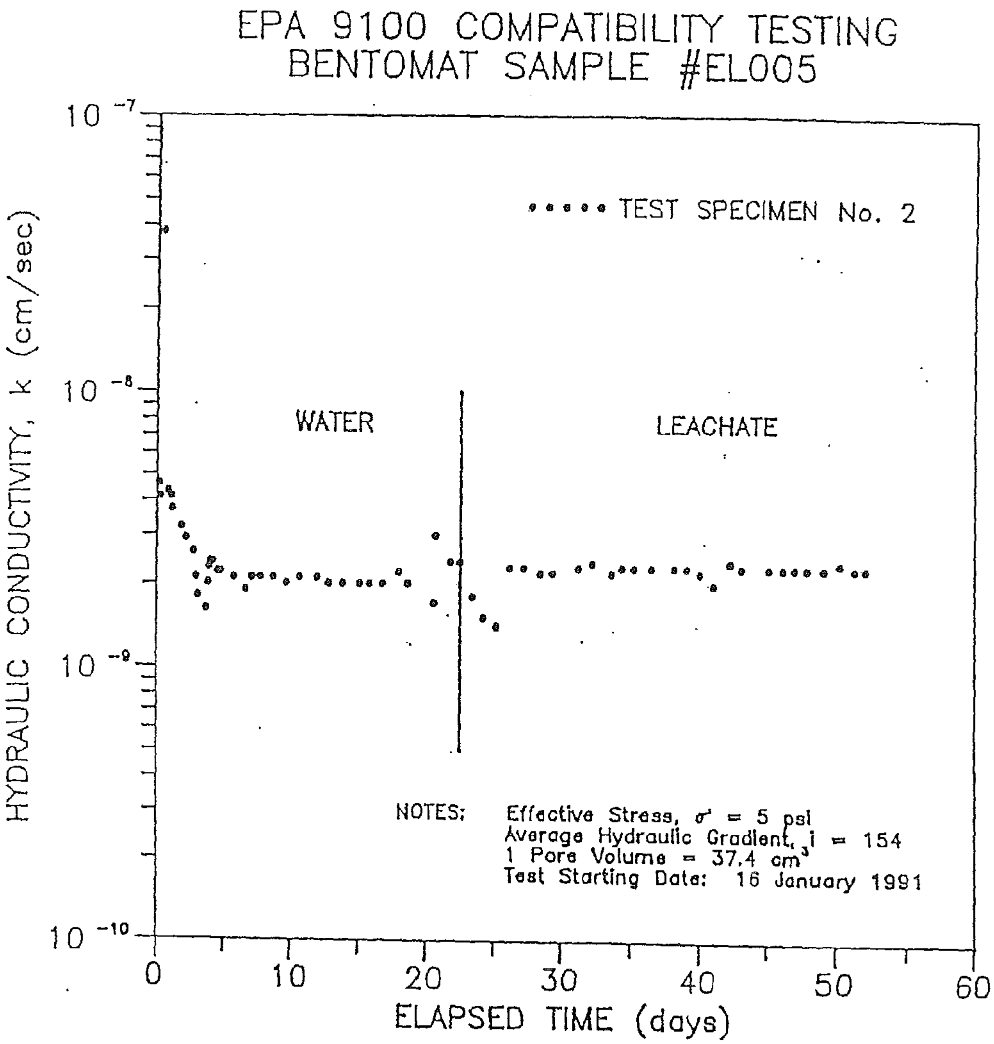

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FIGURE NO.	3.1-2
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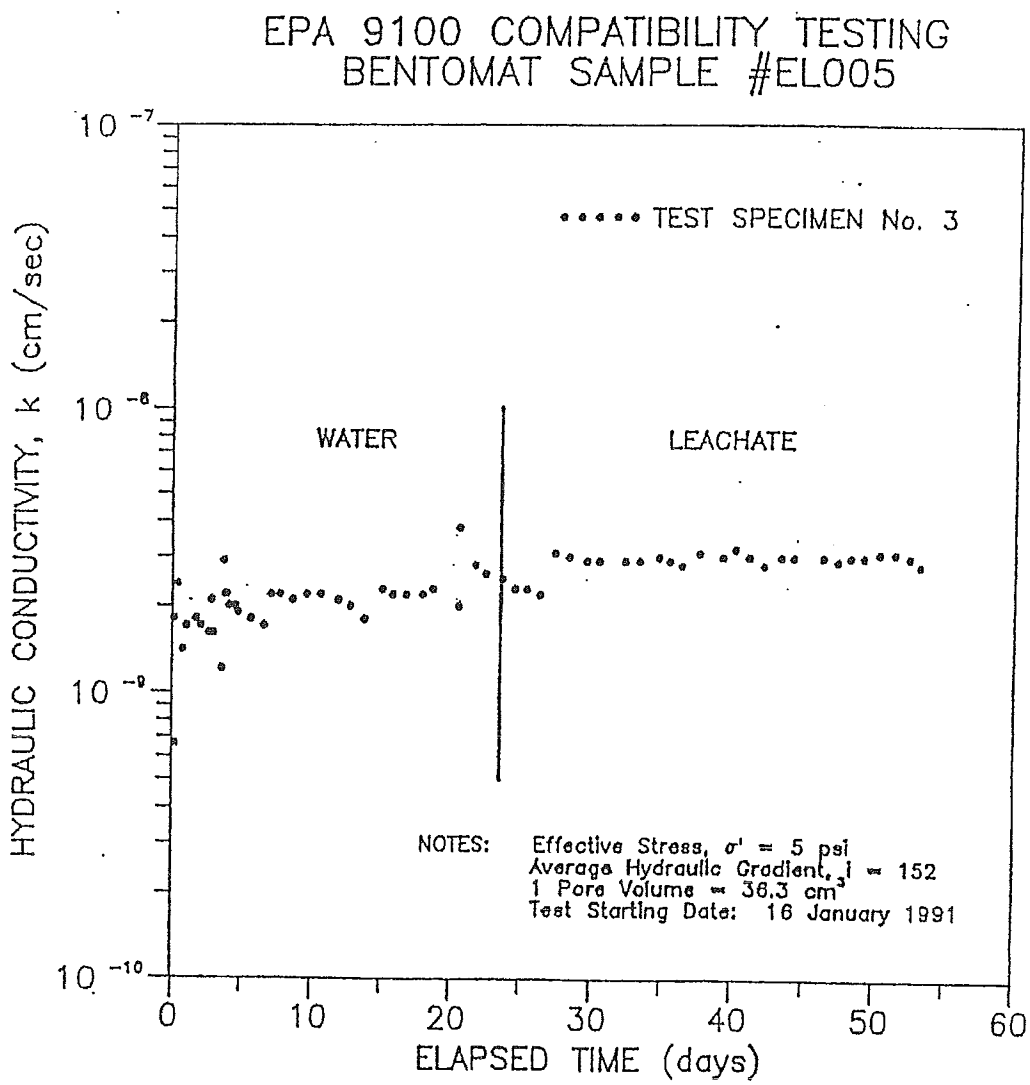

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FIGURE NO.	3.1-3
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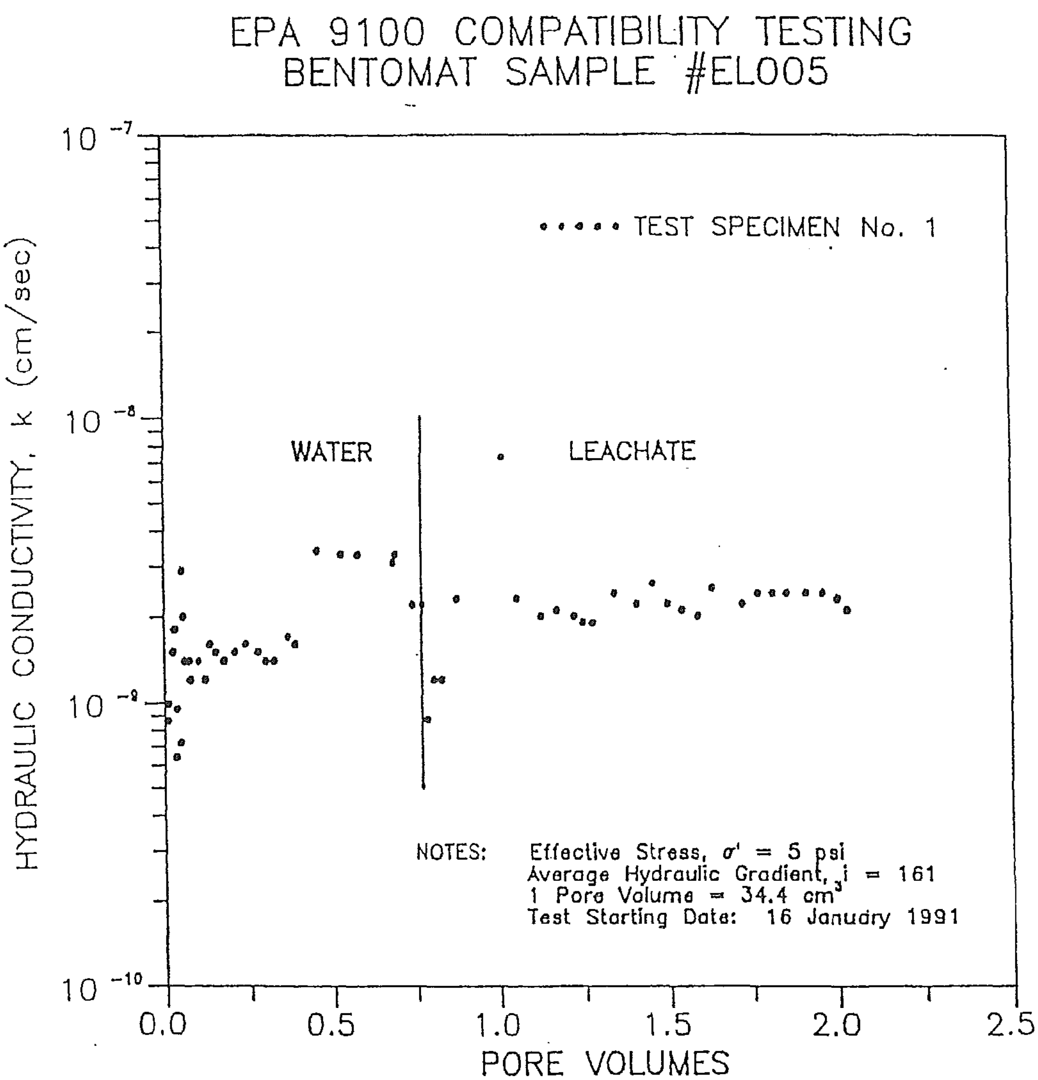

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FIGURE NO.	3.1-4
PROJECT NO.	GL1614
DOCUMENT NO.	GEL91066
PAGE NO.	

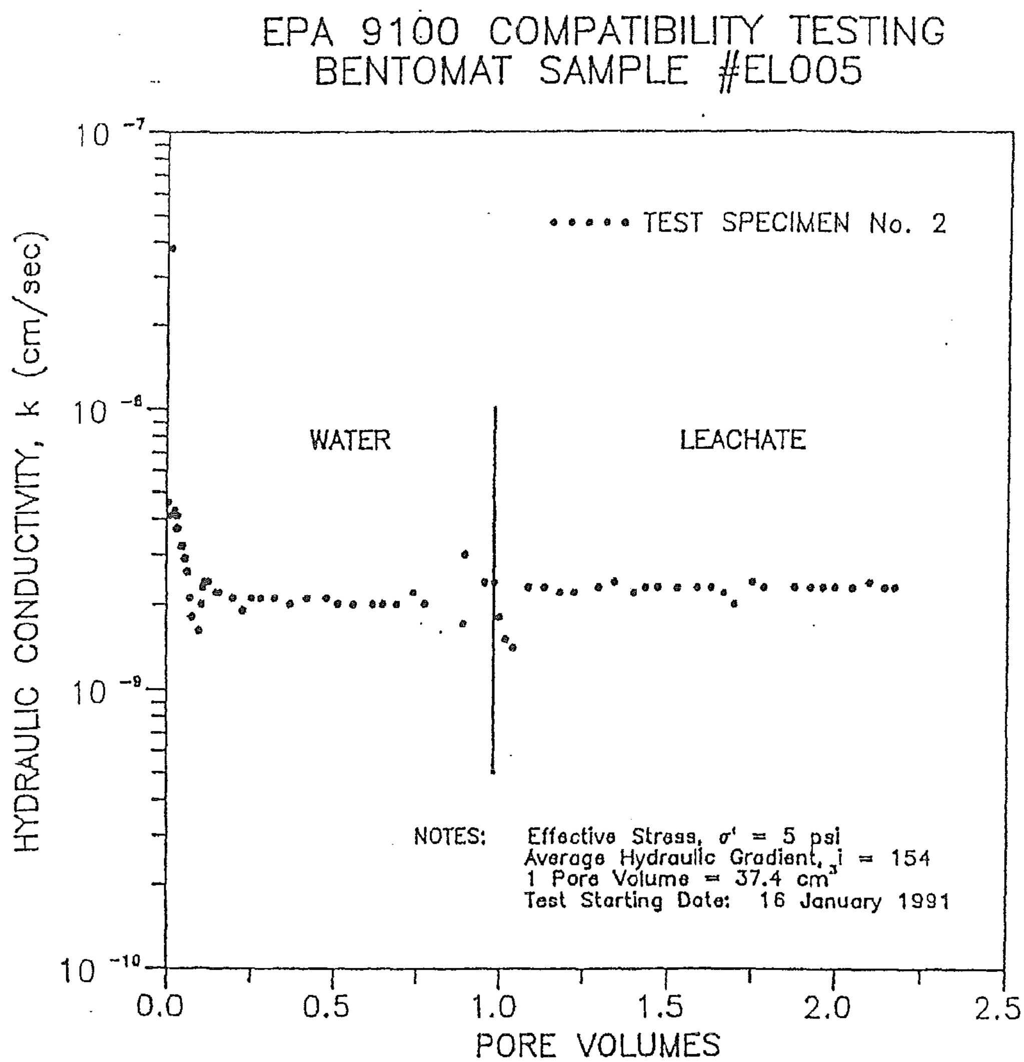

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FIGURE NO.	3.1-5
PROJECT NO.	GL1614
DOCUMENT NO.	GEL91066
PAGE NO.	

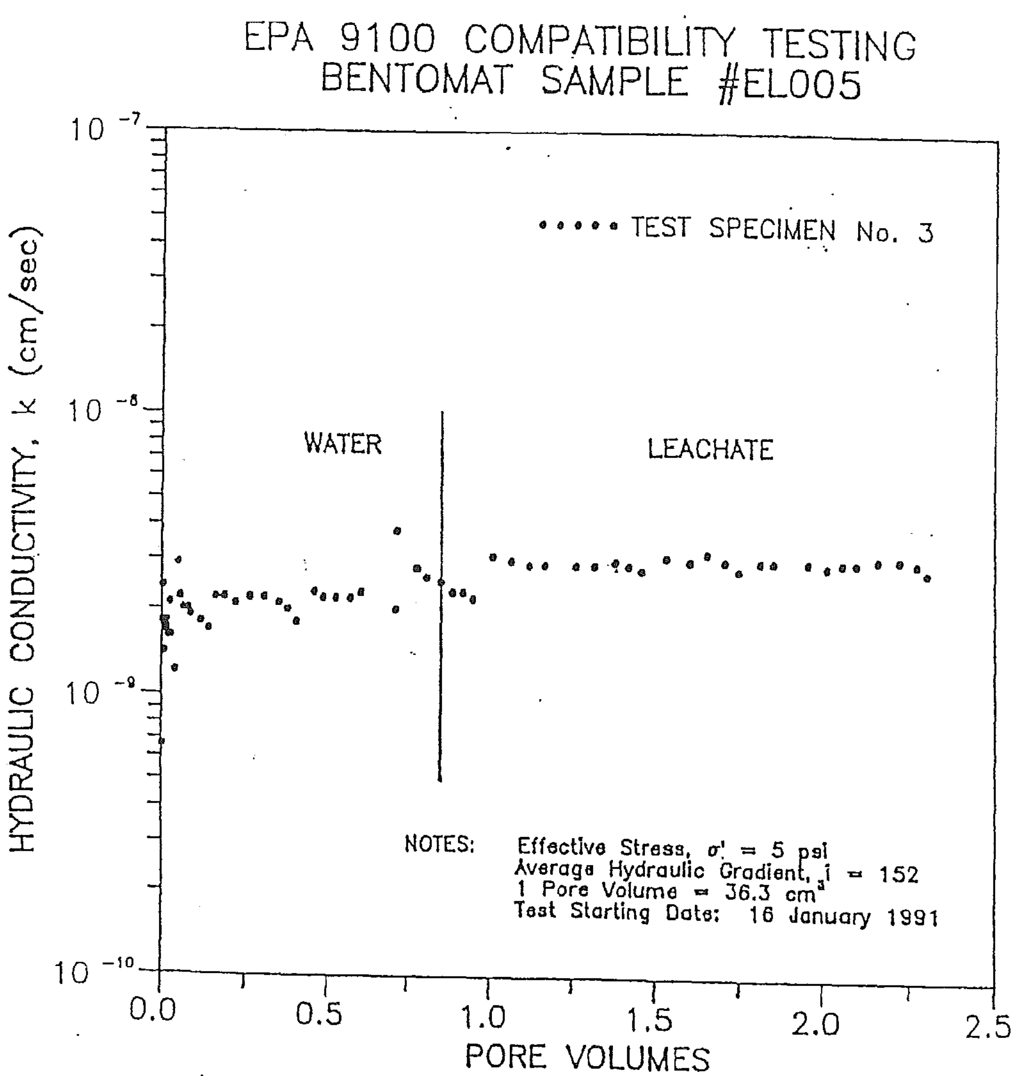

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FIGURE NO.	3.1-6
PROJECT NO.	GL1614
DOCUMENT NO.	GEL91066
PAGE NO.	

3.1 Task 1: EPA 9100 Compatibility Testing

3.1.1 Test Results

The physical conditions of the three Bentomat specimens, measured before and after the tests, are summarized in Table 3.1-1. Graphical presentations of the hydraulic conductivity as a function of elapsed time are presented in Figures 3.1-1, 2, and 3. Graphical presentations of the hydraulic conductivity as a function of the volume of liquid passed through the specimens (i.e., pore volumes) are presented in Figures 3.1-4, 5, and 6.

3.1.2 Observations

Because of the low hydraulic conductivity of the bentonite mat, and in order to maximize the volume of leachate through the mat, the sand layer in each test was replaced by an Amoco 4516 geotextile during that test. This generally occurred shortly before the permeant was switched from water to leachate. In many cases the data indicated erratic behavior for a short time after the switch, but the hydraulic conductivities eventually became consistent.

All specimens were initially permeated at a hydraulic gradient of 50. The resulting hydraulic conductivity measurements were somewhat variable. The hydraulic gradient was subsequently increased to 160 after approximately five days of testing. The test results tended to stabilize after the gradient increase. The average hydraulic gradients that were used for the remainder of each test after the initial increase gradient is indicated on each figure.

In all cases, the data presented in the tables show that each specimen swelled in thickness and in diameter, and that each specimen experienced an apparent loss of mass. The effluent water however, was not visibly cloudy in any of the tests.

In each figure, a transition from water to leachate is indicated. The variability in the test results near this transition is likely the result of disturbance due to leachate injection and removal of the sand layer. Within a short period of time, the test results stabilized.

BENCH-SCALE HYDRAULIC CONDUCTIVITY TESTS OF BENTONITIC BLANKET MATERIALS FOR LINER AND COVER SYSTEMS

by

PAULA ESTORNELL, B.S.C.E.

THESIS

Presented to the Faculty of the Graduate School of

The University of Texas at Austin

in Partial Fulfillment

of the Degree of

MASTER OF SCIENCE IN ENGINEERING

THE UNIVERSITY OF TEXAS AT AUSTIN

August, 1991

aid in maintaining a 6- to 9-in-wide overlap during installation.

2.1.2 Available Laboratory Test Data of the Hydraulic Properties of Bentomat®

2.1.2.1 Bentomat® Permeation with Water

J & L Testing Company (1990) conducted flexible-wall hydraulic conductivity tests on 6-in (150-mm) diameter samples of Bentomat® containing either untreated granular bentonite ("CS" grade) or high-contaminant-resistant bentonite ("SS" grade). Test conditions and results are summarized in Table 2.2. The duration of the tests was not reported. Figure 2.2 presents the relationship between hydraulic conductivity and maximum effective stress. Hydraulic conductivities ranged from 6×10^{-10} cm/s to 6×10^{-9} cm/s.

2.1.2.2 Bentomat® Permeation with Chemical Leachates

GeoSyntec Consultants (1991a) performed compatibility tests on Bentomat® in flexible-wall permeameters in order to measure the effect of landfill leachate on the alternative barrier material. Three 2.8-in (70-mm) diameter replicate samples were permeated first with de-aired water (under an effective stress of 2.0 psi (14 kPa) and a hydraulic gradient of about 50) and then with leachate (under an effective stress of

Table 2.2 Summary of Results of Hydraulic Conductivity Tests on Bentomat® (J&L Testing Company, 1990)

Grade of Bentonite	Stress (psi) Cell	Headwater	Tailwater	Maximum Effective	Hydraulic Conductivity (cm/s)
High-Contaminant-Resistant ("SS")	50	42.2	41.8	8.2	2.1×10^{-9}
	50	44.6	39.4	10.6	7.5×10^{-10}
	50	47.2	36.8	13.2	5.8×10^{-10}
Untreated Granular Bentonite ("CS")	50	42.2	41.8	8.2	5.6×10^{-9}
	50	44.6	39.4	10.6	1.1×10^{-9}
	50	47.2	36.8	13.2	9.8×10^{-10}

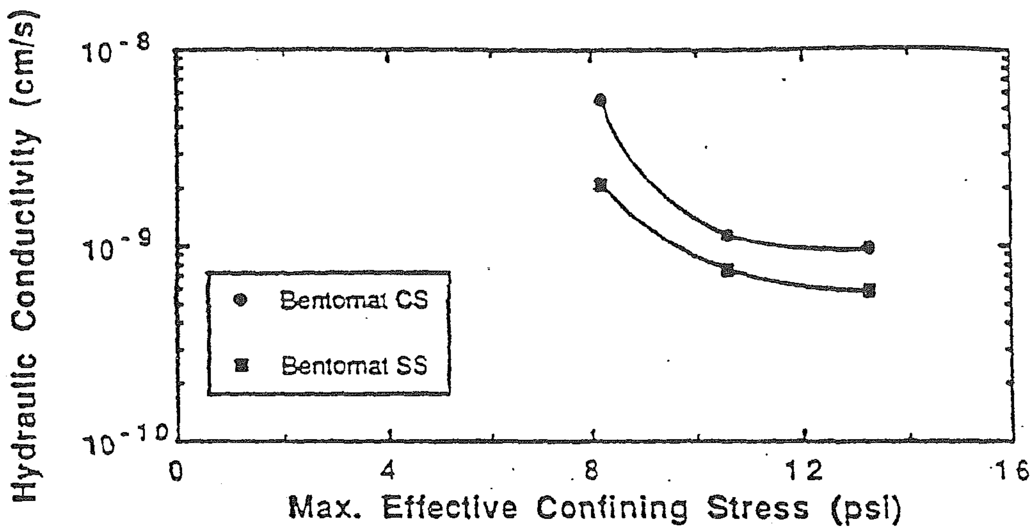

Fig. 2.2 Results of Flexible-Wall Hydraulic Conductivity Tests on Bentomat® (J&L Testing Company, 1990)

5.0 psi (35 kPa) and an average hydraulic gradient of approximately 160). The steady-state hydraulic conductivity, after two months of testing and 2.3 pore volumes of flow, was approximately 2×10^{-9} cm/s using the de-aired water and approximately 2.5×10^{-9} cm/s using the landfill leachate. The results seem to indicate that Bentomat® samples that have been hydrated first with de-aired water will have very little increase in hydraulic conductivity after the introduction of landfill leachate.

2.1.2.3 Effects of Desiccation on Bentomat®

GeoSyntec Consultants (1991a) conducted a flexible-wall hydraulic conductivity test on a 2.8-in (70-mm) sample of Bentomat® that had undergone 4 desiccation cycles. Each cycle involved first permeating the sample with de-aired water (using an effective stress of 5.0 psi (34 kPa) and an average hydraulic gradient of approximately 25) then desiccating the sample for two weeks in a 40°C (104°F) oven. This procedure was repeated 4 times. The steady-state hydraulic conductivity, measured after each cycle, ranged sporadically between 1×10^{-9} cm/s and 3×10^{-9} cm/s. The results show little effect of desiccation on the hydraulic conductivity of Bentomat®.

2.2.2 Available Laboratory Test Data on the Hydraulic Properties of Claymax®

2.2.2.1 Claymax® Permeation with Water

Literature published by the James Clem Corporation lists 2×10^{-10} cm/s as the hydraulic conductivity of Claymax® permeated with de-aired water. A summary of published measurements of the hydraulic conductivity of Claymax® to water is given in Table 2.4. Results are plotted in Fig. 2.5 in terms of hydraulic conductivity versus effective confining stress. The results show that the hydraulic conductivity to water varies from just under about 1×10^{-8} cm/s at low effective stress to just above 1×10^{-10} cm/s at high effective stress.

2.2.2.2 Claymax® Permeation with Various Liquid and Chemical Leachates

The information available concerning hydraulic conductivity of Claymax® permeated with liquids other than water is summarized in Table 2.5. All of the test specimens that were hydrated with water and then permeated with chemicals maintained a hydraulic conductivity $\leq 1 \times 10^{-8}$ cm/s, even for compounds such as diesel fuel and heptane that would normally be very aggressive to soil liner materials. Brown, Thomas, and Green (1984), for example, found that the

Table 2.4 Results of Hydraulic Conductivity Tests on Claymax® Permeated with Water

Source of Information	Permeameter	Backpressure Saturation?	Permeant Water	Diameter of Sample (in.)	Effective Stress (psi)	Hydraulic Conductivity (cm/s)
Clem Corp. Literature	- -	- -	Deaired Water	- -	- -	2×10^{-10}
Chen-Northern (1988)	Flex. Wall	Yes	- -	2.5	3.5	2×10^{-9}
GeoServices (1988a)	Flex. Wall	Yes	Deaired Tap Water	2.8	29	4×10^{-10}
GeoServices (1989c)	Flex. Wall	Yes	Deaired Tap Water	2.8	30	8×10^{-10}
GeoServices (1989c)	Flex. Wall	Yes	Deaired Tap Water	2.8	30	8×10^{-10}
GeoServices (1989c)	Flex. Wall	Yes	Deaired Tap Water	2.8	30	3×10^{-10}
GeoServices (1989c)	Flex. Wall	Yes	Deaired Tap Water	2.8	30	7×10^{-10}
Shan (1990)	Flex. Wall	No	Distilled Water	4.0	2	2×10^{-9}
Shan (1990)	Flex. Wall	No	Tap Water	4.0	2	2×10^{-9}
Shan (1990)	Flex. Wall	No	Distilled Water	4.0	5	1×10^{-9}
Shan (1990)	Flex. Wall	No	Tap Water	4.0	5	8×10^{-10}
Shan (1990)	Flex. Wall	No	Distilled Water	4.0	10	6×10^{-10}
Shan (1990)	Flex. Wall	No	Distilled Water	4.0	20	3×10^{-10}
Shan (Unpub.)	Flex. Wall	Yes	Tap Water	12	2	2×10^{-9}
GeoServices (1990b)	Flex. Wall	Yes	Deaired Water	- -	30	3×10^{-10}
GeoSyntec (1990a)	Flex. Wall	Yes	Deaired Water	- -	1.0	2×10^{-9}
GeoSyntec (1990a)	Flex. Wall	Yes	Deaired Water	- -	1.5	4×10^{-9}

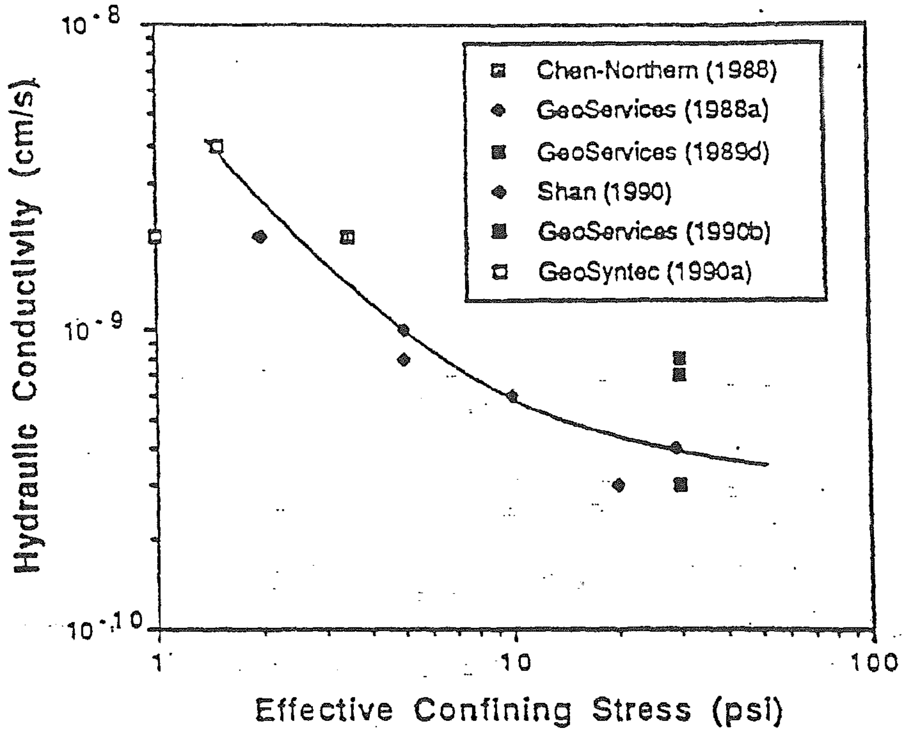

Fig. 2.5 Results of Hydraulic Conductivity Tests on Claymax® Permeated with Water

Table 2.5 Hydraulic Conductivity of Claymax® Permeated with Various Liquids

Source of Information	Permeant Liquid	Hydration Liquid	Pore Volumes of Flow	Effective Stress (psi)	Hydraulic Conductivity (cm/s)
STS Consultants (1988b)	Sewage Leachate	Sewage Leachate	- -	- -	8×10^{-10}
STS Consultants (1988c)	Paper Pulp Sludge	Paper Pulp Sludge	- -	- -	2×10^{-10}
GeoServices (1988b)	Simulated Seawater	Simulated Seawater	- -	30	2×10^{-10}
STS Consultants (1989a)	Landfill Leachate	Landfill Leachate	- -	- -	4×10^{-10}
STS Consultants (1989b)	Ash-Fill Leachate	Ash-Fill Leachate	- -	- -	1×10^{-10}
GeoServices (1989c)	Diesel Fuel	Water	1.5	30	9×10^{-10}
GeoServices (1989c)	Jet Fuel	Water	2.5	30	9×10^{-10}
GeoServices (1989c)	Unleaded Gasoline	Water	1.6	30	3×10^{-10}
Shan (1990)	50% (Vol) Methanol	Water	2.2	5	9×10^{-10}
Shan (1990)	Heptane	Water	0.2	5	1×10^{-10}
Shan (1990)	Sulfuric Acid	Water	3.1	5	6×10^{-11}
Shan (1990)	0.01 N $CaSO_4$	Water	2.2	5	1×10^{-9}
Shan (1990)	0.5 N $CaCl_2$	Water	24	5	8×10^{-9}
Shan (Unpublished)	50% (Vol) Methanol	50% Methanol	4	5	5×10^{-6}
Shan (Unpublished)	Methanol	Methanol	5.4	5	3×10^{-5}
Shan (Unpublished)	Heptane	Heptane	4.3	5	5×10^{-5}
GeoServices (1990a)	Methyl Tertiary Butyl Ether	Deaired Water	1.6	30	7×10^{-10}
Klohn Leonoff (1990)	Solution from Goldmine	Solution from Goldmine	1.8	17.4	2×10^{-10}
GeoSyntec (1991b)	Landfill Leachate	Deaired Water	1.7	5	3×10^{-9}

hydraulic conductivity of a compacted, micaceous soil was 1 to 4 orders of magnitude higher to kerosene, diesel fuel, and gasoline than it was to water. The inconsistency of results reported in Table 2.5 to the research conducted by Brown and his co-workers may be related to either a small cumulative pore volumes of flow in the tests on Claymax® or application of a high compressive stress to the test specimens. The cumulative pore volumes of flow of permeant liquid was not reported in many of the test referenced in Table 2.5; in many cases, there was probably an insufficient quantity of flow to determine the full effects of the permeant liquids. In some tests, a large effective confining stress was used. Broderick and Daniel (1990) found that one compacted clay was vulnerable to significant alterations in hydraulic conductivity when compressive stresses were ≤ 5 - 10 psi (34 - 69 kPa) but did not undergo an increase in hydraulic conductivity when the specimens were permeated with compressive stresses larger than 5 to 10 psi (34 to 69 kPa). Brown and his co-workers applied no compressive stress to their test specimens.

Tests on specimens of Claymax® that were hydrated with the same liquid as the eventual permeant liquid (rather than water) showed mixed results. For leachates, a paper pulp sludge, and simulated seawater, the hydraulic conductivity was found to be $< 1 \times 10^{-9}$ cm/s. However, the significance of these results is questionable because the duration of the tests was short, the cumulative pore volumes of flow was not reported, and the applied compressive stress was not reported. In as-yet unpublished tests by Shan, markedly different results were obtained when Claymax® was not prehydrated with water. Shan found that when dry Claymax® was permeated directly with a 50% mixture of water and methanol, with pure methanol, or with heptane, the bentonite did not hydrate even after several pore volumes of flow, and the hydraulic conductivity did not drop below 1 x 10^{-6} cm/s. Shan used a compressive stress of 5 psi (34 kPa). Thus, with concentrated organic liquids, the conditions of hydration appear to play an important role in determining the ability of the bentonitic blanket to resist the deleterious action of organic chemicals. The bentonite appears to be more chemically resistant if hydrated with fresh water before exposure to concentrated organic chemicals.

2.2.2.3 Effects of Desiccation on Claymax®

The effects of desiccation were investigated by GeoServices (1989d). Three hydrated samples of Claymax® were placed in a temperature- and humidity-controlled chamber. The chambers operated on a timed cycle to simulate day and night conditions. The temperature and humidity during thick HDPE geomebrane, was the material tested during this study.

2.3.2 Available Laboratory Test Data of the Hydraulic Properties of Paraseal and Gundseal

2.3.2.1 Paraseal Permeation with Water

Pittsburgh Testing Laboratory (1985) conducted a hydraulic conductivity test on a 2.5-in (64-mm) diameter sample of Paraseal. A 15-ft (4.6-m) head of water was applied to the sample, which was soaked for 5 days prior to permeation. A single, falling-head test was performed, which yielded a hydraulic conductivity reported to be 4 x 10^{-10} cm/s. Further details of the test procedures are not available. However, because the direction of flow was apparently through the HDPE membrane, the test may have provided a measure of sidewall leakage rather than flow through the material.

2.3.2.2 Gundseal Permeation with Chemical Leachates

The hydraulic conductivity of Gundseal permeated with landfill leachate was measured by GeoSyntec Consultants (1991c). A grid of 0.12-in (3-mm) diameter holes on 0.3 in (0.75 cm) centers were drilled into the Gundseal test samples in order to effectively test the bentonite portion of the Gundseal product. Three 2.8-in (70-mm) diameter samples were placed in flexible-wall permeameters and subjected to an effective stress of 5.0 psi (35 kPa). The test specimens were permeated, first with de-aired water then with leachate. The average hydraulic gradient applied during permeation with de-aired water was 50. The hydraulic gradient was increased to 230 during permeation with the leachate in order to increase flow through the Gundseal. The average hydraulic conductivity of the punctured Gundseal specimens was 1 x 10^{-9} cm/s for both the de-aired water and the leachate after approximately 1.2 pore volumes of flow. The hydraulic conductivity of the prehydrated bentonite appeared unaffected by the introduction of the leachate.

2.3.2.3 Effects of Desiccation on Gundseal

GeoSyntec Consultants (1991c) measured the hydraulic conductivity of a sample of Gundseal that had undergone 4 desiccation cycles. The 2.8-in (70-mm) diameter sample was punctured with small holes in the same grid pattern as the samples described previously. The test sample was permeated with de-aired water in a flexible-wall permeameter under an effective stress of 5.0 psi (34 kPa) and an average hydraulic gradient of 215 in order to determine hydraulic conductivity. The sample was removed from the permeameter, subjected to a 0.4 psi (3 kPa) confining stress, and placed in an oven for two

2.5 <u>Summary of Hydraulic Properties of Bentomat®, Claymax®, and Paraseal/Gundseal</u>

Table 2.10 is an abridged summary of the hydraulic conductivity data of Bentomat®, Claymax®, and Paraseal/Gundseal. The table includes results from tests conducted by GeoSyntec (1991a,b,c), GeoSyntec (1990b), and Shan (1990). Results from hydraulic conductivity tests conducted by other laboratories have not been included in Table 2.10 in order to present the information in a simplified and consise form.

Table 2.10 Summary of Hydraulic Conductivity Tests on Bentomat®, Claymax®, and Paraseal/Gundseal

	Bentomat®			Claymax®			Paraseal/Gundseal		
Sample	Reference	Effective Stress (psi)	Hydraulic Conductivity (cm/s)	Reference	Effective Stress (psi)	Hydraulic Conductivity (cm/s)	Reference	Effective Stress (psi)	Hydraulic Conductivity (cm/s)
Sample Permeated with Deaired Water	GeoSyntec (1991a)	2.0	2.0 x 10^{-9}	GeoSyntec (1991b)	2.0	1.8 x 10^{-9}	GeoSyntec (1991c)	5.0	1 x 10^{-9}
☆ Sample Permeated with Landfill Leachate	GeoSyntec (1991a)	5.0	2.5 x 10^{-9}	GeoSyntec (1991b)	5.0	2.8 x 10^{-9}	GeoSyntec (1991c)	5.0	1 x 10^{-9}
Desiccated Sample	GeoSyntec (1991a)	5.0	1.0 x 10^{-9} to 3.0 x 10^{-9}	Shan (1990)	2.0	2.0 x 10^{-9}	GeoSyntec (1991c)	5.0	5.0 x 10^{-10} to 2.0 x 10^{-9}
Freeze-Thaw Sample	GeoSyntec (1991a)	5.0	1.0 x 10^{-9} to 6.0 x 10^{-9}	Shan (1990)	2.0	2.2 x 10^{-9}	GeoSyntec (1991c)	- -	1.0 x 10^{-9}
Damaged Sample									
1-in diameter hole	GeoSyntec (1991a)	- -	1.3 x 10^{-4}	Shan (1990)(1)	2.0	5.0 x 10^{-9}	GeoSyntec (1991c)	- -	1.0 x 10^{-3}
2-in diameter hole		- -	1.7 x 10^{-4}		- -	- -		- -	1.0 x 10^{-3}
3-in long slit		- -	3.0 x 10^{-5}		- -	- -		- -	1.0 x 10^{-3}
Composite Sample	GeoSyntec (1991a)	- -	3.0 x 10^{-9}	Shan (1990)	2.0	4.0 x 10^{-9}	GeoSyntec (1991c)	- -	2.0 x 10^{-9}
Overlapped Seam Sample	GeoSyntec (1991a)	- -	6.0 x 10^{-7} to 2.0 x 10^{-5}	GeoSyntec (1990b)	1.0	2.0 x 10^{-9}	GeoSyntec (1991c)	- -	5.0 x 10^{-8}

(1) The damaged Claymax® sample tested by Shan (1990) was punctured with 3 - 1 inch diameter holes.

18903

Report

. roject

HYDRAULIC CONDUCTIVITY AND
COMPATIBILITY TESTING OF CLAYMAX
BALTIMORE COUNTY LANDFILL PROJECT
TOWNSON, MARYLAND

Client

CLEM ENVIRONMENTAL CORPORATION
444 NORTH MICHIGAN AVENUE, SUITE 1610
CHICAGO, IL 60611

Project # 25868-XH

Date MAY 11, 1989

STS Consultants Ltd.
Consulting Engineers
111 Pfingsten Road

HYDRAULIC CONDUCTIVITY AND COMPATIBILITY TESTING OF CLAYMAX
BALTIMORE COUNTY LANDFILL PROJECT
TOWNSON, MARYLAND

SCOPE OF SERVICES

STS was to perform two hydraulic conductivity tests on sections of Claymax liner material in conjunction with a six inch sand layer utilizing leachates as the hydration medium and the permeants. The Claymax specimens were supplied to STS by Clem Environmental and the leachate specimens were obtained from L.A. Solamen. Inc. All testing materials were delivered to our Northbrook Testing Facility.

Test Equipment

The equipment used in the compatibility study was a triaxial compression permeameter. This equipment incorporates the use of a flexible membrane, preventing sidewall seepage. back pressure to facilitate specimen saturation small diameter burettes making measurement of small volumes of collected permeant possible and the system is closed preventing the permeant from being exposed to the surrounding air.

Specimen Construction

Each of the specimens, utilized throughout the testing program, consisted of an approximately six inch cylindrical column of silica sand on top of which a circular section of Claymax was placed. The orientation of the Claymax to the sand provided for permeant flow initiated through the sand followed by the Claymax section. The directional flow of the permeant. is similar to those conditions found in the field applications.

Once the specimens were assembled, a flexible rubber membrane was used to encase the specimens while sealed in the triaxial permeameter chamber.

Test Procedures

After its initial construction and placement in a triaxial compression permeameter each of the specimens is backpressure saturated. To aide in specimen saturation, carbon dioxide gas was allowed to flow freely through the test specimen, inundating the voids in the sand and dry Claymax. The use of this carbon dioxide gas has been accepted as a procedure to aide in specimen saturation. The carbon dioxide gas will go into solution more readily than normal atmospheric air. Once it was determined that the carbon dioxide gas had completely inundated the voids of the test specimen, the permeants were allowed to free flow through the test specimen first saturating the silica sand and then the Claymax section. For this study, the leachates were utilized both as a set hydrating medium and as the actual permeant for the hydraulic conductivity determination.

Two leachates were used during the study. The first was labeled Parkton Landfill and the second labeled as Eastern Sanitary Landfill. It is the understanding of STS Consultants that the two leachates were a municipal landfill leachate and contained such things as heavy metals, phenals, cyanide, copper, phosphorus and other substances.

Once the leachate had fully hydrated the test specimen, the specimen was allowed to stand for a 24 hour hydration period. Following the hydration period, the backpressure saturation techniques were implemented to complete the saturation procedures. This was accomplished by simultaneously increasing the cell and back pressures in increments while maintaining a pressure differential of 0.125 kilograms per square centimeter (KSC). Pressures were incrimentally increased until obtaining testing pressures of 4.125 KSC cell pressure and 4.00 KSC back pressure.

Specimen saturation was considered complete when a Skempton's Pore Pressure B-parameter of 0.95 or greater was obtained. The "B" parameter is simply a ratio of an increase in pore water pressure to a simultaneous increase in confining pressure. When full specimen saturation was determined, permeant flow was initiated through the bottom of the test specimen, allowed to flow through the top of the test specimen and collect in a calibrated burette. The test was performed utilizing two separate gradients. The initial gradient consisted of an application of a hydraulic head of one foot. The second gradient was applied as a hydraulic head equivalent to 35 feet.

During the entire test, permeant volume versus time measurements were recorded and the hydraulic conductivity of the test specimen at the two gradients was determined. The test was allowed to continue until it had been determined that a minimum of three pore volumes of pore fluid had passed through the test specimen. Once this had occurred and steady state flow had been established. the test was terminated.

Laboratory Test Results

As a result of the testing as outlined above, the Claymax section utilizing the Parkton Landfill Leachate, as the permeant, obtained hydraulic conductivity values of 2×10^{-10} centimeters per second (cm/sec) for a hydraulic head of one foot and 4×10^{-10} cm/sec for a hydraulic head of 35 feet. The Claymax section exposed to the Eastern Sanitary Landfill leachate obtain hydraulic conductivity values of 3 x 10 -10 cm/sec utilizing a hydraulic head of 1 foot and 4×10^{-10} cm/sec utilizing a hydraulic head of 35 feet. A summary of specific specimen characteristics and final hydraulic conductivity values is attached to this report.

STS Consultants Ltd.

STS PROJECT NO. 25868-XH

PROJECT Baltimore County Landfill Project

DATE 4-24-89

SUMMARY OF HYDRAULIC CONDUCTIVITY TESTS

Permeant	Parkton Landfill	Eastern Sanitary Landfill
Sample No.	1	2
Classification	Claymax with 6" Silica Sand	Claymax with 6" Silica Sand
[illegible]y Unit [illegible]ght (pcf)	51.6	62.5
Water Content (%)	Dry	Dry
Diameter (cm)	7.028	7.026
Length (cm)	0.568	0.616
Saturation B Value	0.97	0.99
Hydraulic Conductivity k (cm/sec)	1 ft. 2×10^{-10} 35 ft. 4×10^{-10}	1 ft. 3×10^{-10} 35 ft. 4×10^{-10}

Dennis F. Rasmussen
County Executive

Rev: 12/87

BALTIMORE COUNTY
WASTEWATER MONITORING AND ANALYSIS DIVISION
INDUSTRIAL DISCHARGE CONTROL PROGRAM

SAMPLING/ANALYSIS FORM   Sample No.: 9 01110

Industry Name: EASTERN SANITARY LANDFILL   Facility No.:

Address: Days Cove Road

Telephone: Requested by: P. Phillips

Sampling Site Location: Leachate pit

Special Instructions: STD 5, metals, Total alkalinity & Chlorides

FIELD

Date and Time of Sampling: Start 1/18/89 10:20 a.m.   Finish

Sampled by: P. Phillips, T.E. Ryan

Type of Sample: Grab

Sampler Settings: N/A

Sample Characteristics: 1 quart: dark gray; 1 quart: dark brown

Preservatives Added: Cooled with ice

Comments and Observations:

Delivered to Lab by: PP, TER   Date: 1/18/89   Time: 11:50 a.m.

LABORATORY

Sample received by: WP   Date: 1/18/89   Time: 11:50 a.m.

Characteristics of Note:

(Origin of Seed: Polyseed)

ANALYTICAL RESULTS

Code	BDL	Parameter	Conc. (mg/L)	Code	BDL	Parameter	Conc. (mg/L)
		pH	6.3	3011	0.05	Ni (Nickel)	BDL
		BOD	122 mg/L	3015	0.01	Zn (Zinc)	0.05 mg/L
		COD	148 mg/L	3130		Phenols	
		TSS	125 mg/L	3013	0.01	Silver	BDL
5012		FOG - A&V					
5013		FOG - Petr		*		GRAB pH	
2026		P(Phosphorus)	2.52 mg/L				
3006	0.01	Cd(Cadmium)	BDL			Total Fe	3.88 mg/L
3007	0.05	Cr(Chromium)	BDL			Total alkalinity	350 mg/L
3008	0.02	Cu(Copper)	0.04 mg/L			Chloride	80 mg/L
4		Cn(Cyanide)					
3009	0.10	Pb (Lead)	0.36 mg/L				

Rev: 12/87

BALTIMORE COUNTY
WASTEWATER MONITORING AND ANALYSIS DIVISION
INDUSTRIAL DISCHARGE CONTROL PROGRAM

Dennis F. Rasmussen
County Executive

SAMPLING/ANALYSIS FORM

Sample No.: 9 02104

Industry Name: PARKTON Facility No.:

Address:

Telephone: Requested by: R. Much

Sampling Site Location: Cell #3

Special Instructions: pH, BOD, COD, TSS, Alkalinity, Chloride, Metals

FIELD

Date and Time of Sampling: Start 2/9/89 Finish

Sampled by: R. Much, B. Kramer

Type of Sample: Grab

Sampler Settings:

Sample Characteristics:

Preservatives Added:

Comments and Observations:

Delivered to Lab by: BK, RM Date: 2/9/89 Time: 2:20 P.M.

LABORATORY

Sample received by: WP Date: 2/9/89 Time: 2:20 P.M.

Characteristics of Note:

(Origin of Seed: Polyseed)

ANALYTICAL RESULTS

Code	BDL	Parameter	Conc. (mg/L)	Code	BDL	Parameter	Conc. (mg/L)
		pH	6.1	3011	0.05	Ni (Nickel)	1.44 mg/L
		BOD	38,888 mg/L	3015	0.01	Zn (Zinc)	5.45 mg/
		COD	60,831 mg/L	3130		Phenols	
		TSS	691 mg/L	3013	0.01	Silver	0.03 mg/L
012		FOG - A&V					
013		FOG - Petr		*		GRAB pH	
026		P(Phosphorus)	Interference				
006	0.01	Cd(Cadmium)	0.10 mg/L			Total Fe	736.00 mg/L
007	0.05	Cr(Chromium)	0.22 mg/L			Total alkalinity	15,000 mg/L
008	0.02	Cu(Copper)	0.17 mg/L			Chloride	1,500 mg/L
002		Cn(Cyanide)					
009	0.10	Pb (Lead)	0.60 mg/L				

ATTACHMENT III.3.E

HDPE PIPE REFERENCE DOCUMENTATION

Chemical Resistance of Plastics and Elastomers Used in Pipeline Construction

1. Introduction

It is now inconceivable to construct pipelines without the use of plastics. Pipes made from plastics are used not only for drinking water, water for general use and waste water, but also for the conveyance of aggressive liquids and gases. Expensive pipe materials such as lined metal, ceramic or glass, have been largely superseded by plastic pipes. It is, however, important that the most suitable plastic material is selected for each application. This "Chemical Resistance List" serves as a useful guide in this respect. The list is periodically revised to include the latest findings. It contains all plastics and elastomers in the George Fischer product range which can come into direct contact with the media.

The information is based on experiments, immersion and, when available, on data from tests which include temperature and pressure as stress factors. The results achieved in immersion experiments cannot be applied without reservation to pipes under stress, i.e. internal pressure, as the factor "stress corrosion cracking" is not taken into consideration. In certain cases it can be of advantage to test the suitability under the planned working conditions. The tests referred to have been carried out partly by George Fischer and partly by the International Standardization Organization (ISO) or national standards organizations.

Pure chemicals were used for the tests. If a mixture of chemicals is to be conveyed in practice this may affect the chemical resistance of the plastic. It is possible in special cases to carry out appropriate tests with the specific mixture. Suitable test equipment is available at George Fischer for this purpose, which we regard as part of our service to the customer. It goes without saying that we are willing to give individual advice at any time. In this connection it is worth mentioning that George Fischer already possesses information concerning the behavior towards plastics of a number of chemicals or mixtures of chemicals which are not yet included in this list. The "Chemical Resistance List" gives valuable assistance in the planning of plastic pipelines. Please refer to the following instructions, which are important for the application and evaluation of this list.

2. Instructions for the Use of the Chemical Resistance List

2.1 General

As stated in the introduction, the "Chemical Resistance List" is only intended as a guide. Changes in the composition of the medium or special working conditions could lead to deviations. If there is any doubt, it is advisable to test the behavior of the material under the specific working conditions, by means of a pilot installation. No guarantees can be given in respect of the information contained in this booklet. The data shown is based upon information available at the time of printing, but it may, however, be revised from time to time in the light of subsequent research and experience.

2.2 Classification

The customary classifications: **resistant, conditionally resistant** and **not recommended** are depicted by the signs: +, O, and –, which allow simple presentation and application. These classifications are defined as:

Resistant: +
Within the acceptable limits of pressure and temperature the material is unaffected or only insignificantly affected.

Conditionally Resistant: O
The medium can attack the material or cause swelling. Restrictions must be made in regard to pressure and/or temperature, taking the expected service life into account. The service life of the installation can be noticeably shortened. Further consultation with George Fischer is recommended.

Not recommended: –
The material cannot be used with the medium at all, or only under special conditions.

(Courtesy George Fischer Engineering Handbook)

2.3 Pipe Joints

2.3.1 Solvent Cement Joints (PVC)

Solvent cement joints made with standard PVC cement and primer systems are generally as resistant as the PVC material itself. The following chemicals are, however, an exception:

- Sulphuric acid H_2SO_4 in concentrations above 70 percent
- Hydrochloric acid HCl in concentrations above 25 percent
- Nitric acid HNO_3 in concentrations above 20 percent

Hydrofluoric acid in any concentration In conjunction with the above media the solvent cement joining is classified as "conditionally resistant". Previously recommended solvent cement (Dytex, by Henkel, Germany) used for pipe and fittings to carry concentrated acids, can no longer be brought into the United States because of its methylene chloride solvent system being classified as a carcinogen. There is no known domestically available substitute. Special consideration should be given to the possible attack of the cemented joints by these concentrated acids.

2.3.2 Fusion Joints

In the case of PE, PP, and PVDF (SYGEF®) heat fusion joints have practically the same chemical resistance as the respective material. In conjunction with media which could cause stress cracking, the fused joints can be subjected to an increased risk due to residual stress from the joining process.

2.4 Sealing Materials

Depending upon the working conditions and the stress involved, the life span of the sealing materials can differ from that of the pipeline material. Seals in PTFE, which are not included in this list, are resistant to all the chemicals indicated. The greater permeability of PTFE should, however, be considered. Under certain working conditions, for example when conveying highly aggressive media such as hydrochloric acid, this material characteristic must be taken into account.

2.5 General Summary and Limits of Application

The following table includes all the materials contained in the George Fischer product range, and their abbreviations. The summary gives preliminary information regarding the general behavior of the materials and the temperature limits.

2.6 Standards

This list has been compiled with reference to the following ISO standards:

ISO/TR 7473
Unplasticized polyvinyl chloride pipes and fittings – Chemical resistance with respect to fluids.

ISO/TR 7474
High density polyethylene pipes and fittings – Chemical resistance with respect to fluids to be conveyed.

ISO/TR 7471
Polypropylene (PP) pipes and fittings – Chemical resistance with respect to fluids.

ISO TR 10358
Plastic pipes and fittings – Combined chemical resistance classification table.

DVS 2205 Part I
Calculations for thermoplastic containers and appliances.

DIN 8080 Supplement 1 «Pipes of chlorinated polyvinyl chloride (PVC-C), PVC-C 250 – Chemical Resistance».

(Courtesy George Fischer Engineering Handbook)

Material	Abbreviation	Remarks	Maximum Permissible Temperature (Water) °C	
			Constant	Short Term
Polyvinyl Chloride	PVC	Resistant to most solutions of acids, alkalis and salts and to organic compounds miscible with water. Not resistant to aromatic and chlorinated hydrocarbons	60°	60°
Chlorinated Polyvinyl Chloride	CPVC	Can be used similarly to PVC but at higher temperatures. Consult factory for specific applications.	90°	110°
High-density Polyethylene	PE 50	Resistant to hydrous solutions of acids, alkalis and salts as well as to a large number of organic solvents. Unsuitable for concentrated oxidizing acids.	60°	80°
Polypropylene, heat stabilized	PP	Chemical resistance similar to that of PE but suitable for higher temperatures	90°	110°
Polyvinylidene Fluoride	PVDF (SYGEF®)	Resistant to acids, solutions of salts, aliphatic, aromatic and chlorinated hydrocarbons, alcohols and halogens. Conditionally suitable for ketones, esters, organic bases and alkaline solutions	140°	150°
Polybutylene-1	PB	Similar to PE 50, but can be used up to 90°C	90°	100°
Polyoxymethylene	POM	Resistant to most solvents and hydrous alkalis. Unsuitable for acids	60°	80°
Polytetrafluoroethylene (e.g. Teflon®)	PTFE	Resistant to all chemicals in this list	250°	300°
Nitrile Rubber	NBR	Good resistance to oil and petrol. Unsuitable for oxidizing media	90°	120°
Butyl Rubber Ethylene Propylene Rubber	IIR EPDM	Good resistance to ozone and weather. Especially suitable for aggressive chemicals. Unsuitable for oils and fats	90°	120°
Chloroprene Rubber (e.g. Neoprene®)	CR	Chemical resistance very similar to that of PVC-U and between that of Nitrile and Butyl Rubber	80°	110°
Fluorine Rubber (e.g. Viton®)	FPM	Has best chemical resistance to solvents of all elastomers	150°	200°
Chlorine Sulphonyl Polyethylene (e.g. Hypalon®)	CSM	Chemical resistance similar to that of EPDM	100°	140°

®Registered trade name

The abbreviations listed below are found throughout the listings and have the following definition:

Q/E (Quellung/Erweichung) = swelling/softening
D/P (Diffusion/Permeation) = diffusion/permeation
SpRB (Spannungsrissbildung) = environmental stress cracking

(Courtesy George Fischer Engineering Handbook)

Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Acetaldehyde	CH_3-CHO (C_2H_4O)	21	technically pure	20	-	-	-	+	O	-		+	O	-	-	O
				40				O	-			O	-			-
				60								-				
				80												
				100												
				120												
				140												
Acetaldehyde			40%, aqueous solution	20	O	-	-	+	+	-		+	+	-	+	+
				40	-			+	+			+	+		+	+
				60				O	+			+	O		O	+
				80					O			+	-		-	+
				100					-							
				120												
				140												
Acetic acid (SpRB)	CH_3COOH	118	technically pure, glacial	20	O	-	-	+	+	+		O	-	-	O	O
				40	-			+	+	O						
				60				O	O	-						
				80					-							
				100												
				120												
				140												
Acetic acid (SpRB)	CH_3COOH		10%, aqueous	20	+	+	+	+	+	+		+	O	+	+	O
				40	+	+	+	+	+	+		+	-	O	+	-
				60	O	+	O	+	+	+		O			O	
				80		+			+	+						
				100					+	+						
				120						+						
				140												
Acetic acid (SpRB)			50%, aqueous	20	+	+	-	+	+	+		+	O	-	O	O
				40	+			+	+	+						
				60	O			+	+	+						
				80						O						
				100						O						
				120												
				140												
Acetic acid (SpRB)	CH_3COOH		60%	20	+	-	-	+	+	+		+				
				40												
				60												
				80												
				100												
				120												
				140												
Acetic acid (SpRB)		118	98%	20	-	-	-	+	+	+		O	-			
				40												
				60												
				80												
				100												
				120												
				140												
Acetic acid anhydride (SpRB)	$(CH_3\text{-}CO)_2O$	139	technically pure	20	-	-	-	+	+	-		O	-	-	-	+
				40				O	O							
				60												
				80												
				100												
				120												
				140												

(Courtesy George Fischer Engineering Handbook)

Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Acetic acid isobutyl ester	$(CH_2)_2$-CH-$(CH_2)_2$-CO_2H		technically pure	20						-						
				40												
				60												
				80												
				100												
				120												
				140												
Acetone	CH_3-CO-CH_3	56	technically pure	20	-	-	-	+	+	-		+	-	-	-	O
				40				+	+			+				O
				60				+	+			+				O
				80												
				100												
				120												
				140												
Acetone			up to 10%, aqueous	20	-	-	O	+	+	O		+	O	-	+	O
				40				+	+	O		+	O		O	O
				60				+	+	O		+	-		-	O
				80												
				100												
				120												
				140												
Acetonitrile	CH_3CN	81.6	100%	20	-	-	-			-						
				40												
				60												
				80												
				100												
				120												
				140												
Acetophenone	CH_3-CO-C_6H_5		100 %	20	-	-	-			-		+	-	-	-	
				40												
				60												
				80												
				100												
				120												
				140												
Acrylic acid methyl ester	CH_2=$CHCOOCH_3$	80.3	technically pure	20	-	-	-			+		O				
				40												
				60												
				80												
				100												
				120												
				140												
Acrylic ester	CH_2=CH-COO CH_2CH_3	100	technically pure	20	-	-	-		-	-		O	-	-	O	+
				40												
				60												
				80												
				100												
				120												
				140												
Acrylonitrile	CH_2=CH-CN	77	technically pure	20	-	-	-	+	+	-		+	O	-	+	O
				40				+	O			+	O		+	O
				60				+				O	-		+	-
				80												
				100												
				120												
				140												

(Courtesy George Fischer Engineering Handbook)

Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Adipic acid	HOOC-(CH$_2$)$_4$-COOH	Fp 153	saturated, aqueous	20	+	+	-	+	+	+		+	+	+	+	+
				40	+	+		+	+			+	+	+	+	+
				60	-	+		+	+			+	+	+	+	+
				80		+			+							
				100												
				120												
				140												
Aluni	see Potassium/ aluminium sulphate															
Alcoholic spirits (Gin, Whisky,etc.)			approx. 40% ethyl alcohol	20	+	O	-	+	+	+		+	+	+	+	+
				40												
				60												
				80												
				100												
				120												
				140												
Allyl alcohol	$H_2C=CH-CH_2-OH$	97	96%	20	O	O	-	+	+			O	O	+	O	+
				40	-			+	+			O	-	+	-	+
				60				+	+			O		+		+
				80								-		+		-
				100												
				120												
				140												
Aluminium chloride	$AlCl_3$		10%, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	+	+	+	+	+	+		+	+	O	+	+
				80		+				+		+	+			+
				100						+		+	+			
				120						+						
				140												
Aluminium chloride	$AlCl_3$	115	saturated	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	+	+	+	+	+	+		+	+	+	+	+
				80		+			+	+			+	O	+	+
				100					O	+			+	-		+
				120						+						
				140												
Aluminium fluoride	AlF_3		saturated	20		+				+						
				40		+				+						
				60		+				+						
				80						+						
				100												
				120												
				140												
Aluminium hydroxide	$Al(OH)_3$		Suspension	20		+						+				
				40		+						+				
				60		+						+				
				80		+										
				100												
				120												
				140												
Aluminium nitrate	$Al(NO_3)_3$		saturated	20		+				+		+				
				40		+				+		+				
				60		+				+		+				
				80		+										
				100												
				120												
				140												

(Courtesy George Fischer Engineering Handbook)

Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Aluminium sulphate	$Al_2(SO_4)_3$		10%, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	O	+	+	+	+	+		+	+	+	+	+
				80		+			+	+			+			O
				100					+	+						
				120						+						
				140												
Aluminium sulphate			cold saturated, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	+	+	+	+	+	+		+	+	+	+	O
				80		+			+	+			+			O
				100						+						
				120						+						
				140												
Ammonia (SpRB)	NH_3	-33	gaseous, technically pure	20	+	-	-	+	+	+		+	+	+	+	+
				40	+			+	+	+			O			
				60	+			+	+	O						
				80						O						
				100						O						
				120												
				140												
Ammonium acetate	CH_3COONH_4		aqueous, all	20	+	+	O	+	+	+		+	+	+	+	+
				40	+	+		+	+	+		+	+	O	+	+
				60	O	+		+	+	+		+	+		O	
				80		+			+	+		O				
				100					+	+						
				120												
				140												
Ammonium aluminium sulfate				20						+						
				40						+						
				60						+						
				80						+						
				100						+						
				120												
				140												
Ammonium bromide				20						+						
				40						+						
				60						+						
				80												
				100												
				120												
				140												
Ammonium carbonate	$(NH_4)_2CO_3$		50%, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	O	+	+	+	+	+		+	+	+	+	+
				80		+			+	+		+	+			+
				100					+	+						
				120						+						
				140												
Ammonium chloride	NH_4Cl	115	aqueous, cold saturated	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	O	+	+	+	+	+		+	+	+	+	+
				80		+			+	+		+	+		+	+
				100					+	+		+	+			+
				120						+			+			
				140												

(Courtesy George Fischer Engineering Handbook)

Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Ammonium citrate				20	+					+						
				40	+					+						
				60	+					+						
				80						+						
				100						+						
				120												
				140												
Ammonium dicromate	$(NH_4)_2 Cr_2 O_7$		saturated	20		+										
				40		+										
				60		+										
				80		+										
				100												
				120												
				140												
Ammonium dihydrogenphosphate				20	+			+	+							
				40	+			+	+							
				60	+			+	+							
				80					+							
				100												
				120												
				140												
Ammonium fluoride	NH_4F			20	+	+		+	+	+						
				40	+			+	+	+						
				60	+			+	+	+						
				80					+	+						
				100						+						
				120												
				140												
Ammonium formiate				20						+						
				40						+						
				60						+						
				80						+						
				100						+						
				120												
				140												
Ammonium hexafluorosilicate				20						+						
				40						+						
				60						+						
				80						+						
				100						+						
				120												
				140												
Ammonium hydrogen fluoride	NH_4HF_2		50%, aqueous	20	+	+	-	+	+	+		+	+			
				40	+	+		+	+	+						
				60	O	+		+	+	+						
				80												
				100												
				120												
				140												
Ammonium hydrogencarbonate				20	+			+	+							
				40	+			+	+							
				60	+			+	+							
				80					+							
				100												
				120												
				140												

(Courtesy George Fischer Engineering Handbook)

Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Ammonium hydrogenphosphate				20	+			+	+							
				40	+			+	+							
				60	+			+	+							
				80					+							
				100												
				120												
				140												
Ammonium hydrogensulfite				20						+						
				40						+						
				60						+						
				80						+						
				100						+						
				120												
				140												
Ammonium hydroxide	NH_4OH		aqueous, cold saturated	20	+	-	+		+	-		+	-	+	+	+
				40	+		+		+			+		O	+	+
				60	O		O		+			O		O	+	O
				80											O	
				100												
				120												
				140												
Ammonium nitrate	NH_4NO_3	112	aqueous, saturated	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	+	+	+	O	+	+		+	+	O		O
				80		+			O	+			+			
				100						+						
				120						+						
				140												
Ammonium oxalate	$H_4NOOC\text{-}COONH_4$			20						+		+				
				40						+						
				60						+						
				80						+						
				100						+						
				120												
				140												
Ammonium persulphate	$(NH_4)_2S_2O_8$			20		+				+						
				40		+				+						
				60		+				+						
				80		+				+						
				100						+						
				120												
				140												
Ammonium phosphate	$(NH_4)_3PO_4$		saturated	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	+	+	+	+	+	+			+	O	+	O
				80					+	+			+			
				100						+			+			
				120												
				140												
Ammonium sulphate	$(NH_4)_2SO_4$		aqueous, saturated	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	+	+	+	+	+	+		+	+	O	+	O
				80		+			+	+		+	+			
				100					+	+			+			
				120						+						
				140												

(Courtesy George Fischer Engineering Handbook)

Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Ammonium sulphide	$(NH_4)_2S$		aqueous, all	20	+	O	+	+	+	+		+	+	+	+	+
				40	+	O	+	+	+	+		+	O	+	+	+
				60	O	O	+	+	+	+		+	-	+	+	+
				80		-			+							
				100												
				120												
				140												
Ammonium tetrafluoroborate				20						+						
				40						+						
				60						+						
				80						+						
				100						+						
				120												
				140												
Ammonium thiocyanate	NH_4SCN		saturated	20		+				+						
				40		+				+						
				60		+				+						
				80		+										
				100												
				120												
				140												
Amyl acetate	$CH_3(CH_2)_4\text{-}COOCH_3$	141	technically pure	20	-	-	-	+	O	+		O	-	-	-	-
				40				+	O	O						
				60				+	-	O						
				80												
				100												
				120												
				140												
Amyl alcohol (SpRB)	$CH_3(CH_2)_3\text{-}CH_2\text{-}OH$	137	technically pure	20	+	+	-	+	+	+		+	O	+	+	O
				40	+	+		+	+	+		+		+	+	
				60	O	+		+	+	+		+		+	+	
				80					+	+						
				100						+						
				120						O						
				140												
Aniline	$C_6H_5NH_2$	182	technically pure	20	-	-	-	O	O	+		-	O	-	-	-
				40						O			O			
				60						-			O			
				80												
				100												
				120												
				140												
Aniline hydrochloride	C_6H_7N+HCl	245	aqueous, saturated	20	+	+	-	+	+	+		+	O	O	-	+
				40	O	+		+	+			+	-	-		+
				60				O	O			+				+
				80												O
				100												
				120												
				140												
Antimony thiocyanate				20						+						
				40						+						
				60						+						
				80						+						
				100						+						
				120												
				140												

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Aggressive Media					Chemical Resistance										
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)	EPDM	FPM	NBR	CR	CSM
Antimony trichloride (SpRB)	$SbCl_3$		90%, aqueous	20	+	+	-	+	+	+	+	+	-	+	+
				40	+			+	+	+					
				60				+	+	+					
				80											
				100											
				120											
				140											
Aqua regia (SpRB)	HNO_3+HCl			20	+	+	-	-	-	O	-	O	-	-	O
				40	O										
				60											
				80											
				100											
				120											
				140											
Arsenic acid	H_3AsO_4		80%, aqueous	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	O	+	+	+	+	+	+	+	+	+	+
				80		+			+	+	+	+	O	+	+
				100						+		+			
				120						+					
				140											
Barium carbonate	$BaCO_3$			20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+		+	+	+	+	+	+		
				60	+	+		+	+	+	+				
				80		+			+						
				100											
				120											
				140											
Barium chloride	$BaCl_2$		saturated	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+		+	+	+	+	+	+		
				60	+	+		+	+	+	+	+			
				80		+			+	+		+			
				100						+					
				120											
				140											
Barium hydroxide	$Ba(OH)_2$	102	aqueous, saturated	20	+	+	+	+	+	-	+	+	+	+	+
				40	+	+	+	+	+		+		+	+	O
				60	O	+	+	+	+		+		+	+	
				80		+			+		+				
				100											
				120											
				140											
Barium salts			aqueous, all	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	+	+	+	+	+	+	+	+	+	+	+
				80		+			+	+	+	+			
				100						+					
				120											
				140											
Barium sulfate	$BaSO_4$			20	+			+	+	+	+				
				40	+			+	+	+	+				
				60	+			+	+	+	+				
				80					+	+					
				100						+					
				120											
				140											

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Barium sulfide	BaS		suspension	20	+	+		+	+	+		+				
				40	+	+		+	+	+		+				
				60	+	+		+	+	+		+				
				80		+			+	+						
				100						+						
				120												
				140												
Battery acid	see Sulphuric acid 40%															
Beef tallow emulsion, sulphonated (Sp&B)			usual commercial	20	+	o	+	+	+	+		-	+	+	+	+
				40						+						
				60						+						
				80												
				100												
				120												
				140												
Beer			usual commercial	20	+	+	+	+	+	+			+	+	+	+
				40	+	+	+	+	+	+						
				60	+	+	+	+	+	+						
				80		+				+						
				100												
				120												
				140												
Benzaldehyde	C_6H_5-CHO	180	saturated, aqueous	20	-	-	-	+	+	+		+	+	O	-	-
				40				+		O		+	+			
				60				+		-		+	+			
				80												
				100												
				120												
				140												
Benzene	C_6H_6	80	technically pure	20	-	-	-	O	O	+		-	+	O	-	-
				40				O	-	O						
				60						-						
				80												
				100												
				120												
				140												
Benzenesulfonic acid	$C_6H_5SO_3H$		technically pure	20						+			+			
				40						+			+			
				60						+						
				80						+						
				100						+						
				120												
				140												
Benzoic acid	C_6H_5-COOH	Fp.*, 122	aqueous, all	20	+	+	+	+	+	+		+	+	-	-	-
				40	+	+	+	+	+	+		+	+			
				60	O	+		+	+	+			+			
				80		O			+	+			+			
				100					+	+			O			
				120						+						
				140												
Benzoyl chloride	$C_6H_5CHCl_2$		technically pure	20						+						
				40						+						
				60						+						
				80						O						
				100						-						
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Benzyl alcohol (SpRB)	C_6H_5-CH_2-OH	206	technically pure	20	O	-	-	+	+	+		-	+	-	+	O
				40				+	+	+					+	
				60				O	O	O					+	
				80						-						
				100												
				120												
				140												
Beryllium chloride				20						+						
				40						+						
				60						+						
				80												
				100												
				120												
				140												
Beryllium sulfate				20						+			+			
				40						+			+			
				60						+			+			
				80						+						
				100						+						
				120												
				140												
Borax	$Na_2B_4O_7$		aqueous, all	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	O	+		+	+	+		+	+	+	+	O
				80		+			+	+		+	+			
				100					+	+						
				120												
				140												
Boric acid	H_3BO_3		all, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	O	+	+	+	+	+		+	+	+	+	+
				80		+			+	+		+	+			
				100					+	+			+			
				120						+						
				140												
Brine, containing chlorine				20	+	+	-	+	O	+		O	+	O	O	O
				40	+	+				+						
				60	+	+				O						
				80												
				100												
				120												
				140												
Brombenzene	C_6H_5Br			20	-	-				+			+			
				40												
				60												
				80												
				100												
				120												
				140												
Bromine, liquid	Br_2	59	technically pure	20	-	-	-	-	-	+		-	+	-	-	-
				40						+						
				60						+						
				80						+						
				100						O						
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Bromine, vapours	Br_2		high	20	-	-	-	-	-	+		-	+	-	-	-
				40						+						
				60						+						
				80						+						
				100						O						
				120												
				140												
Bromine water	$Br.H_2O$		saturated, aqueous	20	+	o	-	-	-	+		-	+	-	-	-
				40						+						
				60						+						
				80						+						
				100												
				120												
				140												
Butadiene (Q/E)	$H_2C{=}CH{-}CH{=}CH_2$	-4	technically pure	20	+	+	-	+	+	+		-	O	-	+	+
				40					+	+					+	O
				60					+	+					O	-
				80						+						
				100						+						
				120												
				140												
Butane	C_4H_{10}	0	technically pure	20	+	+	+	+	+	+		-	+	+	+	+
				40												
				60												
				80												
				100												
				120												
				140												
Butanediol (SpRB)	$HO{-}(CH_2)_4{-}OH$	230	aqueous, 10%	20	+	+	-	+	+			+	+	+	O	+
				40	O	+		+	+			+	+	+	-	+
				60				+	+			+	+	+		+
				80												
				100												
				120												
				140												
Butanol (SpRB)	C_4H_9OH	117	technically pure	20	+	+	-	+	+	+		+	+	+	+	+
				40	+	+		+	+	+		+	O	+	+	+
				60	O	+		+	O	+		+	-	+	O	+
				80		O			-	+						
				100						O						
				120												
				140												
Butyl acetate	$CH_3COOCH_2CH_2CH_2CH_3$	126	technically pure	20	-	-	-	+	O	+		+	O	-	O	O
				40						O		-	-		-	-
				60						-						
				80												
				100												
				120												
				140												
Butyl phenol, p-tertiary	$(CH_3)_3C{-}C_6H_4{-}OH$	237	technically pure	20	O	O	-	O	+	+		-	O	-	-	-
				40	-	-				+						
				60						+						
				80						+						
				100												
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Butylene glycol (SpRB)	$HO\text{-}CH_2\text{-}CH{=}CH\text{-}CH_2\text{-}OH$	235	technically pure	20	+	+	+	+	+	+		+	+	-	+	O
				40	+	+	+	+	+	+		+	+		+	-
				60	O	+	+	+	+	+		+	O		+	
				80						+						
				100												
				120												
				140												
Butylene liquid	C_4H_8	51	technically pure	20	+			-	-	+		O	+	+	+	O
				40												
				60												
				80												
				100												
				120												
				140												
Butyric acid (SpRB)	$CH_3\text{-}CH_2\text{-}CH_2\text{-}COOH$	163	technically pure	20	+	+	-	+	+	+		O	O	-	O	O
				40				+		+						
				60				O		+						
				80						+						
				100						O						
				120												
				140												
Cadmium bromide	$CdBr_2$			20	+	+		+	+			+	+			
				40	+	+		+	+			+	+			
				60	+	+		+	+			+	+			
				80		+							+			
				100												
				120												
				140												
Cadmium chloride	$CdCl_2$			20	+	+		+	+			+	+			
				40	+	+		+	+			+	+			
				60	+	+		+	+			+	+			
				80					+							
				100												
				120												
				140												
Cadmium cyanide	Cd(CN)2			20	+			+	+							
				40	+			+	+							
				60	+			+	+							
				80					+							
				100												
				120												
				140												
Cadmium sulfate	$CdSO_4$			20	+	+		+	+			+	+			
				40	+	+		+	+			+	+			
				60	+	+		+	+			+	+			
				80		+			+				+			
				100												
				120												
				140												
Calcium acetate	$(CH_3COO)_2Ca$		saturated	20	+	+	+	+	+	+		+	+			
				40	+	+		+	+	+		+				
				60		+		+	+	+		+				
				80		+										
				100												
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Calcium bisulphite	$Ca(HSO_3)_2$		cold saturated, aqueous	20	+	+	+			+		+	+	-	O	+
				40		+	+			+			+			
				60		+				+			+			
				80		+				+			+			
				100						+			+			
				120						+						
				140												
Calcium carbonate	$CaCO_3$			20	+	+		+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+		+	+			
				100						+						
				120												
				140												
Calcium chlorate	$Ca(ClO_3)_2$			20	+	+		+	+	+						
				40	+	+		+	+	+						
				60	+	+		+	+	+						
				80		+										
				100												
				120												
				140												
Calcium chloride	$CaCl_2$	125	saturated, aqueous, all	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	O	+		+	+	+		+	+	+	+	+
				80		+			+	+		+	+	O	O	+
				100					+	+		O	+			+
				120						+						
				140												
Calcium fluoride	CaF_2			20	+			+	+				+			
				40	+			+	+				+			
				60	+			+	+				+			
				80					+							
				100												
				120												
				140												
Calcium hydrogencarbonate				20						+		+	+			
				40						+		+	+			
				60						+		+	+			
				80						+		+	+			
				100						+			+			
				120												
				140												
Calcium hydrogensulfide	$Ca(SH)_2$			20		+				+		+				
				40		+				+		+				
				60		+				+		+				
				80		+				+						
				100						+						
				120												
				140												
Calcium hydrosulfite	$Ca(HSO_3)_2$		saturated	20						+						
				40						+						
				60						+						
				80						+						
				100						+						
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Calcium hydroxide	$Ca(OH)_2$	100	saturated, aqueous	20	+	+	+	+	+	O		+	+	+	+	+
				40	+	+	+	+	+	-		+	+	+	+	+
				60	+	+	+	+	+			+	+	O	+	+
				80		+			+			+	+			+
				100									+			+
				120												
				140												
Calcium nitrate	$Ca(NO_3)_2$	115	50%, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60		+		+	+	+		+	+			+
				80		+				+			+			
				100						+						
				120												
				140												
Calcium phosphate	$Ca(H_2PO_4)_2$ $CaHPO_4$ $Ca_3(PO_4)_2$			20						+						
				40						+						
				60						+						
				80						+						
				100						+						
				120												
				140												
Calcium sulfide	Ca_s			20	+				+			+				
				40	+				+							
				60	+				+							
				80					+							
				100												
				120												
				140												
Calcium sulphate	$CaSO_4$		suspensions	20	+	+				+		+				
				40	+	+				+		+				
				60	+	+				+		+				
				80		+				+						
				100						+						
				120												
				140												
Calcium sulphite	$Ca(HSO_3)_2$		aqueous, cold saturated	20	+			+	+			+				
				40	+			+	+							
				60	+			+	+							
				80					+							
				100												
				120												
				140												
Calcium tungstate				20						+						
				40						+						
				60						+						
				80												
				100												
				120												
				140												
Calciumbromide	$CaBr_2$			20	+	+		+	+			+	+			
				40	+	+		+	+			+	+			
				60	+	+		+	+			+	+			
				80		+			+							
				100												
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Calciumlactate	$(CH_3COO)_2Ca$		saturated	20				+	+	+		+				
				40				+	+	+		+				
				60				+	+	+		+				
				80					+	+						
				100						+						
				120												
				140												
Caprolactam	$C_6H_{11}NO$			20		-										
				40												
				60												
				80												
				100												
				120												
				140												
Caprolactone	$C_6H_{10}O_2$			20		-										
				40												
				60												
				80												
				100												
				120												
				140												
Carbon dioxide -carbonic acid	CO_2		technically pure, anhydrous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	+	+	+	+	+	+			+	+	+	+
				80		+			+	+			+			+
				100						+						
				120												
				140												
Carbon disulphide	CS_2	46	technically pure	20	-	-	-	O	O	+			+	-	-	-
				40												
				60												
				80												
				100												
				120												
				140												
Carbon tetrachloride	CCl_4	77	technically pure	20	-	-	-	-	-	+		-	+	-	-	-
				40												
				60												
				80												
				100												
				120												
				140												
Carbonic acid				20	+	+		+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+		+	+			
				100						+			+			
				120												
				140												
Caro's acid	see Peroxomonosulfuric acid															
Casein				20						+						
				40						+						
				60						+						
				80												
				100												
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Cäsium chloride	ClCs			20						+						
				40						+						
				60						+						
				80												
				100												
				120												
				140												
Cäsiumhydroxide	CsOH			20						+						
				40						+						
				60						+						
				80												
				100												
				120												
				140												
Caustic potash solution	KOH	131	50%, aqueous	20	+	+	+	+	+	-		+	-	O	-	+
(potassium hydroxide)				40	+	+	+	+	+			+		-		O
				60	O	+	+	+	+			+				O
				80		+			+			O				-
				100					+							
				120												
				140												
Caustic soda solution	NaOH		50%, aqueous	20	+	+	+	+	+	O		+	-	O	-	+
				40	+	+		+	+			+		-		O
				60		+		+	+			+				-
				80					+							
				100												
				120												
				140												
Cerium (III) -chloride	$CeCl_3$			20						+						
				40						+						
				60						+						
				80												
				100												
				120												
				140												
Chloral hydrate	CCl_3-$CH(OH)_2$	98	technically pure	20	-		-	+	O	-		O	O	-	O	+
				40				+								
				60				+	-							
				80												
				100												
				120												
				140												
Chloric acid (SpRB)	$HClO_3$		10%, aqueous	20	+	+	-	+	-	+		+	-	-	-	+
				40	+	+		+		+		+				+
				60	O	+						+				+
				80												
				100												
				120												
				140												
Chloric acid (SpRB)	$HClO_3$		20%, aqueous	20	+	+	-	O	-	+		+	-	-	-	+
				40	+	+						+				+
				60	O	+										
				80												
				100												
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Chlorosulphonic acid	$ClSO_3H$	158	technically pure	20	O	-	-	-	-	O		-	-	-	-	-
				40						-						
				60												
				80												
				100												
				120												
				140												
Chrome alum (chromium potassium sulphate)	$KCr(SO_4)_2$		cold saturated, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	+	+		+	+			+	+	+	+	+
				80								+	+			
				100									+			
				120												
				140												
Chromic acid (SpRB)	CrO_3+H_2O		up to 50%, aqueous	20	O	+	-	O	O	+		O	+	-	-	O
				40	O	O		-	-	+		O	+			O
				60	-	O				+		O	+			O
				80		-				+						
				100						O						
				120						O						
				140												
Chromic acid (SpRB)			all, aqueous	20	O	O	-	O	O	+			+	-	-	O
				40						+			+			O
				60						+			O			O
				80						O						
				100						O						
				120												
				140												
Chromic acid + sulphuric acid + water (SpRB)	CrO_3 H_2SO_4 H_2O		50 g 15 g 35 g	20	+	+	-	-	-	+		O	+	-	-	O
				40	+	+				+		O	+			O
				60	O	+				+			+			
				80		O				O						
				100												
				120												
				140												
Chromium (II) -chloride				20	+					+						
				40	+					+						
				60	+					+						
				80						+						
				100						+						
				120												
				140												
Chromium (II) -fluoride	CrF_3			20						+						
				40						+						
				60						+						
				80												
				100												
				120												
				140												
Chromium (III) -chloride	$CrCl_3$			20	+					+						
				40	+					+						
				60	+					+						
				80						+						
				100						+						
				120												
				140												

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Aggressive Media					Chemical Resistance										
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)	EPDM	FPM	NBR	CR	CSM
Chlorine	Cl_2		moist, 97%, gaseous	20	-	-	-	-	-	-	-	+	-	-	O
				40											
				60											
				80											
				100											
				120											
				140											
Chlorine	Cl_2		anhydrous, technically pure	20	-	-	-	O	-	+	O	+	-	-	O
				40				O		+					
				60				-		+					
				80						+					
				100						O					
				120											
				140											
Chlorine	Cl_2		liquid, technically pure	20	-	-	-	-	-	+	-	O	-	-	-
				40											
				60											
				80											
				100											
				120											
				140											
Chlorine water (SpRB)	Cl_2 H_2O		saturated	20	+	+	O	O	O	O	O	O	-	O	-
				40	+	+		O							
				60	O	O									
				80		-									
				100											
				120											
				140											
Chloroacetic acid, mono (SpRB)	$ClCH_2COOH$		50%, aqueous	20	+	-	-	+	+	+	O	-	-	-	O
				40	+			+	+	O					
				60				+	+	-					
				80											
				100											
				120											
				140											
Chloroacetic acid, mono (SpRB)	$ClCH_2COOH$	188	technically pure	20	+	-	-	+	+	-	O	-	-	-	O
				40	+			+	+						
				60	O			+	+						
				80											
				100											
				120											
				140											
Chlorobenzene	C_6H_5Cl	132	technically pure	20	-	-	-	O	+	+	-	-	-	-	O
				40						+					
				60						O					
				80						-					
				100											
				120											
				140											
Chloroethanol	$ClCH_2$-CH_2OH	129	technically pure	20	-		-	+	+	+	O	-	+	-	O
				40				+	+	O					
				60				+	+	O					
				80						-					
				100											
				120											
				140											

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Chromium (III) -nitrate	$Cr(NO_3)_3$			20	+					+						
				40	+					+						
				60	+					+						
				80						+						
				100						+						
				120												
				140												
Chromium (III) -sulfate	$Cr_2(SO_4)_3$			20	+					+						
				40	+					+						
				60	+					+						
				80						+						
				100						+						
				120												
				140												
Cider				20	+	+	+	+	+	+		+	+	+	+	+
				40			+			+						
				60						+						
				80												
				100												
				120												
				140												
Citric acid		Fp. *153	10%, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	O	+	+	+	+	+		+	+	O	+	+
				80					+	+						
				100					+	+						
				120												
				140												
Citric acid				20	+			+	+							
				40	+			+	+							
				60				+	+							
				80					+							
				100												
				120												
				140												
Citric acid up to 10 %				20						+						
				40						+						
				60						+						
				80												
				100												
				120												
				140												
Coal gas, benzene free				20	+	+	+	+	+	+			+	+	O	+
				40												
				60												
				80												
				100												
				120												
				140												
Coconut fat alcohol (SpRB)			technically pure	20	+	-	-	+	+	+			+	+	+	+
				40	+			O	+	+			+	+	O	O
				60	O				O	+			+	+		
				80												
				100												
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Compressedair, containing oil (SpRB)				20	-	-	-	+	O	+		-	+	+	+	+
				40				+		+						
				60						+						
				80												
				100												
				120												
				140												
Copper salts	CuCl, $CuCl_2$, CuF_2, $Cu(NO_3)_2$, $CuSO_4$, $Cu(CN)_2$		all, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	O	+	+	+	+	+			+	O	+	O
				80		+			+	+			+			
				100						+						
				120												
				140												
Corn oil (SpRB)			technically pure	20	O	O	O	+	+	+			+	+	O	+
				40		O		+	+	+			+	+	-	+
				60				O	O	+			+	+		O
				80						+						
				100												
				120												
				140												
Cresol	$HO\text{-}C_6H_4\text{-}CH_3$		cold saturated, aqueous	20	O	-	-	+	+	+			+	O	-	O
				40				+	+	+			+	O		
				60						+						
				80						O						
				100												
				120												
				140												
Crotonic aldehyde	$CH_3\text{-}CH{=}CH\text{-}CHO$	102	technically pure	20	-	-	-	+	+	+		+	+	+	+	+
				40						O						
				60						-						
				80												
				100												
				120												
				140												
Cyclohexane (Q/E)	C_6H_{12}	81	technically pure	20	-	-	-	+	+	+		-	+	+	-	-
				40				+		+						
				60				+		+						
				80						+						
				100												
				120												
				140												
Cyclohexanol (SpRB)	$C_6H_{12}O$	161	technically pure	20	+	+	-	+	+	+		-	+	O	+	+
				40	+	+		+	+	+						
				60	+	+		+	O	O						
				80		O				O						
				100						-						
				120												
				140												
Cyclohexanone	$C_6H_{10}O$	155	technically pure	20	-	-	-	+	+	+		O	-	-	-	-
				40				O	O	O						
				60				O	O	-						
				80												
				100												
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Densodrine W				20	+	+	O			+			+	+	+	
				40	+	+										
				60	+	+										
				80												
				100												
				120												
				140												
Detergents (SpäB)	see washing powder		for usual washing lathers													
Dextrine	$(C_6H_{10}O_5)_n$		usual commercial	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+		+		+	+	+	+	+
				60	+	+	+	+		+		+	+	+	+	+
				80		+				+						
				100						+						
				120						+						
				140												
Dextrose	siehe Glucose			20	+	+	+	+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+		+	+			
				100						+			+			
				120												
				140												
Dibutyl ether	$C_4H_9OC_4H_9$	142	technically pure	20	-	-	-	O	O			-	+	+	-	O
				40									+	O		O
				60				-	-				O	-		O
				80												
				100												
				120												
				140												
Dibutyl phthalate	$C_6H_4(COOC_4H_9)_2$	340	technically pure	20	-	-	-	+	+	+		O	O	-	-	-
				40				O	O	+						
				60				O	O	O						
				80												
				100												
				120												
				140												
Dibutyl sebacate	$C_8H_{16}(COOC_4H_9)_2$	344	technically pure	20	-	-	-	+	+	+		+	+	-	-	-
				40												
				60												
				80												
				100												
				120												
				140												
Dichlorbenzol	$C_6H_4Cl_2$	180	technically pure	20	-	-	-									
				40												
				60												
				80												
				100												
				120												
				140												
Dichloroacetic acid	$Cl_2CHCOOH$	194	technically pure	20	+	-	-	+	+	+		+	O	-	O	+
				40	+			+	+	+		+	-		-	O
				60	O			O	O	O		+				-
				80						-						
				100												
				120												
				140												

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Aggressive Media					Chemical Resistance										
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)	EPDM	FPM	NBR	CR	CSM
Dichloroacetic acid (SpRB)	$Cl_2CHCOOH$		50%, aqueous	20	+	-	-	+	+	+	+	O	-	+	+
				40	+			+	+	+	+	O		O	+
				60	O			+	+	+	+	-		-	O
				80						O					
				100						-					
				120											
				140											
Dichloroacetic acid methyl ester	$Cl_2CHCOOCH_3$	143	technically pure	20	-	-	-	+	+	O	+	-	-	-	+
				40				+	+		+				+
				60				+	+		O				O
				80											
				100											
				120											
				140											
Dichloroethan	Ethylene chloride														
Dichloroethylene	ClCH=CHCl	60	technically pure	20	-	-	-	-	O	+	-	O	-	-	-
				40						+					
				60											
				80											
				100											
				120											
				140											
Dichloromethane				20	-	-	-								
				40											
				60											
				80											
				100											
				120											
				140											
Diesel oil (SpRB, Q/E)				20	+	+	O	+	O	+	-	+	+	O	O
				40	+	+				+		+	+		-
				60				O		+					
				80						+					
				100						+					
				120						+					
				140											
Diethyl ether				20	-	-	-								
				40											
				60											
				80											
				100											
				120											
				140											
Diethylamine	$(C_2H_5)_2NH$	56	technically pure	20	O	-	-	+	+	+	O	-	-	-	-
				40						O					
				60						-					
				80											
				100											
				120											
				140											
Diethylene glycol butyl ether				20	-	-	-								
				40											
				60											
				80											
				100											
				120											
				140											

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Diglycolic acid (SpRB)	HOOC-CH_2-O-CH_2-COOH	Fp*., 148	30%, aqueous	20	+	+	+	+	+	+		+	O	+	+	O
				40	+	+		+	+							
				60	O	+		+	+							
				80												
				100												
				120												
				140												
Di-isobutyl ketone	$[(CH_3)2CHCH_2]_2CO$	124	technically pure	20	-	-	-	+	+	+		O	-	-	-	-
				40						+						
				60				-	-	O						
				80												
				100												
				120												
				140												
Dimethyl formamide	$(CH_3)_2CHNO$	153	technically pure	20	-	-	-	+	+	-		O	-	O	+	+
				40				+	+							
				60				O	+							
				80												
				100												
				120												
				140												
Dimethylamine	$(CH_3)_2NH$	7	technically pure	20	O	-	-	+	+	O		O	-	-	-	-
				40						-						
				60				O								
				80												
				100												
				120												
				140												
Dimethylphthalate (DMP)	$C_6H_4(CH_3)_2$			20	-	-	-									
				40												
				60												
				80												
				100												
				120												
				140												
Dinonylphthalate (DNP)			technically pure	20	-	-	-	O	+			O	+	-	-	-
				40												
				60												
				80												
				100												
				120												
				140												
Dioctylephthalate (SpRB) (DOP)			technically pure	20	-	-	-	O	+			O	+	-	-	-
				40												
				60					-							
				80												
				100												
				120												
				140												
Dioxane	$C_4H_8O_2$	101	technically pure	20	-	-	-	+	O	-			-	O	-	-
				40				+	O							
				60				+	O							
				80					-							
				100												
				120												
				140												
Drinking water	see water															

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Ethanolamine	see Amino ethanol															
Ethyl acetate	$CH_3COOCH_2\text{-}CH_3$	77	technically pure	20	-	-	-	+	+	O		+	-	-	-	-
				40				O	O							
				60				O	O							
				80												
				100												
				120												
				140												
Ethyl alcohol + acetic acid (fermentation mixture)			technically pure	20	+	O	-	+	+	+		O	O	O	+	+
				40	+			+		+		O	O	O	+	+
				60	O			+		+			O		+	+
				80						O						
				100												
				120												
				140												
Ethyl alcohol (Ethnol (SpRB)	$CH_3\text{-}CH_2\text{-}OH$	78	technically pure, 96%	20	+	O	-	+	+	+		+	O	O	+	+
				40	+			+	+	O		+	O			
				60	O			+	+	-		+	O			
				80					+							
				100												
				120												
				140												
Ethyl benzene	$C_6H_5\text{-}CH_2CH_3$	136	technically pure	20	-	-	-	O	O	O		-	+	-	-	-
				40												
				60					-							
				80												
				100												
				120												
				140												
Ethyl chloride	$CH_3\text{-}CH_2Cl$	12	technically pure	20	-	-	-	O	O	O		-	O	-	-	-
				40												
				60												
				80												
				100												
				120												
				140												
Ethyl ether	$CH_3CH_2\text{-}O\text{-}CH_2CH_3$	35	technically pure	20	-	-	-	+	O	+		-	-	-	-	-
				40												
				60												
				80												
				100												
				120												
				140												
Ethylenchloride (1,2-Dichloroethane)				20	-	-	-									
				40												
				60												
				80												
				100												
				120												
				140												
Ethylene chloride	$ClCH_2\text{-}CH_2Cl$	83	technically pure	20	-	-	-	O	O	+		-	+	O	O	-
				40						+			+	-	-	
				60						+			O			
				80						O						
				100						-						
				120												
				140												

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Aggressive Media					Chemical Resistance										
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)	EPDM	FPM	NBR	CR	CSM
Ethylene diamine	$H_2N\text{-}CH_2\text{-}CH_2\text{-}NH_2$	117	technically pure	20	O	-	-	+	+	O	+	O	+	+	O
				40				+	+	O		O	O	O	O
				60				+	+	-		-	-	-	-
				80											
				100											
				120											
				140											
Ethylene glycol (SpRB)	$HO\text{-}CH_2\text{-}CH_2\text{-}OH$	198	technically pure	20	+	O	-	+	+	+	+	+	+	+	+
				40	+			+	+	+	+	+	+	+	+
				60	+			+	+	+	+	+	O	O	+
				80					+	+	+	O			O
				100					+	+					
				120						+					
				140											
Ethylene glycol	CH_2OHCH_2OH	198	technically pure	20	+		-	+	+	+	+	+	+	+	+
				40	+			+	+	+	+	+	+	+	+
				60	+			+	+	+	+	+	O	O	+
				80					+	+		O			O
				100						+					
				120											
				140											
Ethylene oxide	CH2-CH2	10	technically pure, moist	20	-	-	-	-	O	+	O	-	-	-	-
				40											
				60											
				80											
				100											
				120											
				140											
Ethylenediaminetetra-acetic acid (EDTA)				20				+	+	+	+				
				40											
				60											
				80											
				100											
				120											
				140											
Fatty acids $>C_6$ (SpRB)	R-COOH		technically pure	20	+	+	-	+	+	+	+	+	O	O	-
				40	+	+		+	+	+					
				60	+	+		O	+	+					
				80						+					
				100											
				120											
				140											
Fatty alcohol sulphonates (SpRB)			aqueous	20	+	+		+	+	+	+	+	+	+	+
				40	+	+		+	+	+	+	+	+	+	+
				60	O	O		+	O	+	+	+	+	+	+
				80						+					
				100						+					
				120											
				140											
Fertilizers			aqueous	20	+	+	O	+	+	+	+	+	+	+	+
				40	+	+		+	+	+	+	+	+	+	+
				60	O	+		+	+	+	+	+	+	+	+
				80		+				+		+			+
				100								+			
				120											
				140											

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Fluorine	F_2		technically pure	20	-	-	-	-	-	-		-	-	-	-	-
				40												
				60												
				80												
				100												
				120												
				140												
Fluorosilicic acid (Q/E)	H_2SiF_6		32%, aqueous	20	+	+	+	+	+	+		+	O	O	O	+
				40	+	+	+	+		+				-	-	O
				60	+	+	+	+		+						-
				80						+						
				100						+						
				120												
				140												
Formaldehyde (SpRB)	HCHO		40%, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60			+	+		+		+	+	O	O	O
				80						+						
				100												
				120												
				140												
Formamide	$HCONH_2$	210	technically pure	20	-	-	-	+	+			+	O	+	+	
				40				+	+							
				60				+	+							
				80												
				100												
				120												
				140												
Formic acid (SpRB)	HCOOH		up to 50%, aqueous	20	+	-	O	+	+	+		+	+	-	+	+
				40	+			+	+	+		+	+		+	+
				60	O			+	O	+		O	O		O	+
				80						+			-			O
				100						+						
				120												
				140												
Formic acid (SpRB)	HCOOH	101	technically pure	20	+	-	-	+	+	+		+	+	-	+	+
				40	O			+	O	+		+			O	+
				60	-			+	-	+		+			-	+
				80						+		O				O
				100						+						
				120												
				140												
Formic acid (SpRB)			25%	20	+	+		+	+	+		+				
				40	+	+		+	+	+		+				
				60	+	+		+	+	+		+				
				80					+	+						
				100												
				120												
				140												
Freon 113	see trifluoro, trichlorethane	48														
Frigen 12 (D/P)	see Freon 12	-30	technically pure													

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Aggressive Media					Chemical Resistance										
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)	EPDM	FPM	NBR	CR	CSM
Fruit juices (SpRB)				20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	+	+	+	+	+	+	+	+	+	+	+
				80		+			+	+	+	+	+	+	+
				100						+	+	+	+		+
				120						+		+			
				140											
Fruit pulp				20	+	+	+	+	+		+	+	+	+	+
				40			+	+	+						
				60				+	+						
				80											
				100											
				120											
				140											
Fuel oil				20	+	+		O	O	+	-	+	+	+	-
				40	O	+		-	-	+		+	+	+	
				60						+		+	+	O	
				80						+					
				100						+					
				120											
				140											
Furfuryl alcohol (SpRB)	$C_5H_6O_2$	171	technically pure	20	-	-	-	+	+	+	O	-	-	O	O
				40				+		+					
				60				+	O	O					
				80						-					
				100											
				120											
				140											
Gasoline (SpRB)	C_5H_{12} to $C_{12}H_{26}$	80-130	free of lead and aromatic compounds	20	+	+	-	+	O	+	-	+	+	-	O
				40	+	+		+		+		+	+		-
				60	+	+		O	-	+		+	+		
				80						+					
				100						+					
				120						+					
				140											
Gelatin			all, aqueous	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60		+	+	+	+	+					
				80						+					
				100											
				120											
				140											
Glucose	$C_6H_{12}O_6$	Fp*., 148	all, aqueous	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	O	+	+	+	+	+	+	+	+	+	+
				80		+			+	+	+	+	+	+	+
				100						+		+			
				120											
				140											
Glycerol	HO-CH_2-CH(OH)-CH_2OH	290	technically pure	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	O	+	+	+	+
				60	+	+		+	+	+	O	O	+	+	+
				80		+			+	+		-	O	+	+
				100					+	+				O	O
				120						+					
				140											

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Glycocoll (SpRB)	NH_2-CH_2-COOH	Fp.* 233	10%, aqueous	20	+	+	+	+	+	+			+	+	+	+
				40	+	+	+	+	+	+			+	O	+	O
				60		+				+						
				80						+						
				100												
				120												
				140												
Glycol	see Ethylene glycol															
Glycolic acid	HO-CH_2-COOH	Fp.*, 80	37%, aqueous	20	+	-	+	+	+	+			+	+	+	+
				40			+	+		+						
				60				+		+						
				80						+						
				100						+						
				120												
				140												
Heptane (SpRB)	C_7H_{16}	98	technically pure	20	+	O	-	+	+	+		-	+	+	+	+
				40						+			+	+	+	O
				60				O	O	+			+	+	+	-
				80						+						
				100						+						
				120												
				140												
Hexane (SpRB)	C_6H_{14}	69	technically pure	20	+	O	-	+	+	+		-	+	+	+	+
				40						+			+	+	+	O
				60				O	O	+			+	+	+	-
				80						+						
				100						+						
				120												
				140												
Hydrazine hydrate (SpRB)	H_2N-$NH_2 . H_2O$	113	aqueous	20	+	-	-	+	+	-		+	O	-	-	+
				40				+	+							
				60				+	+							
				80												
				100												
				120												
				140												
Hydrobromic acid (SpRB)	HBr	124	aqueous, 50%	20	+	+	+	+	+	+		+	+	O	+	+
				40	+	+	+	+	+	+		+	+	-	+	+
				60	+	+		+	+	+		O	+		O	+
				80		O				+		-	O		-	O
				100						+			-			-
				120												
				140												
Hydrochloric acid (Q/E, D/P)	HCl		up to 38%	20	+	+	-	+	O	+		+	+	-	O	+
				40	+	+		+		+			+			
				60	+	+				+						
				80						+						
				100						+						
				120												
				140												
Hydrochloric acid (Q/E, D/P)	HCl		5%, aqueous	20	+		+	+	+	+		+	+	O	O	+
				40	+		+	+	+	+		+	+	-	-	O
				60	O			+	+	+		+	+			-
				80					O	+			+			
				100						+						
				120						+						
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Hydrochloric acid (Q/E, D/P)	HCl		10%, aqueous	20	+	+	+	+	+	+		+	+	O	O	+
				40	+	+	+	+	+	+		+	+	-	-	O
				60	O	+		+	O	+		+	+			-
				80		+			O	+			+			
				100						+						
				120						+						
				140												
Hydrochloric acid (Q/E, D/P)	HCl		up to 30%, aqueous	20	+	+	O	+	+	+		+	+	-	-	+
				40	+	+	-	+	O	+		+	+			O
				60	O	+		+	O	+		O	O			-
				80		+			-	+						
				100						+						
				120												
				140												
Hydrochloric acid (Q/E, D/P)	HCl		36%, aqueous	20	+	+	-	+	+	+		O	+	-	-	O
				40	+	+		+	O	+		O	O			-
				60	O	O		+	-	+		-	-			
				80		O				+						
				100						+						
				120												
				140												
Hydrocyanic acid	HCN	26	technically pure	20	+	+	-	+	+	+		+	+	O	O	+
				40	+	+		+	+	+		O	O	-	-	O
				60	O	+		+	+	+						
				80						+						
				100												
				120												
				140												
Hydrofluoric acid	HF			20	+	-	-	+	+	+		-	+	-	-	+
				40	O			+	+	+			+			+
				60	O			O	+	+			O			O
				80						+						
				100						+						
				120												
				140												
Hydrogen	H_2	-253	technically pure	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	+	+	+	+	+	+		+	+	+	+	+
				80		+				+		+	+	+	+	+
				100					-	+		+	+	+		
				120												
				140												
Hydrogen chloride (Q/E)	HCl	-85	technically pure, gaseous	20	+	+	-	+	+	+		+	+	O	O	O
				40	+	+		+	+	+		+	+	-	-	O
				60	O	+		+	+	+		+	+			-
				80		O				+						
				100						+						
				120												
				140												
Hydrogen perocide			70%	20	+	+	-	+	+	O		O	+			
				40						O						
				60												
				80												
				100												
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Hydrogen peroxide (SpRB)	H_2O_2		50%, aqueous	20	+	+	-	+	+	O		O	+			
				40												
				60												
				80												
				100												
				120												
				140												
Hydrogen peroxide (SpRB)	H_2O_2		10%, aqueous	20	+	+	-	+	+	O		O	+	O	-	+
				40	+			+	+	O		O	O	-		+
				60	O			+	+	-		-	-			O
				80												-
				100												
				120												
				140												
Hydrogen peroxide (SpRB)	H_2O_2	139	90%, aqueous	20	+		-	+	-	O			O	-	-	O
				40												
				60				-								
				80												
				100												
				120												
				140												
Hydrogen peroxide (SpRB)	H_2O_2	105	30%, aqueous	20	+	+	-	+	+	O		O	+	-	-	+
				40												O
				60												-
				80												
				100												
				120												
				140												
Hydrogen sulphide	H_2S		technically pure	20	+	+	+	+	+	+		+	+	+	O	+
				40	+	+	+	+	+	+		-	+	O	-	O
				60	+	+		O	+	+			O	-		O
				80						+			-			-
				100						+						
				120						+						
				140												
Hydrogen sulphide	H_2S		saturated, aqueous	20	+	+	+	+	+	+		+	+	-	+	+
				40	+	+	+	+	+	+		-	+	-	-	+
				60	O	+		+	+*	+			+			O
				80						+			O			-
				100						+						
				120						+						
				140												
Hydroquinone	$C_6H_4(OH)_2$		saturated	20	+	+		+	+			+				
				40	+	+		+	+							
				60				+	+							
				80					+							
				100												
				120												
				140												
Hydrosulphite	see Sodium dithione															
Hydroxylamine sulfate				20	+			+				+				
				40	+			+								
				60	+			+								
				80												
				100												
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Hydroxylamine sulphate	$(NH_3OH)_2SO_4$		all, aqueous	20	+	+	-	+	+			+	+	+	O	+
				40	+	+		+	+				+	O		+
				60				+	+							
				80												
				100												
				120												
				140												
Iodine-potassium iodide solution (lugol's solution)				20	+	-	-			+			+			
				40												
				60												
				80												
				100												
				120												
				140												
Iodium	I_2	185	100%	20	-	-	-			+			+			
				40												
				60												
				80												
				100												
				120												
				140												
Iron (II) -chloride			saturated	20	+	+	+	+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+			+			
				100						+			+			
				120												
				140												
Iron (II) -chloride	$FeCl_2$		saturated	20	+	+	+	+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+		+	+			
				100						+			+			
				120												
				140												
Iron (II) -nitrate	$Fe(NO_3)_2$		saturated	20	+	+	+	+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+			+			
				100						+			+			
				120												
				140												
Iron (III) -chloride	$FeCl_3$		saturated	20	+	+	+	+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+		+	+			
				100						+			+			
				120												
				140												
Iron (III) -chloride			saturated	20	+	+	+	+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+		+	+			
				100						+			+			
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Iron (III) -chloridsulfate			saturated	20	+	+	+	+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+		+	+			
				100						+			+			
				120												
				140												
Iron (III) -nitrate			saturated	20	+	+	+	+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+		+	+			
				100						+			+			
				120												
				140												
Iron (III) -nitrate	$Fe(NO_3)_3$		saturated	20	+	+	+	+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+		+	+			
				100						+			+			
				120												
				140												
Iron (III) -sulfate	$Fe_2(SO_4)_3$		saturated	20	+	+	+	+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+		+	+			
				100						+			+			
				120												
				140												
Iron (III) -sulfate			saturated	20	+	+	+	+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+		+	+			
				100						+			+			
				120												
				140												
Iron (III) -nitrate	$FE(NO_3)3$		saturated	20	+					+		+	+			
				40	+					+		+	+			
				60	+					+		+	+			
				80						+		+	+			
				100						+			+			
				120												
				140												
Iron (II) -sulfate	$FeSO_4$		saturated	20	+	+	+	+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+		+	+			
				100						+			+			
				120												
				140												
Iron (III) -sulfate			saturated	20						+						
				40						+						
				60						+						
				80						+						
				100						+						
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Iron salts			all, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	O	+		+	+	+		+	+	+	+	+
				80		+			+	+		+	+			+
				100						+			+			
				120						+						
				140												
Isooctane (SpRB)	$(CH_3)_3$-C-CH_2-CH-$(CH_3)_2$	99	technically pure	20	+		-	+	+	+			+	+	+	O
				40						+						
				60				O	O	+						
				80						+						
				100						+						
				120												
				140												
Isophorone (SpRB)	$C_9H_{14}O$		technically pure	20						-						
				40												
				60												
				80												
				100												
				120												
				140												
Isopropyl alcohol (SpRB)	$(CH_3)_2$-CH-OH	82	technically pure	20				+	+	+		+				
				40						+						
				60						+						
				80						O						
				100												
				120												
				140												
Isopropyl ether	$(CH_3)_2$-CH-O-CH-$(CH_3)_2$	68	technically pure	20	-	-	-	O	O	+		O	-	-	-	-
				40						+						
				60				-	-	+						
				80												
				100												
				120												
				140												
Isopropylbenzene				20	-	-	-									
				40												
				60												
				80												
				100												
				120												
				140												
Jam, Marmalade				20	+	+	+	+	+	+		+	+	+	+	+
				40	O	+	+	+	+	+		+	+	+	+	+
				60	O	+		+	+	+		+	+	+	+	+
				80					+	+		+	+			
				100					+	+						
				120						+						
				140												
Lactic acid (SpRB)	$CH_3CHOHCOOH$		10%, aqueous	20	+	+	+	+	+	+		O	+	-	-	O
				40	O	+	O	+	+	+		O	O			O
				60	-	+	-	+	+	O		O	O			O
				80		+			+	O		-	O			
				100					+	-						
				120												
				140												

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Aggressive Media				Chemical Resistance												
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Lanolin (SpRB)			technically pure	20	+	o	+	+	+	+			+	+	+	O
				40	O		+	+	+	+			+	+	O	·
				60			+	+	+	+			+	+	·	
				80						+						
				100						+						
				120						+						
				140												
Lead acetate	$Pb(CH_3COO)_2$		aqueous, saturated	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	+	+	+	+	+	+		+	+	+	+	+
				80		+				+						
				100						+						
				120												
				140												
Lead salts	$PbCl_2$, $Pb(NO_3)_2$, $PbSO_4$		saturated	20		+										
				40		+										
				60		+										
				80		+										
				100												
				120												
				140												
Leadcarbonate				20	+	+		+	+	+		+				
				40						+						
				60						+						
				80												
				100												
				120												
				140												
Leadnitrate	$Pb(NO_3)2$			20		+										
				40		+										
				60		+										
				80		+										
				100												
				120												
				140												
Leadnitrate				20	+					+						
				40	+					+						
				60	+					+						
				80						+						
				100						+						
				120												
				140												
Leadtetrafluoroborate				20						+						
				40						+						
				60						+						
				80						+						
				100						+						
				120												
				140												
Linoleic acid				20						+						
				40						+						
				60						+						
				80						+						
				100						+						
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Linseed oil (SpRB)			technically pure	20	+	+	+	+	+	+			+	+	O	+
				40	+	+	-	+	+	+			+	+	-	O
				60	O			+	+	+			+	+		-
				80					+	+						
				100					+	+						
				120						+						
				140												
Liqueurs				20	+			+	+	+		+	+	+	+	+
				40	+			+		+						
				60						+						
				80						+						
				100												
				120												
				140												
Liquid fertilizers				20				+	+			+				
				40				+	+			+				
				60				+	+			+				
				80					+							
				100												
				120												
				140												
Lithiumbromide	LiBr			20	+	+		+	+	+		+	+			
				40						+						
				60						+						
				80						+						
				100						+						
				120												
				140												
Lithiumsulfate				20	+	+		+	+	+		+	+			
				40						+						
				60						+						
				80												
				100												
				120												
				140												
Lubricating oils				20	+	O	-	+	O	+		-	+	+	+	+
				40	+			+		+			+	+	O	O
				60	+			O		+			+	O	-	-
				80						+			O			
				100						+			-			
				120						+						
				140												
Magnesium salts	$MgCl_2$, $MgCO_3$, $Mg(No3)_2$, $Mg(OH)_2$, $MgSO_4$		all, aqueous,saturated	20	+	+	+	+	+	+			+	+	+	+
				40	+	+	+	+	+	+			+	+	+	+
				60	O	+		+	+	+		+	+	+	+	+
				80		+			+	+		+	+			+
				100					+	+			+			
				120						+						
				140												
Magnesiumhydrogen-carbonate				20	+			+	+			+				
				40	+			+	+			+				
				60	+			+	+			+				
				80												
				100												
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Maleic acid (SpR8)	$(CH\text{-}COOH)_2$	Fp. *131	cold saturated, aqueous	20	+	+	+	+	+	+			+	-	-	-
				40	+	+		+	+	+			+			
				60	O			+	+	+			+			
				80						+			-			
				100						+						
				120						+						
				140												
Media water or similar media				20	+	+	+	+	+	+						
				40	+	+	+	+	+	+						
				60	+	+	+	+	+	+						
				80		+			+	+						
				100					+	+						
				120						+						
				140						+						
Mercury	Hg	357	pure	20	+	+	+	+	+	+		+	+	+	+	+
				40	+			+	+	+		+	+	+	+	+
				60	+			+	+	+		+	+	+	+	+
				80						+			+			
				100						+						
				120						+						
				140												
Mercury (II) -chloride	$HgCl_2$			20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+		+	+	+		+	+	+	+	+
				60	+	+		+	+	+		+	+	+	+	+
				80		+			+	+						
				100						+						
				120												
				140												
Mercury (II) -cyanide	Hg(CN)2			20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+		+	+	+		+	+	+	+	+
				60	+	+		+	+	+		+	+	+	+	+
				80		+				+						
				100						+						
				120												
				140												
Mercury (II) -cyanide	$Hg(NO_3)_2$			20	+	+		+	+	+		+	+	+	+	+
				40	+	+		+	+	+		+	+	+	+	+
				60	+	+		+	+	+		+	+	+	+	+
				80		+			+	+			+			
				100						+						
				120												
				140												
Mercury (II) -sulfate				20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+		+	+	+		+	+	+	+	+
				60	+	+		+	+	+		+	+	+	+	+
				80		+			+	+			+			
				100						+						
				120												
				140												
Mercury salts	$HgNO_3$, Hg Cl_2, $Hg(CN)_2$		cold saturated, aqueous	20	+	+	+	+	+	+		+	+	O	O	O
				40	+	+		+	+	+		+	+	O	O	O
				60	O	+		+	+	+			+	-	-	-
				80						+						
				100						+						
				120						+						
				140												
Methane	see natural gas	-161	technically pure													

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Methanol (SpRB)	CH_3OH	65	all	20	+	-	-	+	+	+		+	O	+	+	+
				40	+			+	+	O		+	O	+	+	+
				60	O			+	+	-		+	O	+	O	+
				80												
				100												
				120												
				140												
Methyl acetate	CH_3COOCH_3	56	technically pure	20	-	-	-	+	+	+			-	-	-	-
				40					+	O						
				60					O							
				80												
				100												
				120												
				140												
Methyl amine	CH_3NH_2	-6	32%, aqueous	20	O	-	-	+	+	O			+	-	+	+
				40												
				60												
				80												
				100												
				120												
				140												
Methyl bromide	CH_3Br	4	technically pure	20	-	-	-	O	-	+			O	-	-	O
				40						+						
				60						+						
				80												
				100												
				120												
				140												
Methyl chloride	CH_3Cl	-24	technically pure	20	-	-	-	O	-	+			-	-	-	-
				40						+						
				60						+						
				80												
				100												
				120												
				140												
Methyl ethyl ketone	$CH_3COC_2H_5$	80	technically pure	20	-	-	-	+	+	-			-	-	-	-
				40				O	O							
				60				-	O							
				80												
				100												
				120												
				140												
Methylene chloride	CH_2Cl_2	40	technically pure	20	-	-	-	O	O	+			O	-	-	-
				40						O						
				60						O						
				80												
				100												
				120												
				140												
Methylisobutylketone	$C_6H_{12}O$			20	-	-	-									
				40												
				60												
				80												
				100												
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Methylmethacrylate	$C_5H_8O_2$			20	-	-	-									
				40												
				60												
				80												
				100												
				120												
				140												
Methylphenylketone (Acetophenon)	C_8H_8O			20	-	-	-									
				40												
				60												
				80												
				100												
				120												
				140												
Milk (SpRB)				20	+	+	+	+	+	+			+	+	+	+
				40	+	+	+	+	+	+						
				60	+	+	+	+	+	+						
				80		+			+	+						
				100					+	+						
				120						+						
				140												
Mineral oils, free of aromatics				20	+	+	-	+	+	+			+	+	O	O
				40	+			+	+	+			+	+	-	-
				60	+			O	O	+			+	+		
				80						+						
				100						+						
				120						+						
				140												
Mineral water				20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	+	+	+	+	+	+		+	+	+	+	+
				80		+			+	+		+	+	+		+
				100					+	+		+	+			+
				120						+			+			
				140												
Mixed acids	$15\% \; HNO_3$		3 parts	20	O	O	-	O	-	+			+	-	-	+
- nitric	15% HF		1 part	40						+			O			O
- hydrofluoric	$18\% \; H_2SO_4$		2 parts	60						+						
- sulphuric				80												
				100												
				120												
				140												
Mixed acids	H_2SO_4		48%	20	+	+	-	-	-	+			-	-	-	-
- sulphuric	HNO_3		49%	40	O											
- nitric	H_2O		43%	60	-											
- water				80												
				100												
				120												
				140												
Mixed acids	H_2SO_4		50%	20	O	O	-	-	-	+			-	-	-	-
- sulphuric	HNO_3		50%	40	-											
- nitric	H_2O		40%	60												
- water				80												
				100												
				120												
				140												

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Aggregssive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Mixed acids	H_2SO_4		10%	20	O	O	-	-	-	O			-	-	-	-
- sulphuric	HNO_3		87%	40												
- nitric	H_2O		43%	60												
- water				80												
				100												
				120												
				140												
Mixed acids	H_2SO_4		50%	20	+	+	-	-	-	+			+	-	-	O
- sulphuric	HNO_3		33%	40	O											
- nitric	H_2O		17%	60												
- water				80												
				100												
				120												
				140												
Mixed acids	H_2SO_4		10%	20	+	+	-	O	-	+			+	-	O	+
- sulphuric	HNO_3		20%	40	+					+			+			O
- nitric	H_2O		70%	60						+			+			
- water				80						+						
				100												
				120												
				140												
Mixed acids	H_2SO_4		50%	20	+		-	-	-	+			+	-	O	O
- sulphuric	HNO_3		31%	40												
- nitric	H_2O		19%	60												
- water				80												
				100												
				120												
				140												
Mixed acids	H_2SO_4		30%	20	+	+	-	+	+	+			+	-	+	+
- sulphuric	H_3PO_4		60%	40	+	+		O	O	+			+		O	O
- phosphoric	H_2O		10%	60		+				+			+			
- phosphoric				80						+						
				100												
				120												
				140												
Molasses				20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	O	+	+	+	+	+		+	+	+	+	+
				80		+				+		+	+	+	O	+
				100												
				120												
				140												
Molasses wort				20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	+	+	+	+	+	+		+	+	+	+	+
				80		+				+						
				100												
				120												
				140												
Monochloroacetic acid ethyl ester	$ClCH_2COOC_2H_5$	144	technically pure	20	-	-	-	+	+	O			O	-	-	-
				40				+	+	-						
				60				+	+							
				80												
				100												
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Morpholin	C_4H_9NO	129	technically pure	20	-	-	-	+	+	+			+	-	O	O
				40				+	+	+						
				60				+	+	O						
				80												
				100												
				120												
				140												
Mowilith D			usual commercial	20	+	+		+	+	+			+	+	+	+
				40												
				60												
				80												
				100												
				120												
				140												
Naphthalene		218	technically pure	20	-	-	-	+	+	+		-	+	+	-	O
				40						+			+	+		-
				60				O		O			+	+		
				80												
				100												
				120												
				140												
Natriumhydrogensulfite	$NaHSO_3$			20	+	+		+	+	+		+	+			
				40	+	+		+	+	+		+				
				60	+	+		+	+	+		+				
				80		+			+	+						
				100						+						
				120												
				140												
Natriumsulfate				20	+	+	+	+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+		+	+			
				100						+			+			
				120												
				140												
Natriumtetraborate (Borax)				20	+	+	+	+	+	+		+	+			
				40	+	+		+	+	+		+				
				60	+	+		+	+	+		+				
				80		+			+							
				100												
				120												
				140												
Nickel salts	$(CH_3COO)_2Ni$, $NiCl_2$, $Ni(NO_3)_2$, $NiSO_4$		cold saturated, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	O	+	+	+	+	+			+	+	+	+
				80						+			+			
				100						+			+			
				120						+						
				140												
Nitrating acid	H_2SO_4 HNO_3 H_2O		65% 20% 15%	20						+						
				40												
				60												
				80												
				100												
				120												
				140												

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Aggregssive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Nitric acid (SpRB)	HNO_3			20	+	+	-	+	O	+		+	+			
				40	+	+				+			+			
				60	+	+				+			+			
				80						+						
				100						+						
				120												
				140												
Nitric acid (SpRB)	HNO_3			20	+	+	-	+	+	+		+	+			
				40	+	+		+	O	+			+			
				60	+	+		+		+						
				80		+				+						
				100						+						
				120												
				140												
Nitric acid up to 55% (SpRB)				20	+	+	-	+	-	+			+			
				40	+	+				+						
				60						+						
				80												
				100												
				120												
				140												
Nitric acid (see note 2.3.1 on jointing) (SpRB)	see Salpetre		6,3%, aqueous													
Nitric acid (see note 2.3.1 on jointing) (SpRB)	see Salpetre		up to 40%, aqueous													
Nitric acid (see note 2.3.1 on jointing) (SpRB)	see Salpetre		65%, aqueous													
Nitric acid (see note 2.3.1 on jointing) (SpRB)	see Salpetre		100%													
Nitric acid (see note 2.3.1 on jointing) (SpRB)	see Salpetre		85%													
Nitric oxide	see Nitrous gases															
Nitrilotriacetic acid	$N(CH_2\text{-}COOH)_3$			20				+	+			+				
				40												
				60												
				80												
				100												
				120												
				140												
Nitrobenzene	$C_6H_5\text{-}NO_2$	209	technically pure	20	-	-	-	+	+	+		-	O	-	-	-
				40				O	+	O						
				60				O		-						
				80												
				100												
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Nitrotoluene (o-, m-, p-)		222-238	technically pure	20	-	-	-	+	+	+		-	O	O	-	-
				40				O	O	+			-	-		
				60						+						
				80						+						
				100						O						
				120												
				140												
Nitrous acid	HNO_2			20	+	+	-	+	-	+		+	+			
				40	+	+				+						
				60						+						
				80												
				100												
				120												
				140												
Nitrous gases	see Nitric oxide		diluted, moist, anhydrous													
N-Methylpyrrolidon				20	-	-	-									
				40												
				60												
				80												
				100												
				120												
				140												
N,N-Dimethylaniline	$C_6H_5N(CH_3)_2$		technically pure	20	-	-	-	+	+			+				
				40												
				60												
				80												
				100												
				120												
				140												
n-Pentylacetate				20	-	-	-									
				40												
				60												
				80												
				100												
				120												
				140												
Oleic acid (SpRB)	$C_{17}H_{33}COOH$		technically pure	20	+	O	-	+	+	+		-	+	O	-	-
				40	+			+	+	+			O	-		
				60	+			O	O	+			-			
				80						+						
				100						+						
				120						+						
				140												
Oleum (SpRB)	$H_2SO_4+SO_3$		10% SO_3	20	-	-	-	-	-	-		-	-	-	-	-
				40												
				60												
				80												
				100												
				120												
				140												
Oleum vapours (SpRB)			traces	20	+	-	-	-	-	-		-	+	-	-	O
				40												
				60												
				80												
				100												
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Olive oil (SpRB)				20	+	-	-	+	+	+		-	+	+	+	+
				40	+			+	+	+			+	+	+	+
				60	+			O	+	+			+	+	+	O
				80					+	+			+			-
				100												
				120												
				140												
Oxalic acid (SpRB)	$(COOH)_2$		cold saturated, aqueous	20	+	+	+	+	+	+		+	+	O	O	O
				40	+	+	+	+	+	+			+	-	-	O
				60	+	+		+	+	+			O			-
				80		O				+			-			
				100						+						
				120												
				140												
Oxygen	O_2		technically pure	20	+	+	+	+	+	+		+	+	+	+	+
				40	+		+	+	+	+		+	+		+	+
				60	+		+	O	O	+		+	+		+	+
				80						+			+		+	+
				100						O			+			+
				120						O			+			
				140												
Ozone (SpRB)	O_3		up to 2%, in air	20	+	+	-	O	O	O		O	+	-	O	+
				40				-	-							
				60												
				80												
				100												
				120												
				140												
Ozone (SpRB)	O_3		cold saturated, aqueous	20	+	+	-	O	O	O		-	+	-	O	+
				40	+			-	-				O		-	+
				60									-			O
				80												
				100												
				120												
				140												
Palm oil, palm nut oil (SpRB)				20	+	O	+	+	+	+		-	+	+	+	O
				40	-			+	+	+			+	+	O	-
				60				O	O	+			+	O	-	
				80						+						
				100						+						
				120												
				140												
Palmitic acid (SpRB)	$C_{15}H_{31}COOH$	390	technically pure	20	+	-	+	O	O	+		O	+	O	+	O
				40						+			O	-	-	-
				60					-	+			-			
				80						+						
				100						+						
				120						+						
				140												
Paraffin emulsions			usual commercial, aqueous	20	+	+	O	+	+	+		-	+	+	+	+
				40	+	+		+	+	+			+	+	O	-
				60				O	O	+			+	O	-	
				80						+			+			
				100						+						
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Paraffin oil				20	+	+	O	+	+	+		-	+	+	+	O
				40	+			+	+	+			+	O	O	-
				60	O			+	O	+			+	O	-	
				80						+			O			
				100						+						
				120						+						
				140												
p-Dibromo benzene	$C_6H_5Br_2$		technically pure	20	-	-	-	O	O	+		-	+	-	-	-
				40						+						
				60						+						
				80						+						
				100						+						
				120												
				140												
Perchlorethylene (tetrachlorethylene)	$Cl_2C{=}CCl_2$	121	technically pure	20	-	-		O	O	+			+	O	-	-
				40						+			+	-		
				60						+			+			
				80						O						
				100						-						
				120												
				140												
Perchlorid acid (SpRB)	$HClO_4$		10%, aqueous	20	+	+	O	+	+	+		+	+	-	-	+
				40	+	+		+	+	+		O	+			+
				60	O	+		+	+	+			+			O
				80						+			O			-
				100						+						
				120												
				140												
Perchlorid acid (SpRB)			70%, aqueous	20	O	O	-	+	O	+		-	+	-	-	+
				40				O	-	+			+			+
				60				-		+			+			O
				80						+			O			
				100						+						
				120												
				140												
Petroleum			technically pure	20	+	-	-	+	+	+		-	+	+	O	-
				40				+	O	+			+	+	-	
				60				O	O	+			O	+		
				80						+						
				100						+			-			
				120						+						
				140												
Petroleum ether (SpRB)		40-70	technically pure	20	+	-	-	+	+	+		-	+	+	-	-
				40	+			O	O	+			+	O		
				60	+			O	O	+			O	-		
				80						+						
				100						+						
				120												
				140												
Phenol (SpRB)	C_6H_5-OH	182	up to 10%, aqueous	20	+	+	-	+	+	+			+	-	-	-
				40	O	+		+	+	+			+			
				60				O	+	+		+	+			
				80						+		O	O			
				100						+						
				120												
				140												

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Aggressive Media					Chemical Resistance										
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)	EPDM	FPM	NBR	CR	CSM
Phenol (SpRB)			up to 5%	20	+	+	-	+	+	+	+	+	-	-	
				40		+		+	+	+	O	+			
				60				+	+	+		+			
				80						+		O			
				100						O					
				120											
				140											
Phenol (SpRB)	C_6H_5-OH		up to 90%, aqueous	20	O	-	-	+	+	+	-	+	-	-	-
				40				+	+	+		O		O	
				60				O	+	O		-			
				80											
				100											
				120											
				140											
Phenylhydrazine	C_6H_5-NH-NH_2	243	technically pure	20	-	-	-	O	O	O	-	+	-	-	-
				40						-		+			
				60								O			
				80											
				100											
				120											
				140											
Phenylhydrazine hydrochloride	C_6H_5-NH-NH_2.HCl		aqueous	20	O	O	-		+	+		+	O	O	+
				40					O	+		+	-	-	+
				60					O	+	O	O			O
				80								-			-
				100											
				120											
				140											
Phosgene (SpRB)	$COCl_2$	8	liquid, technically pure	20	-	-	-	-	-	-	-	+	O	+	+
				40											
				60											
				80											
				100											
				120											
				140											
Phosgene (SpRB)			gaseous, technically pure	20	+	-	-	O	O	+	+	+	+	+	+
				40	O					+		+	+	O	O
				60	O							O	+	-	
				80											
				100											
				120											
				140											
Phosphate disodique	see d'isodiumphosphate		saturated												
Phosphoric acid	H_3PO_4		up to 30%, aqueous	20	+	+	+	+	+	+	+	+	O	+	+
				40	+	+	+	+	+	+	+	+	O	+	+
				60	O	+	O	+	+	+	O	+	-	+	+
				80		+			+	+		+		O	O
				100						+		+			
				120						+					
				140											
Phosphoric acid			50%, aqueous	20	+	+	+	+	+	+	+	+	O	+	+
				40	+	+	+	+	+	+	O	+	-	+	+
				60	+	+	O	+	+	+		+		O	+
				80		+			+	+		+			+
				100						+		O			O
				120						+					
				140											

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Phosphoric acid			85%, aqueous	20	+	+	+	+	+	+		+	+	-	+	+
				40	+	+	+	+	+	+		+	+		+	O
				60	+	+	O	O	+	+		O	+		O	-
				80		+			+	+			+			
				100						+			O			
				120						+						
				140												
Phosphoric acid	H_3PO_4			20	+	+	-	+	+	+		O	+	-	-	-
				40	+	+		+	+	+			+			
				60		+				+			O			
				80						+						
				100												
				120												
				140												
Phosphoric acid	H_3PO_4			20	+	+	-	+	+	+			+			
				40	+	+		+	+	+			+			
				60	+	+			+	+			+			
				80		+			+	+			+			
				100						+			O			
				120												
				140												
Phosphoric acid tributyl ester	$(H_9C_4O)_3P{=}O$			20	-	-	-	+	+	-		+	-			
				40												
				60												
				80												
				100												
				120												
				140												
Phosphorous chlorides: - Phosphorous trichloride - Phosphorous pentachloride - Phosphorous oxichloride (SpRB)	 PCl_3 PCl_5 $POCl_3$	 175 162 105	technically pure	20	-	-	-	+	O	-			+	-	-	+
				40												
				60				O	O							
				80												
				100												
				120												
				140												
Photographic developer (SpRB)			usual commercial	20	+	+	+	+	+	+		+	+	O	+	+
				40	+	+	+	+	+	+		+	+	O	+	+
				60	O	+	O	O		+						
				80		O										
				100												
				120												
				140												
Photographic emulsions (SpRB)				20	+	+	+	+	+	+		+	+	O	+	+
				40	+	+	+	+	+	+		+	+		+	+
				60		O				+						
				80												
				100												
				120												
				140												
Photographic fixer (SpRB)			usual commercial	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	O	+	O			+						
				80												
				100												
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Phthalic acid (SpRB)	$C_6H_4(COOH)_2$	Fp.*, 208	saturated, aqueous	20	+	-	-	+	+	+		+	-	-	+	+
				40	O			+	+	+		O			+	+
				60	-			+	+	+					O	
				80						+						
				100						+						
				120												
				140												
Phthalic acid dioctyl ester	$C_{24}H_{38}O_4$			20	-	-	-	+	+	-		+	-	-		
				40												
				60												
				80												
				100												
				120												
				140												
Picric acid (SpRB)	$C_6H_3N_3O_7$	FP. 122	1%, aqueous	20	+	-	-	+	+	+		+	+	O	O	+
				40						+		+	+	-	-	O
				60						+		+	+			-
				80						+		+	+			
				100						+		+	+			
				120												
				140												
Potash	see potassium carbonate		cold saturated, aqueous													
Potash lye	KOH		50%	20	+	+		+	+	-		+				
				40	+	+		+	+			+				
				60	+	+		+	+			+				
				80												
				100												
				120												
				140												
Potassium (SpRB)	$KMnO_4$		cold saturated, aqueous	20	+	+		+	+	+		+	+	O	O	+
				40	+	+		+	+	+			+	-	-	+
				60	O			O		+			+			+
				80						+			+			
				100						+						
				120												
				140												
Potassium acetate (SpRB)	CH_3COOK		saturated	20	+	+	+	+	+	+		+	-			
				40	+	+		+	+	+		+				
				60	+	+		+	+	+		+				
				80		+			+	+		+				
				100						+						
				120												
				140												
Potassium bichromate (SpRB)	$K_2Cr_2O_7$	107	saturated, aqueous	20	+	+	+	+	+	+		+	+	+	O	+
				40	+	+	+	+	+	+			+	O	-	+
				60	O	+	+	+	+	+			+			+
				80					+	+						
				100					+	+						
				120						+						
				140												
Potassium borate	K_3BO_3		10%, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+			+	+	+	+
				60	O	+	+	+	+	+			+	+	+	+
				80		+										
				100												
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Potassium bromate	$KBrO_3$		cold saturated, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	O	+	+	O	+	+		+	+	+	+	+
				80		+			+	+			+	+	O	+
				100					+	+				+	O	+
				120						+						
				140												
Potassium bromide	KBr		all, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	O	+	+	+	+	+		+	+	+	+	+
				80		+				+			+	O	+	+
				100						+			+	O	O	+
				120						+						
				140												
Potassium carbonate (potash)				20	+	+	+	+	+	O		+				
				40	+	+		+	+			+				
				60	+	+		+	+			+				
				80		+			+							
				100												
				120												
				140												
Potassium chlorate (SpRB)	$KClO_3$		cold saturated, aqueous	20	+	+	+	+	+	O		+	+	+	+	+
				40	+	+	+	+	+	-		+	+	O	O	+
				60	+	+	+	+	+				+			+
				80		+							+			O
				100									+			
				120												
				140												
Potassium chloride	KCl		all, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	+	+	+	+	+	+		+	+	+	+	+
				80		+			+	+			+			+
				100					+	+			+			
				120						+						
				140												
Potassium chromate (SpRB)	K_2CrO_4		cold saturated, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+		+	+			+	O	+	+
				60	+	+	+		+	+			+	-	O	O
				80						+						
				100						+						
				120												
				140												
Potassium cyanide	KCN		cold saturated, aqueous	20	+	+	+	+	+	+			+	+	+	+
				40	+	+	+	+	+	+			O	+	+	+
				60	+	+	+	+	+	O		+	-	+	O	+
				80		+			+			+		+	-	+
				100												
				120												
				140												
Potassium dichromate	$K_2Cr_2O_7$		saturated	20		+		+	+	+		+	+			
				40		+		+	+	+						
				60		+		+	+	+						
				80		+				+						
				100						+						
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Potassium fluoride	KF		saturated	20	+	+		+	+	+			+			
				40	+	+		+	+	+						
				60	+	+		+	+	+						
				80		+			+	+						
				100						+						
				120												
				140												
Potassium Hexacyanoferrate -(II)	$K_4[Fe(CN)_6]\cdot 3H_2O$			20	+	+		+	+	+		+	+			
				40	+	+		+	+	+						
				60	+	+		+	+	+						
				80		+			+	+						
				100						+						
				120												
				140												
Potassium hydrogen carbonate	$KHCO_3$		saturated	20	+	+		+	+	+		+	+			
				40	+	+		+	+	+		+				
				60	+	+		+	+	+		+				
				80		+			+							
				100												
				120												
				140												
Potassium hydrogen sulphate	$KHSO_4$		saturated	20	+	+		+	+			+				
				40	+	+		+	+			+				
				60	+	+		+	+			+				
				80		+			+			+				
				100												
				120												
				140												
Potassium iodide	KJ		cold saturated, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+			+	O	O	+
				60	+	+	+	+	+	+			+	·	-	+
				80		+				+			+			
				100						+						
				120												
				140												
Potassium nitrate	KNO_3		50%, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+			+	+	+	+
				60	+	+	+	+	+	+			+	+	+	+
				80		+				+						
				100						+						
				120												
				140												
Potassium perchlorate (SpRB)	$KClO_4$		cold saturated, aqueous	20	+	+		+		+		+	+	+	+	+
				40	+	+				+			+	O	O	+
				60	O	+				+			+			+
				80		+				+			+			O
				100												
				120												
				140												
Potassium persulphate (SpRB)	$K_2S_2O_8$		all, aqueous	20	+	+	+	+	+	+		+	+	-	+	+
				40	+	+	+	+	+	+		+	+		+	+
				60	O	+	+	+	+	+			+		+	+
				80						+			+		O	O
				100									+			
				120												
				140												

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Aggregressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Potassium sulphate	K_2SO_4		all, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	O	+	+	+	+	+			+	+	+	+
				80		+				+			+			
				100						+			+			
				120												
				140												
Potassium sulphide	K_2S		saturated	20	+	+		+	+	O		+				
				40	+	+		+	+	O		+				
				60	+	+		+	+	O		+				
				80		+			+			+				
				100												
				120												
				140												
Potassium sulphite	K_2SO_3		saturated	20	+	+		+	+			+				
				40	+	+		+	+							
				60	+	+		+	+							
				80		+										
				100												
				120												
				140												
Potassium-aluminiumsulfate (alum)			50%	20	+	+		+	+	+		+				
				40	+	+		+	+	+		+				
				60	+	+		+	+	+		+				
				80		+			+	+		+				
				100						+						
				120												
				140												
Pottasium hexacyanoferrate -(III)	$K_3[Fe(CN)_6]$.			20	+	+		+	+	+		+	+			
				40	+	+		+	+	+						
				60	+	+		+	+	+						
				80		+			+	+						
				100						+						
				120												
				140												
Pottasium tartrat				20	+			+	+	+		+				
				40	+			+	+	+		+				
				60				+	+	+		+				
				80					+	+						
				100						+						
				120												
				140												
Pottasiumhydrogensulfite				20	+					+		+				
				40	+					+		+				
				60						+						
				80						+						
				100						+						
				120												
				140												
Pottasiumhypochlorite	KOCl			20	+	O		+	+	O		+	O			
				40												
				60												
				80												
				100												
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Pottasiumperoxodisulfate	$K_2S_2O_8$		saturated	20	+	+										
				40	+	+										
				60	+	+										
				80		+										
				100												
				120												
				140												
Pottasiumphosphate	KH_2PO_4 und $K_2H\ PO_4$		all, aqueous	20	+	+	O	+	+	+		+	+	+	+	+
				40	+	+		+	+	+		+	+	O	O	+
				60	O	+		+	+	+			+	-	-	+
				80		+			+	+			+			O
				100									+			
				120												
				140												
Pottasiumphosphate				20	+				+							
				40	+				+							
				60	+				+							
				80					+							
				100												
				120												
				140												
Propane	C_3H_8	-42	technically pure, liquid	20	+	-	-	+	+	+		-	+	+	-	-
				40						+						
				60						+						
				80												
				100												
				120												
				140												
Propane			technically pure, gaseous	20	+	+	-	+	+	+		-	+	+	+	O
				40						+						
				60						+						
				80												
				100												
				120												
				140												
Propanol, n- and Iso- (SpRB)	C_3H_7OH	97 bzw. 82	technically pure	20	+	-	-	+	+	+		+	+	+	+	+
				40	O			+	+	+		+	+	O	+	O
				60	O			+	+	+			+	-	+	O
				80						O						
				100												
				120												
				140												
Propargyl alcohol (SpRB)	$CH{\equiv}C\text{-}CH_2\text{-}OH$	114	7%, aqueous	20	+	-	-	+	+	+		+	+	+	+	+
				40	+			+	+	O		+	+	+	+	+
				60	+			+	+	O			+	+	O	O
				80												
				100												
				120												
				140												
Propionic acid (SpRB)	CH_3CH_2COOH	141	50%, aqueous	20	+	O	-	+	+	+		+	+	-	O	O
				40	+			+	+	+		+	+		-	-
				60	O			+	+	+			O			
				80												
				100												
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Propionic acid (SpRB)		141	technically pure	20	+	O	-	+	+	+		+	+	-	-	-
				40	O			O	O	+		O	+			
				60				O	O	+			+			
				80									O			
				100												
				120												
				140												
Propylene glycol (SpRB)	$C_3H_8O_2$	188	technically pure	20	+	-	O	+	+	+		+	+	+	+	+
				40	+			+	+	+		+	+	O	+	+
				60	+			+	+	+			O	-		+
				80												
				100												
				120												
				140												
Propylene oxide	C_3H_6O	35	technically pure	20	O		-	+	+	+		O	-	-	-	-
				40						O						
				60												
				80												
				100												
				120												
				140												
Pyridine	C_5H_5N	115	technically pure	20	-	-	-	+	O	+		O	-	-	-	-
				40				O	O	-						
				60				O	O							
				80												
				100												
				120												
				140												
Pyrogallol	$C_6H_3(OH)_3$		100%	20						+			+			
				40						+						
				60												
				80												
				100												
				120												
				140												
Ramsit fabric waterproofing agents			usual commercial	20	+			+	+	+		+	+	+	+	+
				40	+					+						
				60	+					+						
				80												
				100												
				120												
				140												
Salicylic acid	$C_6H_4(OH)COOH$		saturated	20	+	+	O	+	+	+		+	+	+	+	+
				40	+			+	+	+		+				
				60				+	+	+		+				
				80						+						
				100												
				120												
				140												
Sea water	see Brine															
Silicic acid	$Si(OH)_4$			20	+	+	+	+	+			+				
				40	+	+		+	+			+				
				60	+	+		+	+			+				
				80					+							
				100												
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Silicone oil				20	+	+	+	+	+	+		+	+	+	+	+
				40	O	+		+	+	+		+	+	+	+	+
				60	-			+	+	+		+	+	+	O	
				80					+	+						
				100						+						
				120												
				140												
Silver	AgCn		saturated	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80												
				100												
				120												
				140												
Silver salts	$AgNO_3$, AgCN, AgCl		cold saturated, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	O	+	+	+	+	+		+	+	+	+	+
				80		+			+	+						
				100						+						
				120												
				140												
Silvercyanide				20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80												
				100												
				120												
				140												
Soap solution (SpRB)			all, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	O	+		+	+	+		+	+	+	+	+
				80						+						
				100						+						
				120												
				140												
Soda	see Sodium carbonate															
Sodium acetate	CH_3COONa		all, aqueous	20	+	+	+	+	+	+		+	-	+	+	O
				40	+	+		+	+	+		+		+	+	
				60	+	+		+	+	+		+				
				80		+			+	+						
				100					+	O						
				120												
				140												
Sodium aluminium sulfate				20	+			+	+							
				40	+			+	+							
				60	+			+	+							
				80					+							
				100												
				120												
				140												
Sodium arsenite	Na_3AsO_3		saturated	20	+	+		+	+			+				
				40	+	+		+	+			+				
				60	+	+		+	+			+				
				80		+			+							
				100												
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Sodium benzoate	C_6H_5-COONa		cold saturated, aqueous	20	+	+	-	+	+	+		+	+	+	+	+
				40	+	+		+	+	+		O	+	+	+	+
				60	O	+		+	+	+			+			O
				80		+				+			O			
				100						O						
				120												
				140												
Sodium bicarbonate	$NaHCO_3$		cold saturated, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	+	+	+	+	+	+		+	+	+	+	+
				80					+	+		+	+			
				100						+						
				120												
				140												
Sodium bisulphate	$NaHSO_4$		10%, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		O	+	O	+	+
				60	O	+	+	+	+	+			+	-	O	
				80						+			+			
				100						+			+			
				120						+						
				140												
Sodium bisulphite	$NaHSO_3$		all, aqueous	20	+	+		+	+	+		+	O	O	+	+
				40	O	+		+	+	+		O	-	-	+	+
				60	-	+		+	+	+		-			O	+
				80						+					-	O
				100						+						
				120												
				140												
Sodium borate	Na_3BO_3		saturated	20	+	+		+	+			+	+			
				40	+	+		+	+			+	+			
				60	+	+		+	+			+	+			
				80		+			+							
				100												
				120												
				140												
Sodium bromate	$NaBrO_3$		all, aqueous	20	+	+		+	+	+		+	+	-	+	+
				40	O	+		O	O	+			+	O	+	+
				60						+			+	-	O	+
				80						+						
				100						+						
				120												
				140												
Sodium bromide	NaBr		all, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+			+	O	+	+
				60	O	+	+	+	+	+			+		O	O
				80		+			+	+			+			
				100						+						
				120						+						
				140												
Sodium carbonate	see soda		cold saturated, aqueous													
Sodium chlorate (SpRB)	$NaClO_3$		all, aqueous	20	+	+	+	+	+	O		+	+	+	+	+
				40	+	+	+	+	+			+	+	O	+	+
				60	O	+	+	+	+			+	+	-	O	+
				80		+						O	+		-	O
				100								-				
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Sodium chlorite (SpRB)	$NaClO_2$		diluted, aqueous	20	O	+		+	+	+		+	+	-	O	+
				40		+		O	O	O		+	+		-	+
				60		+				O		+	+			+
				80		+										
				100												
				120												
				140												
Sodium chromate (SpRB)	Na_2CrO_4		diluted, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+		+	+		+	+	O	+	+
				60	O		+			+		+	+	-	O	O
				80						+						
				100						+						
				120												
				140												
Sodium disulphite	$Na_2S_2O_5$		all, aqueous	20	+	+		+	+	+		+	+	O	+	+
				40	+	+				+		+	+	-	+	+
				60	O	+				+		+	+		+	O
				80						+						
				100						+						
				120												
				140												
Sodium dithionite	see hyposulphite		up to 10%, aqueous													
Sodium fluoride	NaF		cold saturated, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+			+		+	+	+	+	+
				60	+	+	+			+		+	+	O	+	+
Sodium hydroxide (see Caustic soda)				80						+						
				100						+						
				120												
				140												
Sodium hypochlorite (SpRB)	NaOCl		12,5% active chlorine, aqueous	20	+			O	O	O		+	+	-	-	+
				40	+			-	-							
				60	O											
Sodium iodide	NaI		all, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+			+			+	+	+	+
				60	O	+	+			+			+	O	+	O
				80		+				+						
				100						+						
				120												
				140												
Sodium nitrate	$NaNO_3$		cold saturated, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	O	+		+	+	+		+	+	+	+	+
				80					+	+						
				100						+						
				120						+						
				140												
Sodium nitrite	$NaNO_2$		cold saturated, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+			+	O	+	+
				60	+	+		+	+	+			+	-	+	+
				80		+			+	+						
				100						+						
				120						+						
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Sodium oxalate	$Na_2C_2O_4$		cold saturated, aqueous	20	+	+	+	+	+	+			+	+	+	+
				40	+	+				+						
				60	O	+				O						
				80												
				100												
				120												
				140												
Sodium perborate	$NaBO_3 \cdot 4H_2O$		saturated	20	+	+		+	+	+		+	+			
				40	+	+				+						
				60	+	+				+						
				80		+										
				100												
				120												
				140												
Sodium perchlorate	$NaClO_4$		saturated	20	+	+		+	+			+	+			
				40	+	+										
				60	+	+										
				80		+										
				100												
				120												
				140												
Sodium persulphate (SpRB)	$Na_2S_2O_8$		cold saturated, aqueous	20	+			+	+	+		+	+	-	+	+
				40	+			+	+	+		+	+		+	+
				60	O			+	+	+			+		+	+
				80									+		O	O
				100									+			
				120												
				140												
Sodium phosphate	Na_3PO_4		cold saturated, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+		+	+	+		+	+	+	+	+
				60	O	+		+	+	+		+	+	+	+	+
				80		+			+	O						
				100					+	-						
				120												
				140												
Sodium silicate	Na_2SiO_3		all, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	O	+		+	+	O		+	+	+	+	+
				80					+	-						
				100												
				120												
				140												
Sodium Sulfide	Natriumsulfid															
Sodium sulphate	Na_2SO_4, $NaHSO_4$		cold saturated, aqueous	20	+	+	+	+	+	+		O	+	+	+	+
				40	+	+	+	+	+	+		O	+	+	+	+
				60	O	+	+	+	+	+		O	+	+	+	+
				80					+	+			+			
				100						+						
				120						+						
				140												
Sodium sulphide	Na_2S		cold saturated, aqueous	20	+	+	+	+	+	O		+	+	+	-	+
				40	+	+	+	+	+	O		+		+		+
				60	O	+	+	+	+	O		+		+		+
				80		+			+							
				100												
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Sodium sulphite	Na_2SO_3		cold saturated, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+		+	+	+		+	+	O	+	+
				60	O	+		+	+	+		+	+	-	O	+
				80		+			+	+						
				100						+						
				120												
				140												
Sodium thiosulphate	$Na_2S_2O_3$		cold saturated, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40										O	+	+
				60										-	O	O
				80												
				100												
				120												
				140												
Sodiumchloride	NaCl		each, aqueous	20	+	+	+	+	+	+		+	+			
				40	+	+	+	+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+		+	+			
				100						+			+			
				120												
				140												
Sodiumcyanide	NaCN			20	+	+		+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+							
				100												
				120												
				140												
Sodiumdichromate	Na_2Cs2O_7			20	O	+		+	+			+	+			
				40		+		+				+	+			
				60		+							+			
				80		+										
				100												
				120												
				140												
Sodiumhydrogen-carbonate	$NaHCO_3$			20	+	+	+	+	+	+		+	+			
				40	+	+		+	+	+		+				
				60	+	+		+	+	+		+				
				80		+			+							
				100												
				120												
				140												
Sodiumhydrogensulfate	$NaHSO_4$			20	+	+	+	+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+						
				100						+						
				120												
				140												
Spindle oil				20	O	O	-	O	+	+		-	+	+	O	-
				40					O	+			O	+	-	O
				60				O	-	+			-	O		-
				80						+				-		
				100												
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Spinning bath acids containing carbon disulphide (SpRB)			100 mg CS_2/l	20	+			+	+	+			+	-	-	O
				40	+					+						
				60												
				80												
				100												
				120												
				140												
Spinning bath acids containing carbon disulphide (SpRB)			200 mg CS_2/l	20	O			+	+	+		-	+	-	-	-
				40						+						
				60												
				80												
				100												
				120												
				140												
Spinning bath acids containing carbon disulphide (SpRB)			700 mg CS_2/l	20	-			+	+	+		-	+	-	-	-
				40						+						
				60												
				80												
				100												
				120												
				140												
Stannous chloride	see Tin II chloride		cold saturated, aqueous													
Stannous chloride - Tin IV chloride	$SnCl_4$		cold saturated, aqueous	20				+	+							
				40				+	+							
				60				+	+							
				80					+							
				100												
				120												
				140												
Starch solution	$(C_6H_{10}O_5)n$		all, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	+	+		+	+	+		+	+	+	+	+
				80		+				+						
				100						+						
				120												
				140												
Starch syrup			usual commercial	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	+	+		+	+	+		+	+	+	+	+
				80		+			+	+		+	+	+	+	+
				100						+		+	+	+	+	+
				120												
				140												
Stearic acid (SpRB)	$C_{17}H_{35}COOH$	Fp. 69	technically pure	20	+	O	+	+	+	+		+	+	+	+	O
				40	+		+			+		+	+	+	+	O
				60	+			O	O	+		O	O	O	O	-
				80						+						
				100						+						
				120						+						
				140												
Styrol				20	-	-	-			+			+			
				40												
				60												
				80												
				100												
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Succinic acid	HOOC-CH_2-CH_2-COOH	Fp*., 185	aqueous, all	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+		+	+	+		+	+	+	+	+
				60	+	+		+	+	+		+	+	+	+	+
				80									+			
				100												
				120												
				140												
Sugar syrup			usual commercial	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+	O	+	+	+		+	+	+	+	+
				60	O	+		+	+	+		+	+	+	+	+
				80					+	+		+	+			+
				100					+	+						
				120						+						
				140												
Sulfur	S	Fp.*, 119	technically pure	20	O	O	-	+	+	+		+	+	-	+	+
				40	-			+	+	+			+			+
				60				+	+	+			+			+
				80					+	+			+			+
				100						+						
				120						+						
				140												
Sulfur dioxide	SO_2	-10	technically pure, anhydrous	20	+	+	-	+	+	O		+	+	-	-	O
				40	+	+		+	+	O		O	O			-
				60	+	+		+	+	-		-				
				80												
				100												
				120												
				140												
Sulfur dioxide	SO_2		technically pure, moist	20	-	-	-	-	-	-		-	O	-	-	O
				40												
				60												
				80												
				100												
				120												
				140												
Sulfur dioxide	SO_2		all, moist	20	+	+	-	+	+	+		+	+	-	-	O
				40	+	+		+	+	O		O	O			-
				60	O			+	+	-		-	-			
				80												
				100												
				120												
				140												
Sulfur trioxide	SO_3			20	-	-	-	-	-	-		-	-	-	-	-
				40												
				60												
				80												
				100												
				120												
				140												
Sulfuric acid saturated by Chlorine	H_2SO_4+Cl_2		60%	20						+						
				40						+						
				60						+						
				80						+						
				100						+						
				120												
				140												

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Aggregative Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Sulfuric acid (see note 2.3.1 on jointing)	H_2SO_4	120	up to 40%, aqueous	20	+	+	+	+	+	+		+	+	O	+	+
				40	+	+	O	+	+	+		+	+	-	O	+
				60	O	+		+	+	+		+	+			O
				80		+				+		O	O			O
				100						+		-	-			-
				120						+						
				140												
Sulfuric acid (see note 2.3.1 on jointing) (SpRB)	H_2SO_4	140	up to 60%, aqueous	20	+	+	-	+	+	+		+	+	-	-	+
				40	+	+		+	O	+		+	+			O
				60	+	+		+	-	+		O	+			O
				80		+				+		-	O			-
				100						+						
				120						+						
				140												
Sulfuric acid (see note 2.3.1 on jointing) (SpRB)	H_2SO_4	195	up to 80%, aqueous	20	+	+	-	+	+	+		O	+	-	-	+
				40	+	+		+	+	+		O	+			O
				60	+	+		O	O	+		-	O			-
				80		+				+			-			
				100						+						
				120						O						
				140												
Sulfuric acid (see note 2.3.1 on jointing) (SpRB)	H_2SO_4	250	90%, aqueous	20	+	+	-	O	O	+		-	+	-	-	-
				40	+	+				+			+			
				60		+				+						
				80						+						
				100						O						
				120						O						
				140												
Sulfuric acid (see note 2.3.1 on jointing) (SpRB)	H_2SO_4		96%, aqueous	20	+	+	-	-	-	+		-	+	-	-	-
				40	+	+				+			+			
				60	O	+				-						
				80												
				100												
				120												
				140												
Sulfuric acid (see note 2.3.1 on jointing) (SpRB)	H_2SO_4		97%	20	+	+	-	-	-	O		-	+	-	-	-
				40		+										
				60												
				80												
				100												
				120												
				140												
Sulfuric acid (see note 2.3.1 on jointing) (SpRB)	H_2SO_4	340	98%	20	+	+	-	-	-	-		-	O	-	-	-
				40	O	+										
				60		O										
				80												
				100												
				120												
				140												
Sulfurous acid	H_2SO_3		saturated, aqueous	20	+	+	O	+	+	+		+	+	-	-	O
				40	+	+	+	+	+	+		-	+			O
				60	O			+	+	+			O			-
				80						+			-			
				100						+						
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Sulfuryl chloride	SO_2Cl_2	69	technically pure	20	-	-	-	-	-	O			+	-	O	+
				40												
				60												
				80												
				100												
				120												
				140												
Surfactants (SpRB)			up to 5%, aqueous	20	O	-	-	+	+	+		+	+	+	+	+
				40	O				O	O						
				60	O				O	O						
				80						O						
				100												
				120												
				140												
Surfactants (ESC)				20	O	O	O	O	O	O		O	O	O	O	
				40												
				60												
				80												
				100												
				120												
				140												
Tallow (SpRB)			technically pure	20	+	-	-	+	+	+		+	+	+	+	+
				40	+			+	+	+		+	+	+	+	+
				60	+			+	+	+		+	+	+	+	+
				80						+						
				100						+						
				120												
				140												
Tannic acid (SpRB)			all, aqueous	20	+	+	+	+	+				+	+	+	+
				40		+	+	+	+							
				60		+		+	+							
				80												
				100												
				120												
				140												
Tanning extracts form plants (SpRB)			usual commercial	20	+	+	+	+	+	+		+	+	+	+	+
				40		+	+									
				60												
				80												
				100												
				120												
				140												
Tartaric acid				20						+						
				40						+						
				60												
				80												
				100												
				120												
				140												
Tartaric acid	$HO_2C\text{-}CH(OH)\text{-}CH(OH)\text{-}CO_2H$		all, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+		+	+	+	+		+	+	+	+	+
				60	O			+	+	+		+	+	O	+	+
				80						+						
				100						+						
				120						+						
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Tartaric acid up to 10%				20						+						
				40						+						
				60						+						
				80												
				100												
				120												
				140												
Tetrachlorethylene				20	-	-	-	-	-	+		-	+			
				40												
				60												
				80												
				100												
				120												
				140												
Tetrachloroethane	Cl_2CH-$CHCl_2$	146	technically pure	20	-	-	-	O	O	+		-	O	-	-	-
				40						+						
				60						O						
				80												
				100												
				120												
				140												
Tetrachloroethylene	see Perchloroethylene	121														
Tetraetylene lead (SpRB)	$(C_2H_5)_4Pb$		technically pure	20	+	+	-	+	+	+		O	+	+	O	+
				40						+						
				60						+						
				80						+						
				100						+						
				120						+						
				140												
Tetrahydrofurane	C_4H_8O	66	technically pure	20	-	-	-	O	O	-		O	-	-	-	-
				40												
				60												
				80												
				100												
				120												
				140												
Tetrahydronaphthalene	Teralin	207	technically pure													
Thionyl chloride	$SOCl_2$	79	technically pure	20	-	-	-	-	-	-		O	+	-	-	-
				40												
				60												
				80												
				100												
				120												
				140												
Tin (IV) -chloride				20	+	+				+		+	+			
				40	+	+				+		+	+			
				60	+	+				+		+	+			
				80		+				+			+			
				100						+						
				120												
				140												

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Tin-(II)-chloride	$SnCl_2$			20				+	+							
				40				+	+							
				60				+	+							
				80					+							
				100												
				120												
				140												
Toluene	C_6H_5-CH_3	111	technically pure	20	-	-	-	O	O	+		-	+	-	-	-
				40												
				60												
				80												
				100												
				120												
				140												
Triacetin (Glycerintriacetat)	$C_9H_{14}O_6$			20	-	-	-	+	+	+		+				
				40						+						
				60												
				80												
				100												
				120												
				140												
Tributylphosphate	$(C_4H_9)_3PO_4$	289	technically pure	20	-	-	-	+	+	+		+	-	-	-	-
				40				+	+							
				60				+	+							
				80												
				100												
				120												
				140												
Trichloroacetic acid	Cl_3C-COOH	196	technically pure	20	O	-	-	+	+	O		O	-	-	-	-
				40				O	+							
				60				-	O							
				80												
				100												
				120												
				140												
Trichloroacetic acid	Cl_3-C-COOH		50%, aqueous	20	+	-	-	+	+	+		O	-	-	-	-
				40	O			+	+	+						
				60				+	O	O						
				80						-						
				100												
				120												
				140												
Trichloroethane	Methylchloroform	74	technically pure													
Trichloroethylene	Cl_2C=CHCl	87	technically pure	20	-	-	-	-	O	+		-	+	-	-	-
				40						+						
				60						+						
				80						O						
				100												
				120												
				140												
Trichloromethane	Chloroform	61														

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Aggressive Media					Chemical Resistance										
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)	EPDM	FPM	NBR	CR	CSM
Tricresyl phosphate (SpRB)	$H_3C\text{-}C_6H_5\text{-}O)_3PO_4$		technically pure	20	-	-	-	+	+		+	-	O	-	-
				40				+					-		
				60				+	O						
				80											
				100											
				120											
				140											
Triethanolamine (SpRB)	$N(CH_2\text{-}CH_2\text{-}OH)_3$	Fp. *21	technically pure	20	O	-	-	+	+	+	O	-	O	-	-
				40						+					
				60											
				80											
				100											
				120											
				140											
Triethylamine (SpRB)	$N(CH_2\text{-}CH_3)3$	89	technically pure	20	-	-	-	+	+	O	-	-	-	-	-
				40						-					
				60											
				80											
				100											
				120											
				140											
Trifluoro acetic acid (SpRB)	$F_3C\text{-}COOH$		up to 50%	20	-	-	-	+	+	+	O	-	-	-	-
				40						O					
				60											
				80											
				100											
				120											
				140											
Trioctyl phosphate (SpRB)	$(C_8H_{17})_3\,PO_4$		technically pure	20	-	-	-	+	+	O	+	-	O	-	-
				40				+	O						
				60											
				80											
				100											
				120											
				140											
Turpentine oil (SpRB)			technically pure	20	+	-	-	O	-	+	-	+	O	-	-
				40	O			O				+			
				60								+			
				80											
				100											
				120											
				140											
Urea (SpRB)	$H_2N\text{-}CO\text{-}NH_2$	Fp.*, 133	up to 30%, aqueous	20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	O	+		+	+	+	+	+	+	+	+
				80		O				+					
				100						O					
				120											
				140											
Urine				20	+	+	+	+	+	+	+	+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	O	+		+	+	+	+	+	+	+	+
				80						+					
				100						+					
				120											
				140											

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Vaseline			technically pure	20	O	O	-	+	O	+		-	+	+	-	-
				40	-					+			+	+		
				60				-	-	+			+	+		
				80						+			+	+		
				100						+			+	+		
				120						+			+			
				140												
Vegetable oils				20	O	-	-	+	+	+		-	+	+	O	O
				40						+						
				60						+						
				80												
				100												
				120												
				140												
Vegetable oils and fats (SpRB)				20	+	O	-	+	+	+		-	+	+	O	O
				40	O			O	+	+			+	+	O	O
				60					O	+			+	+	-	-
				80						+						
				100						+						
				120												
				140												
Vinegar	see wine vinegar															
Vinyl acetate	$CH_2{=}CHOOCCH_3$	73	technically pure	20	-	-	-	+	+	+		+	-	-	-	-
				40				+		-						
				60					O							
				80												
				100												
				120												
				140												
Vinyl chloride	$CH_2{=}CHCl$	-14	technically pure	20	-	-	-	-	-	+		-	+	-	-	
				40						+						
				60												
				80												
				100												
				120												
				140												
Viscose spinning solution				20	+	-	-	+	+	+			+	-	O	+
				40	+			+	+	+		+	+		O	+
				60	+			+	+	+		+	+		-	+
				80												
				100												
				120												
				140												
Waste gases containing - Alkaline				20	+	+		+	+	+		+	+	+	+	+
				40	+	+		+	+	O		+	+	+	+	+
				60	+	+		+	+	-		+	+	+	+	O
				80		+			+			+	O			-
				100									-			
				120												
				140												
Waste gases containing - Carbon oxides			all	20	+	+		+	+	+		+	+	+	+	+
				40	+	+		+	+	+		+	+	+	+	+
				60	+	+		+	+	+		+	+	+	+	+
				80		+			+	+		+	+			+
				100						+			+			
				120						+						
				140												

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Aggressive Media					Chemical Resistance										
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)	EPDM	FPM	NBR	CR	CSM
Waste gases containing - Hydrochloric acid			all	20	+	+		+	+	+	+	+	O	+	+
				40	+	+		+	+	+	+	+	-	+	+
				60	+	+		+	O	+	+	+		+	+
				80		+				+	O	+			+
				100						+		+			
				120						+					
				140											
Waste gases containing - Hydrogen fluoride (SpRB)			traces	20	+	+		+	+	+	+	+	+	+	+
				40	+	+		+	+	+	+	+	O	+	+
				60	+	+		+	+	+	O	+	-	O	+
				80		+				+		+			
				100						+					
				120											
				140											
Waste gases containing - Nitrous gases			traces	20	+	+		+	+	+	+	+	O	+	+
				40	+	+		+	+	+	+	+	-	+	+
				60	+	+		+	O	+	+	+		O	+
				80		+				+	O	+			O
				100						+		O			
				120											
				140											
Waste gases containing - Sulphur dioxide			traces	20	+	+		+	+	+	+	+	O	+	+
				40	+	+		+	+	+	+	+	-	+	+
				60	+	+		+	+	+	+	+		+	+
				80		+			+	+	+	+			+
				100						+		+			
				120						+					
				140											
Waste gases containing - Sulphur trioxide (SpRB)			traces	20	+	+		+	+	+	+	+	O	+	+
				40	+	+		+	+	+	+	+	-	+	+
				60	+	+		+	O	+	+	+		+	+
				80		+				+	O	+			
				100						+					
				120											
				140											
Waste gases containing - Sulphuric acid			all	20	+	+		+	+	+	+	+	O	+	+
				40	+	+		+	+	+	+	+	-	+	+
				60	+	+		+	+	+	+	+		+	+
				80		+			O	+	O	+			+
				100						+		+			
				120						+					
				140											
Water - distilled - deionised	H_2O	100		20	+	+	+	+	+	+		+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	+	+	+	+	+	+	O	+	+	+	+
				80		+			+	+	-	+	+		+
				100					+	+		+	+		
				120						+		+			
				140											
Water, condensed				20	+	+	+	+	+	+		+	+	+	+
				40	+	+	+	+	+	+	+	+	+	+	+
				60	O	+	+	+	+	+	O	+	+	+	+
				80		+			+	+		+	O		+
				100						+					
				120						+					
				140											

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Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Water, drinking, chlorinated				20	+	+	+	+	+	+			+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60	+	+	+	+	+	+		O	+	+	+	+
				80					+	+			+	O		+
				100					+	+			+			
				120						+						
				140												
Water, waste water without organic solvent and surfactants				20	+	+	+	+	+	+			+	+	+	+
				40	+	+	+	+	+	+		+	+	+	+	+
				60		+	+	+	+	+		O	+	+	+	+
				80		+			+	+			+	+		+
				100						+				O		
				120						+						
				140												
Wax alcohol (SpRB)	$C_{31}H_{63}OH$		technically pure	20	+	O	-	O	O	+		+	+	+	+	-
				40	+			-	-	+		+	+	+	+	
				60	+					+		+	+	+	+	
				80												
				100												
				120												
				140												
Wine vinegar (SpRB)			usual commercial	20	+	o	O	+	+	+		+	O	-	O	+
				40	+			+	+	+			-		-	O
				60	+			+	+	+						-
				80					+	+						
				100						+						
				120												
				140												
Wines, red and white			usual commercial	20	+	O	+	+	+	+		+	+	+	+	+
				40			+	+	+	+						
				60				+	+	+						
				80						+						
				100						+						
				120												
				140												
Xylene	$C_6H_4(CH_3)_2$	138? 144	technically pure	20	-	-	-	-	-	+		-	+	-	-	-
				40						+			O			
				60						O			-			
				80						-						
				100												
				120												
				140												
yeasts			all, aqueous	20	+	+	+	+	+	+		+	+	+	+	+
				40	+	+		+	+	+		+	+	+	+	+
				60		+		+	+	+						
				80		+				+						
				100												
				120												
				140												
Zinc salts	$ZnCl_2$, $ZnCO_3$, $Zn(NO_3)_2$, $ZnSO_4$		all, aqueous	20	+	+	+	+	+	+			+	+	+	+
				40	+	+	+	+	+	+		+	+	O	+	+
				60	O	+		+	+	+		+	+	-	+	+
				80						+						
				100						+						
				120						+						
				140												

(Courtesy George Fischer Engineering Handbook)

Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
Zinccarbonate				20	+	+	+	+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+		+	+			
				100						+						
				120												
				140												
Zincchloride			saturated	20	+	+	+	+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+			+			
				100						+						
				120												
				140												
Zincnitrate	$Zn(NO_3)_2$		saturated	20	+	+	+	+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+			+			
				100						+						
				120												
				140												
Zincoxide			Suspension	20						+						
				40						+						
				60						+						
				80						+						
				100						+						
				120												
				140												
Zincphosphate			saturated	20	+	+	O	+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+			+			
				100						+						
				120												
				140												
Zincstearate			Suspension	20	-	-	-	+	+	+		+	O			
				40				+	+	+		+				
				60				+	+	+		+				
				80					+	+						
				100						+						
				120												
				140												
Zincsulfate	$ZnSO_4$			20	+	+		+	+	+		+	+			
				40	+	+		+	+	+		+	+			
				60	+	+		+	+	+		+	+			
				80		+			+	+		+	+			
				100						+			+			
				120												
				140												
1-Chloropentan	$C_5H_{11}Cl$			20	-	-	-									
				40												
				60												
				80												
				100												
				120												
				140												

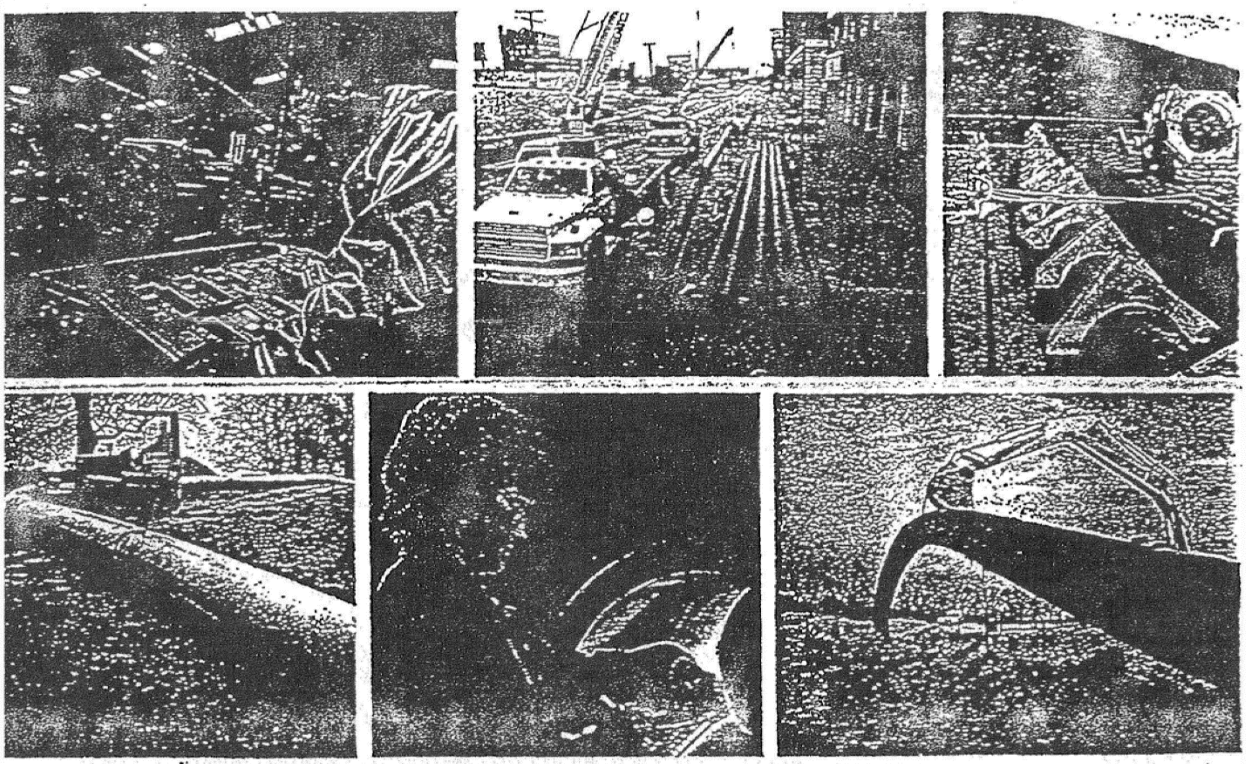
(Courtesy George Fischer Engineering Handbook)

Aggressive Media					Chemical Resistance											
Medium	Formula	Boiling point °C	Concentration	Temperature °C	PVC	CPVC	ABS	PE	PP-H	PVDF (SYGEF)		EPDM	FPM	NBR	CR	CSM
1,1,2-Trifluoro, 1,2,2-Trichloroethane (Freon 113) (SpRB)	$FCl_2C\text{-}CClF_2$	47	technically pure	20	+		-			+			+	+	+	+
				40	+											
				60												
				80												
				100												
				120												
				140												

(Courtesy George Fischer Engineering Handbook)

DRISCOPIPE

Engineering Characteristics



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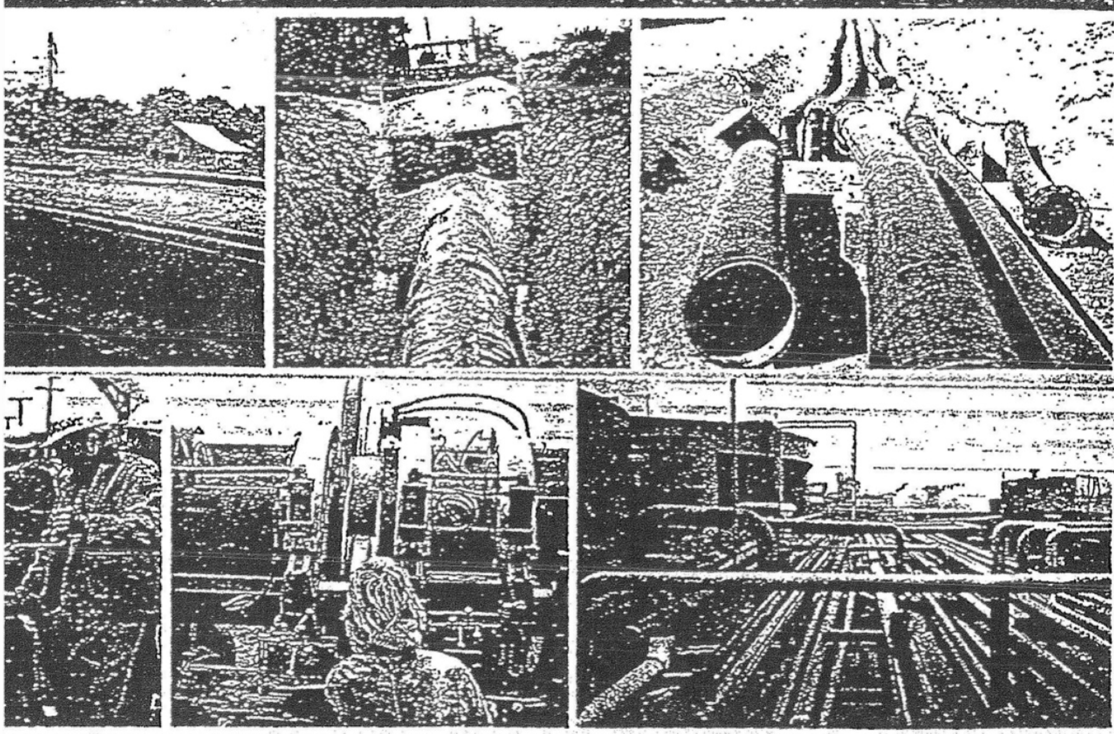
Photographs shown are typical Driscopipe installations.



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Driscopipe® Engineering Characteristics

Introduction

Driscopipe high density polyethylene piping systems offer the modern engineer the opportunity to take advantage of the unusual characteristics of these materials and use them to solve many old problems and to design systems for applications where traditional materials are either unsuitable or too expensive. When compared to the older traditional piping materials, Driscopipe polyethylene piping systems offer a new freedom in environmental design, extended service life, significant savings for installation labor and equipment costs, and reduced maintenance for pipeline systems where operating conditions are within the pressure and temperature capabilities of the material.

This brochure outlines the Engineering Characteristics of Driscopipe high density polyethylene pipe and fittings and points out many of the advantages and benefits to be realized through the use of these systems. The discussion is directed primarily toward the large diameter (3" through 54") Driscopipe 8600 and Driscopipe 1000 Industrial and Municipal product lines. However, these engineering characteristics are also typical of other Driscopipe polyethylene product lines.

Physical Properties

Driscopipe 8600 is manufactured from Marlex M-8000 very high molecular weight high density PE 3408 resin. Pipe and fittings made from Marlex M-8000 are extremely tough and durable, and possess exceptional long term strength. Marlex M-8000 is a proprietary product and is extruded only by Phillips Driscopipe, Inc.

Driscopipe 1000 is manufactured from Marlex TR-480, a PE 3408 polyethylene pipe resin in a molecular weight range which permits the pipe to be extruded by conventional methods. In this respect, Driscopipe 1000 is comparable to other extra high molecular weight, high density, PE 3408 polyethylene pipes commercially available in North America.

Sheets detailing typical physical properties for Driscopipe 1000 and Driscopipe 8600 are available upon request.

Long Term Hydrostatic Strength

One of the outstanding engineering characteristics of Driscopipe high density polyethylene pipe is its long term hydrostatic strength under various thermal and environmental conditions. Life expectancy is conservatively estimated to be in excess of 50 years using the standard design basis. This strength is determined by standardized methods and procedures which the plastic pipe industry has used for many years to evaluate the long term strength of all types of plastic pipe.

Pipe hoop stress versus time to failure plots of long term hydrostatic pressure data for thermoplastic pipe have been studied and analyzed for many years. The mathematical equations used to evaluate the test data and extrapolate values to longer periods of time were chosen after careful evaluation of more than 1,000 sets of long term test data representing more than 400 plastic pipe compounds. Continued testing on new compounds and extended testing of older compounds have proven the validity of these test methods. Actual data from more than 11½ years (100,000 hours) of continuous testing shows the industry methods to be slightly conservative in that actual values are slightly higher than those calculated by the industry-accepted ASTM method.

The reduction in strength which occurs with time, as indicated by the stress-life curves, does not represent a strength degradation of the material but is more in the nature of a relaxation effect. Plastic pipe samples which have been on test for periods up to 70,000 hours have been de-pressurized and checked for permanent reduction of strength by using the quick-burst test. No loss has been found when compared to samples previously quick-burst from the same test lot.

All evidence confirms that the methods used to predict the long term strength of plastic pipe are sound methods. Through the years, these policies and procedures, used to develop recommended hydrostatic design strengths, have influenced manufacturers to research and develop improved piping products such as Driscopipe 8600 and Driscopipe 1000.

Typical calculated long term strengths are shown below:

Long Term Strength @ 73.4°F(23°C)

Time	Hoop Stress, psi
100,000 hrs. (11.43 yrs.)	1635
438,000 hrs. (50 yrs.)	1604
500,000 hrs. (57 yrs.)	1601
1,000,000 hrs. (114 yrs.)	1586

The 114-year long term strength has been included to show more about the nature of the method used by the industry to evaluate the long term strength of plastic pipe and to illustrate the very slow reduction in strength as time progresses.

Long term hoop stresses for design purposes are normally selected at a level which is much lower than the long term strength of the materials. This ensures that the pipe is operating in a hoop stress range where creep (relaxation) of the materials is nil and assures service life in excess of 50 years. Design stress levels are discussed further in the next section.

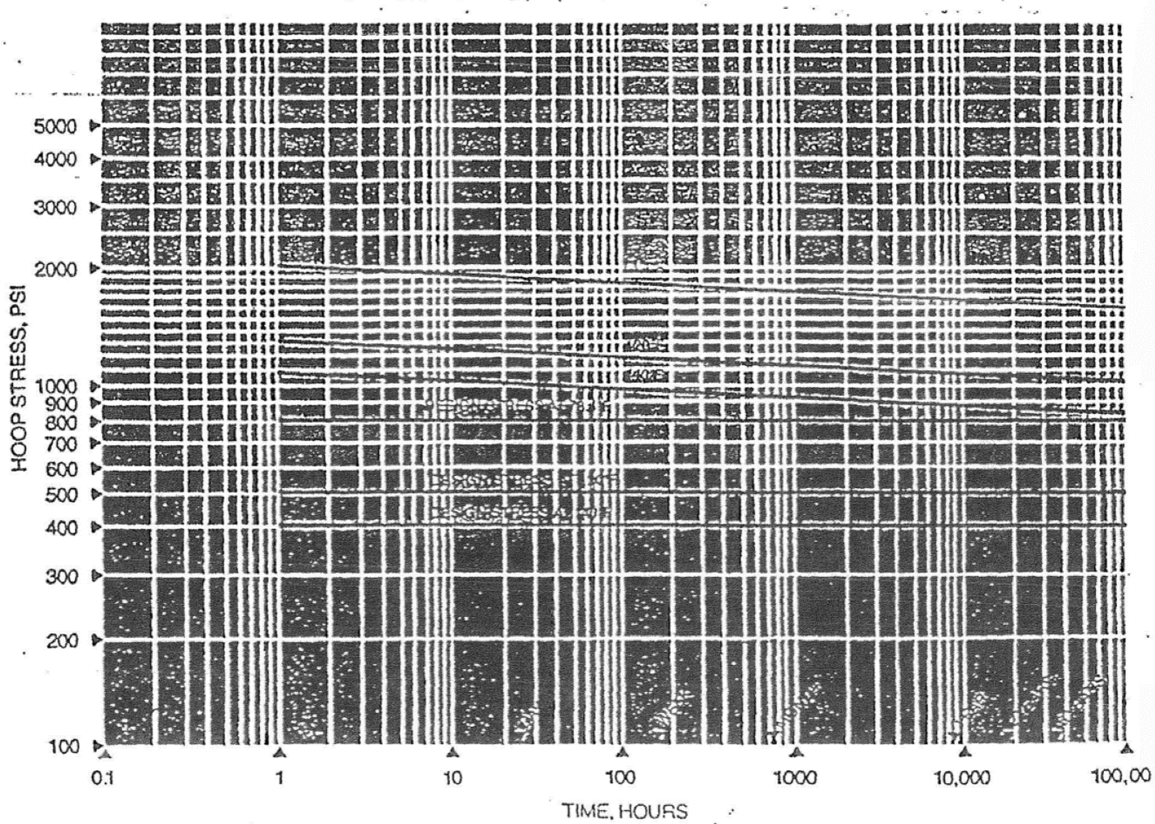
The long term hydrostatic tests are conducted by using ASTM standard test procedures which may be applied to all types of plastic pipe (ASTM D 1598 Test for Time-to-Failure of Plastic Pipe Under Constant Internal Pressure). Stress-life tests are conducted by using numerous pipe samples which are filled with water (or other environmental fluids) and subjected to a controlled pressure at a controlled temperature.

Samples are held on test until they fail. The pressure, temperature and time-to-failure data from all samples are used to calculate and plot stress-life curves for the particular type pipe being tested (ASTM D 2837 Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials). This data is then used to predict the probable safe life of the pipe at various stress levels (working pressures) and various temperatures. Because it is not practical to test at all temperature levels, these tests are generally conducted at temperatures of 73.4°F and one or more higher temperatures such as 100°F, 120°F and 140°F.

These stress-life curves give a relationship of the expected life span of the pipe when subjected to various internal stress levels (working pressures) at various temperatures. By comparing stress-life curves, one can compare relative long term performance ability of different plastic pipes. Stress-life curves for Driscopipe 8600 and Driscopipe 1000 are shown in Figure 1.

Figure 1

Stress-Life of Driscopipe® 8600 and Driscopipe® 1000



Th·ese stress-life curves were obtained using water as ... st medium. However, years of laboratory testing an.. field experience have shown that these same curves may be used to design Driscopipe systems for natural gas, salt water, sewage and hundreds of other industrial and municipal fluids, mixtures and effluents. The long term strength of Driscopipe indicated by these curves must be de-rated in some environmental circumstances, such as in the presence of liquid hydrocarbons or abrasive fluids, although the pipe is very suitable for use in these environments. An outstanding engineering advantage of Driscopipe is its exceptionally long term service life in the presence of internal and external corrosive service conditions.

Design Pressure Ratings

Since plastic pipe was introduced in the late 50s, the safety factor for design of water systems at standard temperature has been 2 to 1. The 2:1 design factor which was officially adopted by the plastic pipe industry in 1963, was based on allowances for many sources of variation. The guiding principle has always been to make the selection on a conservative basis but not to be unreasonably conservative.

The sources of variation for which allowances are made include ... variation in test methods and ...cedures among laboratories ... variation among ..s of the same compound ... variation of lots of pipe .rom the compound in different plants and from different extruders ... variation in compounds of the same general class ... variations in handling and installation techniques ... variation in operating pressures (water hammer and surge) ... a strength-time allowance to give service life well beyond 50 years ... and, finally, the great unknown. Each of the factors was judged to reduce the 100,000 hour design strength by 5%-10% or 20% ... for a total of 100% ... or a design factor of 2:1. This is why polyethylene pipe, with a designated 100,000 hour strength of 1600 psi at 73.4°F, has a hydrostatic design strength of 800 psi hoop stress.

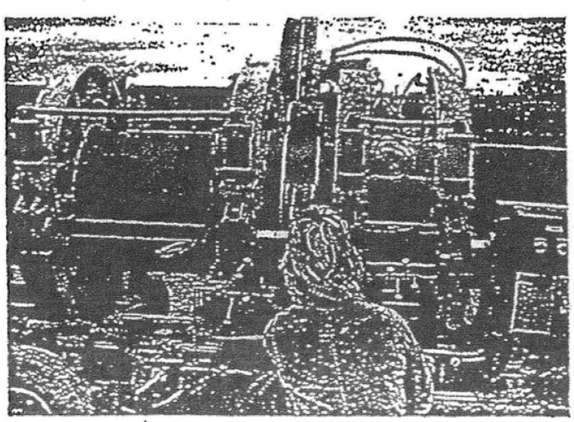
The design pressures for Driscopipe are determined by the following equation, adopted internationally by the industry for this purpose:

$$P = \frac{2S}{SDR-1} \times F \quad \text{or} \quad P = 2S\frac{t}{D-t} \times F$$

Where:
- D = Specified Outside Diameter, Inches
- P = Design Pressure, psi
- S = Long Term Hydrostatic Strength, psi, at the design temperature
- t = Minimum Wall Thickness, Inches
- F = Service Design Factor
- SDR = Standard Dimension Ratio of D/t

The traditional Service Design Factor for water at standard temperature (73.4°F) is one-half (.5). The Service Design Factor for oil or liquid hydrocarbons is 0.25 @ 73°F. The service design factor may be adjusted by the design engineer to reflect the particular conditions anticipated for the application. The temperature selected for design should consider both internal and external conditions. The design temperature should be based on the temperature of the pipe itself. For practical purposes, it is safer to design to the highest temperature.

The design service factor for water may also be used for solutions of inorganic salts, alkaline fluids, non-oxidizing acids, low concentrations of oxidizing acids and many other solutions. See the discussion on chemical resistance for more information.



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All standard design pressure ratings shown in Driscopipe literature are based on water at 73.4°F temperature; ie, a safety factor of 2:1 based on the long term hydrostatic strength of the material. Driscopipe is applicable at pressures from 0 to 265 psi and temperatures from below 32°F up to 180°F. Standard Dimension Ratios (SDR) are available from SDR 32.5 to SDR 7.0

Flow Characteristics

Driscopipe polyethylene has excellent flow characteristics as compared to traditional materials. An extremely smooth interior surface offers low resistance to flow. It maintains these excellent flow properties throughout its service life in most applications due to the inherent chemical and abrasion resistance of the material. Because of smooth walls and the non-wetting characteristic of polyethylene, higher flow capacity and less friction loss is possible with Driscopipe. In many cases this higher flow capacity may permit the use of smaller pipe at a lower cost.

A "C" factor of 155 is commonly used in the Hazen-Williams formula for calculating flow in pressure applications. For gravity flow, an "n" factor of .009 is used in Manning's formula.

Experimental test data regarding pumping and pressure drop through Driscopipe is available upon request. This study compares the flow through 8" Driscopipe with and without internal fusion beads using clear water. It also includes flow data for some clay-water slurries and clay-water-sand slurries. Velocities up to 20 fps are studied. Data includes determination of Hazen-Williams "C" factor, Reynolds number, boundry drag, relative roughness, sand grain roughness and friction loss at various velocities.

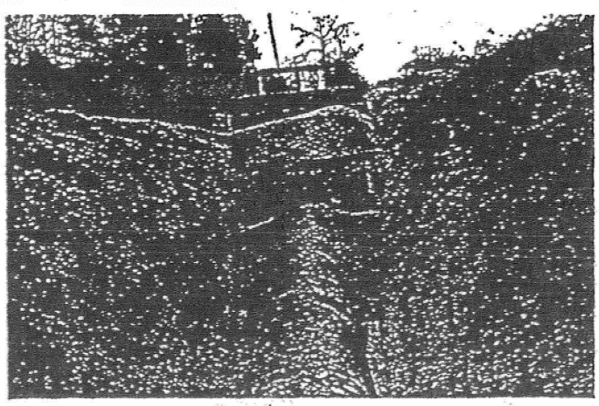
Lightweight – Flexible

The inherent light weight and flexibility of Driscopipe provides many cost saving benefits related to handling, storage, hauling, unloading, stringing, joining and installation. Because of its light weight, Driscopipe can be moved, handled and placed in the ditch with smaller and less expensive construction equipment. Usually, manpower requirements are also reduced.

Driscopipe weighs less than water; it has a specific gravity of .955-.957. Because it will float, it can be joined in long strings and easily towed into position on job sites where water is encountered. The combination of light weight and flexibility provides opportunity to fusion join the pipe in a convenient work area and pull it into position in difficult work areas where terrain or other obstacles present installation problems. The pipe can be joined above ground and rolled or lowered into the trench thus allowing the use of smaller trench widths and eliminating the necessity of placing men and equipment inside the trench. Such installation methods can dramatically reduce the time required for installation in many instances.

The flexibility of Driscopipe allows it to be curved over, under and around obstacles and to make elevation and directional changes, thus eliminating fittings and reducing installation costs. The pipe can be cold bent as it is installed to a radius of 20-40 times the pipe diameter. This flexibility and the butt fusion joining method make Driscopipe ideally suited for inserting it inside older piping systems to renew and renovate such systems at a much lower cost than would be possible otherwise.

Pipe flexibility and toughness also allow small diameter Driscopipe to be plowed-in or pulled-in with suitable equipment.



Toughness — "Ductile PE Pipe"

Overall "toughness" of Driscopipe is an important characteristic of the pipe which is derived from many of the chemical and physical properties of the material as well as the extrusion method. The pipe is ductile. It flexes, bends and absorbs impact loads over a wide temperature range of −180°F up to +180°F. This inherent resiliency and flexibility allow the pipe to absorb surge pressures, vibration and stresses caused by soil movement. Driscopipe can be deformed without permanent damage and with no adverse effect on long term service life. It is flexible for contouring to installation conditions. The toughness of Driscopipe is one of its outstanding engineering characteristics leading to innovative piping design.

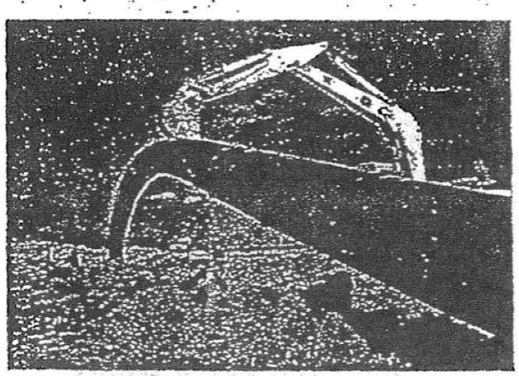
Even though "toughness" has become generally recognized by the industry as a highly desirable characteristic ... there is no standard test which can be used to directly compare the "toughness" among polyethylenes ... as well as among the different plastic materials which are considered suitable for piping.

A "toughness" test has not been devised is simply because it is influenced by so many of the physical and chemical properties of the material. The extreme toughness of Driscopipe has been noted as one of its outstanding features since its introduction to the industry ... yet to explain "toughness", many properties are discussed and demonstrated. To obtain a complete evaluation of the toughness of a plastic material, it is necessary to see demonstrations of tests and to conduct some tests in person in order to compare it with materials which are more familiar, such as cast iron, steel, cement, copper, etc.

Toughness is related to ... Environmental Stress Crack Resistance (ESCR) ... Notch sensitivity ... Resistance to secondary stresses from external loading ... Impact strength ... Tear strength ... Flexibility ... Kink resistance ... Abrasion and scratch resistance ... Flexural strength ... Elongation ... Chemical resistance ... Tensile strength ... Ductility ... Creep resistance ... Temperature resistance ... Density ... Molecular weight ... and the thermoplastic nature of the material. Part of the toughness of any polyethylene material can be attributed to its flexibility, flexural strength and impact resistance as compared to the more rigid thermoplastic materials such as PVC. Polyethylene is ductile and will elongate many times more than PVC. Consequently, it will absorb more impact without damage or failure. PE will flex or elongate and stress relieve itself rather than rupture. Generally, impact strength is greater for the higher molecular weight PE resins. Impact resistance is also important from the standpoint of a piping system being able to absorb energy imposed on it by external forces.

The expansive force of water freezing inside Driscopipe will not damage it.

ESCR is one of the properties closely related to "toughness" and has been studied as a possible means to define and measure toughness. The exceptional resistance of Driscopipe 8600 to environmental stress cracking as compared to other PE materials is discussed further in the next section.



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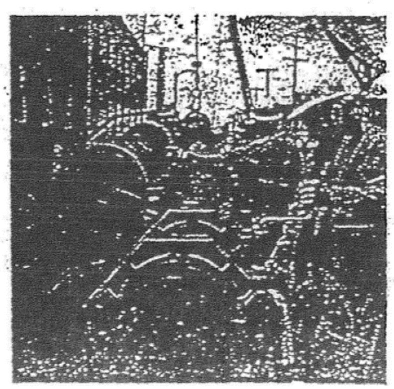
Driscopipe 8600 is unique and differs from Driscopipe 1000 and from all other polyethylene pipes. Driscopipe 8600 exhibits a superior toughness which gives the pipe the highest impact strength, highest tear strength and lowest notch sensitivity of any polyethylene pipe currently available. Driscopipe 8600 offers the highest resistance to cuts, scratches and abrasions which occur when handling and installing the pipe.

These properties are maintained throughout its temperature range without a loss of ductility or reduced resistance to notch sensitivity. Driscopipe has been successfully installed in numerous arctic applications. Some of these applications have included direct burial in the unstable arctic permafrost.

To learn more of the relative toughness of Driscopipe 8600, we encourage you to take a piece of pipe with a butt fusion joint and try to tear it up without using sharp tools. Pound it flat with a sledge hammer ... slam it against a corner of angle iron ... run over it with a truck ... then do the same with steel, copper, PVC, cast iron and the less rugged PEs. It's not very scientific ... but we believe you'll be convinced that Driscopipe 8600 has extremely high toughness. We have evaluated Driscopipe many times in laboratory and field test experiments to demonstrate and prove this toughness.

- One excellent indicator of the relative toughness of Driscopipe 8600, as compared to other polyethylene pipe materials, can be observed in the ASTM Standard Test for determination of flow rate of the thermoplastic materials.

  When Driscopipe 8600 is heated to 190°C (374°F) to measure the flow rate, it requires 432.5 pounds/sq. in. force, applied for 10 minutes, to flow 1½ grams of 8600 material through the orifice of the test unit! Other commercially available polyethylene pipe materials will flow 10 to 20 times this amount under the same conditions.
- When Driscopipe 8600 is heated to 475-500°F to melt it for fusion joining, it requires 150 pounds pressure per square inch of material to make the melted surfaces flow together. This is another indicator of toughness. Other commercially available polyethylene pipe materials require about one-half that amount of pressure and some competitive pipes require less than 25 psi!
- Driscopipe 8600 has been pressure tested for long periods at temperatures up to 140°F and performance requirements at these high temperatures can be used in purchase specifications to assure that the user is getting the highest performing polyethylene pipe.



Environmental Stress Crack Resistance

The most recent ASTM specification written to identify polyethylene plastic pipe and fittings materials is ASTM D 3350, "Polyethylene Plastics Pipe and Fittings Materials", adopted in 1974. This specification uses six (6) properties to classify PE material ... one of these is ESCR.

ASTM D 3350 lists three cell limits for ESCR classification which use the ESCR test outlined in ASTM D 1693, Test Method for Environmental Stress Cracking of Ethylene Plastics. The cell limits are:

Cell Classification Limit	Test Condition ASTM D 1693	Test Duration Hours	Percent of Failures Allowed	Test Temp. °C
1	A	48	50	50°
2	B	24	50	50°
3	C	192	20	100°

Minimum Notch for A is .020"; for B and C is .012". Minimum Thickness for A is .120"; for B and C is .070". A and B use a diluted aqueous solution reagent, C uses full strength reagent.

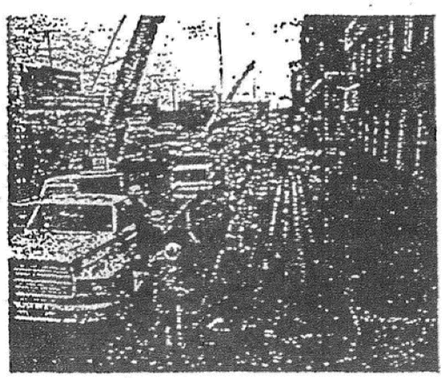
This method of testing for ESCR was first written in 1959 and was developed primarily to evaluate polyethylene as a jacketing material for power and communications cable. Although the method requires the use of laboratory compression molded specimens rather than pipe, it became the generally accepted method for evaluating ESCR of PE materials used for piping. Its wide use was responsible for its inclusion in ASTM D 3550 to describe one of the six primary properties of a PE pipe material.

The test method, ASTM D-1693, is an accelerated test method to determine the resistance of a polyethylene material to environmental stress cracking. It is a measure of the ability of the polyethylene to withstand secondary stress loadings. These loadings are typically thought of as low-level, long-term, external stresses which may act upon the polyethylene pipe in field installations.

Under conditions of the test, high local multiaxial stresses are developed through the introduction of a controlled imperfection (notch). The notched sample is subjected to an elevated temperature bath of a surface active agent. Environmental stress cracking has been found to occur most readily under such conditions.

A note in the test specifications states that, generally, low density (Type I) polyethylenes are tested under Condition A, medium and high density (Type II and Type III) polyethylenes are generally tested under Condition B and high density resins with high melt viscosity, such as pipe grade P34, are tested under Condition C.

As pipe grade polyethylenes have improved, the testing requirements of ASTM D-1693 have become less stringent for P34 pipe grade polyethylenes such as Driscopipe 8600 and Driscopipe 1000. As a result, a more severe stress crack resistance test has been developed to evaluate high density polyethylene pipe. The ASTM F-1248 stress crack resistance test method was developed by a gas distribution company for quality control purposes and is often referred to as Ring ESCR since it tests actual produced pipe ring samples rather than molded specimens.



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ASTM F-1248 utilizes rings cut from a pipe sample. The rings are notched on one side and compressed between parallel plates until the distance between the plates is three times the specified pipe minimum wall thickness. The compressed ring samples are subjected to an elevated temperature bath of a surface active agent and visibly inspected for crack formation or propagation.

The Ring ESCR test provides useful information regarding the different polyethylene pipe grade materials. Driscopipe 8600 shows no tendency for sample failures when tested in excess of 10,000 hours. This further reinforces the unique ability of Driscopipe 8600 to provide the highest degree of resistance to the external stresses inherent to a pipeline installation.

Driscopipe 1000, an extra high molecular weight HDPE pipe, will exhibit a ring ESCR of F_{50}>1000 hours. Other lower molecular weight pipes may exhibit lower F_{50} values.

Chemical Corrosion Resistance

The outstanding resistance of Driscopipe to attack by most chemicals makes it suitable to transport these chemicals or to be installed in an environment where these chemicals are present. Factors which determine the suitability and service life of each particular application include the specific chemical and its concentration, pressure, temperature, period of contact and service conditions which may introduce stress concentrations in the pipe or fittings.

Driscopipe is, for all practical purposes, chemically inert within its temperature use range. This advantageous engineering characteristic is one of the primary reasons for the wide use of Driscopipe in industrial applications. It does not rot, rust, pit, corrode or lose wall thickness through chemical or electrical reaction with the surrounding soil, whether acid, alkaline, wet or dry. It neither supports the growth of, nor is affected by, algae, bacteria or fungi and is resistant to marine biological attack. It contains no ingredients which make it attractive to rodents, gophers, etc.

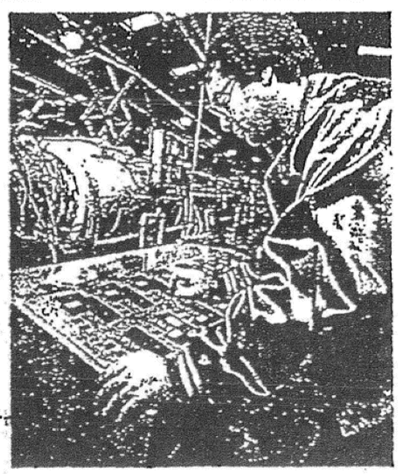
Information relative to the resistance of Driscopipe to a wide range of chemicals is shown in the following tables. This information is based on results of immersion tests (usually 3 months) at various temperatures. Changes in tensile strength and elongation are evaluated at a rapid strain rate to emphasize any strength decay in the material.

Most acids, bases and other chemicals can be transported by Driscopipe using the same design parameters as would apply to water, natural or manufactured gas and water solutions of inorganic salts. Strong oxidizing agents such as fuming sulfuric acid may adversely affect the pipe, depending upon concentration, temperature and period of contact. In many cases, such as gravity flow waste lines, these chemicals can be handled because of dilution and intermittent flow.

Some chemicals, such as all types of liquid hydrocarbons, will mechanically absorb into the wall of the pipe and cause a reduction in hoop stress but this does not degrade the material. This effect is temporary if exposure is intermittent. Where exposure is continuous, it is necessary to derate the pressure capability of the pipe for long term service. This includes such products as gasoline, ethyl alcohol, benzene, carbon tetrachloride, crude and refined oils, etc. Where 5-100% hydrocarbon liquids are continuously present in a pressure system, a service design factor of .25 should be used to calculate design pressures instead of the service design factor of .5 used with water.

$$P=\frac{2S}{SDR-1}\times F \quad \text{or} \quad P=2S\frac{t}{D-t}\times F$$

Where:
- D = Outside Diameter, Inches
- P = Design Pressure, psi
- S = Long Term Hydrostatic Strength, psi, at the design temperature
- t = Minimum Wall Thickness, Inches
- F = Service Design Factor
- SDR = Standard Dimension Ratio of D/t



CHEMICAL RESISTANCE OF DRISCOPIPE

S – Satisfactory
U – Unsatisfactory
M – Marginal
N – Not known

All concentrations are 100% unless noted otherwise.

On reagents marked marginal, chemical attack will be recognized by a loss of physical properties of the pipe which may require a change in design factors.

Reagent	70°F (21°C)	140°F (60°C)
Acetic Acid 1-10%	S	S
Acetic Acid 10-60%	S	M
Acetic Acid 80-100%	S	M
Acetone	M	U
Acrylic Emulsions	S	S
Aluminum Chloride-Dilute	S	S
Aluminum Chloride Conc.	S	S
Aluminum Fluoride Conc.	S	S
Aluminum Sulfate Conc.	S	S
ums (All Types) Conc.	S	S
Ammonia 100% Dry Gas	S	S
Ammonium Carbonate	S	S
Ammonium Chloride Sat'd	S	S
Ammonium Fluoride 20%	S	S
Ammonium Hydroxide 0.88 S.G.	S	S
Ammonium Metaphosphate Sat'd	S	S
Ammonium Nitrate Sat'd	S	S
Ammonium Persulfate Sat'd	S	S
Ammonium Sulfate Sat'd	S	S
Ammonium Sulfide Sat'd	S	S
Ammonium Thiocyanate Sat'd	S	S
Amyl Acetate	M	U
Amyl Alcohol 100%	S	S
Amyl Chloride 100%	N	U
Aniline 100%	S	N
Antimony Chloride	S	S
Aqua Regia	U	U
Barium Carbonate Sat'd	S	S
Barium Chloride	S	S
Barium Hydroxide	S	S
Barium Sulfate Sat'd	S	S
Barium Sulfide Sat'd	S	S
Beer	S	S
Benzene	M	U
Benzene Sulfonic Acid	S	S
Bismuth Carbonate Sat'd	S	S
leach Lye 10%	S	S
Black Liquor	S	S
Borax Cold Sat'd	S	S
Boric Acid Dilute	S	S
Boric Acid Conc.	S	S
Bromic Acid 10%	S	S
Bromine Liquid 100%	M	U
Butanediol 10%	S	S
Butanediol 60%	S	S
Butanediol 100%	S	S
Butyl Alcohol 100%	S	S
Calcium Bisulfide	S	S
Calcium Carbonate Sat'd	S	S
Calcium Chlorate Sat'd	S	S
Calcium Chloride Sat'd	S	S
Calcium Hydroxide	S	S
Calcium Hypochlorite BL'GH Sol.	S	S
Calcium Nitrate 50%	S	S
Calcium Sulfate	S	S
Camphor Oil	N	U
Carbon Dioxide 100% Dry	S	S
Carbon Dioxide 100% Wet	S	S
Carbon Dioxide Cold Sat'd	S	S
Carbon Disulfide	N	U
Carbon Monoxide	S	S
Carbon Tetrachloride	M	U
Carbonic Acid	S	S
Castor Oil Conc.	S	S
Chlorine Dry Gas 100%	S	M
Chlorine Moist Gas	M	U
Chlorine Liquid	M	U
Chlorobenzene	M	U
Chloroform	M	U
Chlorosulfonic Acid 100%	M	U
Chrome Alum Sat'd	S	S
Chromic Acid 20%	S	S
Chromic Acid Up to 50%	S	S
Chromic Acid and Sulfuric Acid	S	M
Cider	S	S
Citric Acid Sat'd	S	S
Coconut Oil Alcohols	S	S
Cola Concentrates	S	S
Copper Chloride Sat'd	S	S
Copper Cyanide Sat'd	S	S
Copper Fluoride 2%	S	S
Copper Nitrate Sat'd	S	S
Copper Sulfate Dilute	S	S
Copper Sulfate Sat'd	S	S
Cottonseed Oil	S	S
Crude Oil*	S	M
Cuprous Chloride Sat'd	S	S
Cyclohexanol	S	S
Cyclohexanone	M	U
Detergents Synthetic	S	S
Developers, Photographic	S	S
Dextrin Sat'd	S	S
Dextrose Sat'd	S	S
Dibutylphthalate	S	M
Disodium Phosphate	S	S
Diazo Salts	S	S
Diethylene Glycol	S	S
Diglycolic Acid	S	S
Dimethylamine	M	U
Emulsions, Photographic	S	S
Ethyl Acetate 100%	M	U
Ethyl Alcohol 100%	S	S
Ethyl Alcohol 35%	S	S
Ethyl Butyrate	M	U
Ethyl Chloride	M	U
Ethyl Ether	U	U
Ethylene Chloride	U	U
Ethylene Chlorohydrin	U	U
Ethylene Dichloride	M	U
Ethylene Glycol	S	S
Ferric Chloride Sat'd	S	S
Ferric Nitrate Sat'd	S	S
Ferrous Chloride Sat'd	S	S
Ferrous Sulfate	S	S
Fish Solubles	S	S
Fluoboric Acid	S	S
Fluorine	S	U
Fluosilicic Acid 32%	S	S
Fluosilicic Acid Conc.	S	S
Formaldehyde 40%	S	N
Formic Acid 0-20%	S	S
Formic Acid 20-50%	S	S
Formic Acid 100%	S	S
Fructose Sat'd	S	S
Fruit Pulp	S	S
Fuel Oil	S	U
Furfural 100%	M	U
Furfuryl Alcohol	M	U
Gallic Acid Sat'd	S	S
Gas Liquids*	S	M
Gasoline*	M	U
Gin	S	U
Glucose	S	S
Glycerine	S	S
Glycol	S	S
Glycolic Acid 30%	S	S
Grape Sugar Sat'd Aq.	S	S
Hexanol, Tert.	S	S
Hydrobromic Acid 50%	S	S
Hydrocyanic Acid Sat'd	S	S
Hydrochloric Acid 10%	S	S
Hydrochloric Acid 30%	S	S
Hydrochloric Acid 35%	S	S
Hydrochloric Acid Conc.	S	S
Hydrofluoric Acid 40%	S	S
Hydrofluoric Acid 60%	S	S
Hydrofluoric Acid 75%	S	S
Hydrogen 100%	S	S
Hydrogen Bromide 10%	S	S
Hydrogen Chloride Gas Dry	S	S

*HDPE Resin Service Design Factor for hydrocarbons per the formula on page 3 and 8 is F = 0.25 to compensate for hydrocarbon saturation effects on long term hydrostatic strength.

continued on page 10

DRISCOPIPE

continued from page 9

CHEMICAL RESISTANCE OF DRISCOPIPE

Reagent	70°F (21°C)	140°F (60°C)
Hydrogen Peroxide 30%	S	S
Hydrogen Peroxide 90%	S	M
Hydrogen Phosphide 100%	S	S
Hydroquinone	S	S
Hydrogen Sulfide	S	S
Hypochlorus Acid Conc.	S	S
Inks	S	S
Iodine (Alc. Sol.) Conc.	S	U
Lactic Acid 10%	S	S
Lactic Acid 90%	S	S
Latex	S	S
Lead Acetate Sat'd	S	S
Lube Oil*	S	M
Magnesium Carbonate Sat'd	S	S
Magnesium Chloride Sat'd	S	S
Magnesium Hydroxide Sat'd	S	S
Magnesium Nitrate Sat'd	S	S
Magnesium Sulfate Sat'd	S	S
Mercuric Chloride Sat'd	S	S
Mercuric Cyanide Sat'd	S	S
Mercurous Nitrate Sat'd	S	S
Mercury	S	S
Methyl Alcohol 100%	S	S
Methyl Bromide	M	U
Methyl Chloride	M	U
Methyl Ethyl Ketone 100%	M	U
Methylsulfuric Acid	S	S
Methylene Chloride 100%	M	U
Milk	S	S
Mineral Oils	S	U
Molasses Comm.	S	S
Nickel Chloride Sat'd	S	S
Nickel Nitrate Conc.	S	S
Nickel Sulfate Sat'd	S	S
Nicotine Dilute	S	S
Nicotinic Acid	S	S
Nitric Acid 0-30%	S	S
Nitric Acid 30-50%	S	M
Nitric Acid 70%	S	M
Nitric Acid 95-98%	U	U
Nitrobenzene 100%	U	U
Octyl Cresol	S	U
Oils and Fats*	S	M
Oleic Acid Conc.	S	U
Oleum Conc.	U	U
Orange Extract	S	S
Oxalic Acid Dilute	S	S
Oxalic Acid Sat'd	S	S
Ozone 100%	S	U
Perchloric Acid 10%	S	S
Petroleum Ether	U	U
Phenol 90%	U	U
Phosphoric Acid Up to 30%	S	S
Phosphoric Acid Over 30%	S	S
Phosphoric Acid 90%	S	S
Phosphorous (Yellow) 100%	S	N
Phosphorus Pentoxide 100%	S	N
Photographic Solutions	S	S
Pickling Baths		
Sulfuric Acid	S	S
Hydrochloric Acid	S	S
Sulfuric-Nitric	S	U
Plating Solutions		
Brass	S	S
Cadmium	S	S
Chromium	N	N
Copper	S	S
Gold	S	S
Indium	S	S
Lead	S	S
Nickel	S	S
Rhodium	S	S
Silver	S	S
Tin	S	S
Zinc	S	S
Potassium Bicarbonate Sat'd	S	S
Potassium Borate 1%	S	S
Potassium Bromate 10%	S	S
Potassium Bromide Sat'd	S	S
Potassium Carbonate	S	S
Potassium Chlorate Sat'd	S	S
Potassium Chloride Sat'd	S	S
Potassium Chromate 40%	S	S
Potassium Cyanide Sat'd	S	S
Potassium Dichromate 40%	S	S
Potassium Ferri/ Ferro Cyanide Sat'd	S	S
Potassium Fluoride	S	S
Potassium Hydroxide 20%	S	S
Potassium Hydroxide Conc.	S	S
Potassium Nitrate Sat'd	S	S
Potassium Perborate Sat'd	S	S
Potassium Perchlorate 10%	S	S
Potassium Sulfate Conc.	S	S
Potassium Sulfide Conc.	S	S
Potassium Sulfite Conc.	S	S
Potassium Persulfate Sat'd	S	S
Propargyl Alcohol	S	S
Propyl Alcohol	S	S
Propylene Dichloride 100%	U	U
Propylene Glycol	S	S
Rayon Coagulating Bath	S	S
Sea Water	S	S
Selenic Acid	S	S
Shortening	S	S
Silicic Acid	S	S
Silver Nitrate Sol.	S	S
Soap Solution Any Conc'n	S	S
Sodium Acetate Sat'd	S	S
Sodium Benzoate 35%	S	S
Sodium Bicarbonate Sat'd	S	S
Sodium Bisulfate Sat'd	S	S
Sodium Bisulfite Sat'd	S	S
Sodium Borate	S	S
Sodium Bromide Dilute Sol.	S	S
Sodium Carbonate Con.	S	S
Sodium Carbonate	S	S
Sodium Chlorate Sat'd.	S	S
Sodium Chloride Sat'd	S	S
Sodium Cyanide	S	S
Sodium Dichromate Sat'd	S	S
Sodium Ferricyanide	S	S
Sodium Ferrocyanide Sat'd	S	S
Sodium Fluoride Sat'd	S	S
Sodium Hydroxide Conc.	S	S
Sodium Hypochlorite	S	S
Sodium Nitrate	S	S
Sodium Sulfate	S	S
Sodium Sulfide 25%	S	S
Sodium Sulfide Sat'd Sol.	S	S
Sodium Sulfite Sat'd	S	S
Stannous Chloride Sat'd	S	S
Stannic Chloride Sat'd	S	S
Starch Solution Sat'd	S	S
Stearic Acid 100%	S	S
Sulfuric Acid 0-50%	S	S
Sulfuric Acid 70%	S	M
Sulfuric Acid 80%	S	U
Sulfuric Acid 96%	M	U
Sulfuric Acid 98%	M	U
Sulfuric Acid, Fuming	U	U
Sulfurous Acid	S	S
Tallow*	S	M
Tannic Acid 10%	S	S
Tanning Extracts Comm.	S	S
Tartaric Acid Sat'd	N	N
Tetrahydrofurane	N	U
Titanium Tetrachloride Sat'd	N	U
Toluene	M	U
Transformer Oil	S	M
Trisodium Phosphate Sat'd	S	S
Trichloroethylene	U	U
Urea Up to 30%	S	S
Urine	S	S
Vinegar Comm.	S	S
Vanilla Extract	S	S
Wetting Agents	S	S
Whiskey	S	N
Wines	S	S
Xylene	M	U
Yeast	S	S
Zinc Chloride Sat'd	S	S
Zinc Sulfate Sat'd	S	S

For additional chemical resistance listings, consult the P.P.I. technical report #TR 19/10-84, Table I and the ISO technical report #ISO/Data 8-1979, Tables I, II, III.

Temperature Characteristics

nce polyethylene is a thermoplastic material, many of its physical and chemical properties are dependent on temperature and will change as the temperature of the material is increased or decreased. However, the exposure of Driscopipe to temperature variations within the recommended operating range does not result in degradation of the material. As these temperature changes are reversed, the material properties also reverse to their original values.

You will note from the information on physical properties that Driscopipe has a brittleness temperature below −180°F and a softening temperature of +257°F. The recommended operating temperature is limited only on the higher temperature side to a range of 140-180°F, dependent upon the pressure of the application and other operating and installation considerations. On the lower temperature side, Driscopipe gains strength without becoming brittle and is ideal for use at sub-zero temperatures.

Driscopipe becomes molten at 400-500°F and temperatures in this range are used to fusion join the piping system. Pipe is extruded at about the same temperature. To protect the material against degradation at the higher temperature, it is chemically stabilized. This stabilizer protects the material against thermal degradation which might otherwise occur during manufacture, outside storage and installation.

Driscopipe has been tested for thousands of hours at elevated temperatures of 140°F and 180°F without thermal degradation. These long term pressure tests at the higher temperatures are used to obtain recommended design strengths for the pipe at these temperatures.

Since all thermoplastic piping materials are affected by temperature, it is a general practice to characterize these materials at ambient temperature of 23°C (73.4°F). Nearly all ASTM tests relating to physical, mechanical and chemical properties of thermoplastic materials are conducted at this temperature. If a test is conducted, or a property defined, at other than 73.4°F, it is always noted.

One example of the effect of temperature on Driscopipe is the change in long term strength of the material as shown on the stress-life curves. This type behavior is true for all thermoplastics but there are large differences between the performance of specific materials at the higher temperatures.

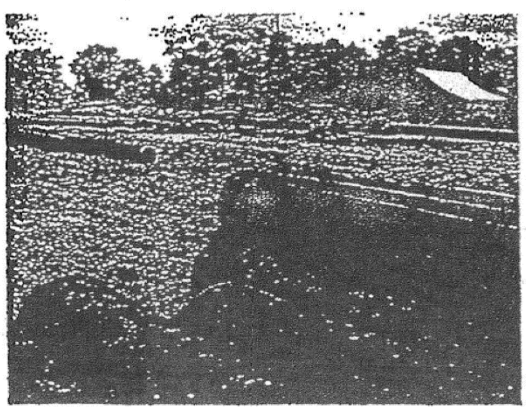
Knowledge of the long term strength of Driscopipe at the various temperatures allows selective design of a system. Accurate interpolations can be made for other temperatures between those which are known when data at three or more temperature levels is available.

Other properties of thermoplastic pipe which change with temperature and can affect system design and installation procedures include the following.

Burst strength – Short term (1 minute) burst tests on Driscopipe at various temperatures show these typical hoop stress values:

Temperature, °F	Hoop Stress, psi
73.4°	3250
32°	4300
0°	5290
−20°	5670
−40°	6385

Driscopipe will quick-burst at a pressure approximately four times greater than the rated operating pressure.



DRISCOPIPE

Chemical Resistance – The ability of most thermoplastics to resist degradation in the presence of corrosive chemicals is reduced as temperature increases. This is also true for Driscopipe but to a lesser extent because of its high density and high molecular weight. The effect of temperature on Driscopipe in the presence of various chemicals is shown in the chemical resistance tables.

Flexibility – As temperature is decreased, the flexibility of Driscopipe is also decreased. This has very little effect on installation except that at the lower winter temperatures, coiled pipe becomes more difficult, mechanically, to uncoil and stretch out in the ditch. Although Driscopipe becomes stiffer at low temperature, it can be bent, uncoiled or plowed in with sufficient mechanical power and no damage will occur to the pipe because of bending it at cold temperatures.

Other Physical Properties – There is a slight change with temperature of impact strength, notch sensitivity, flexural modulus, hardness and elongation ... but none are of such extent as to affect design parameters or installation procedures over the normal range of temperatures.

Modulus of Elasticity – Typical values for the variance in modulus of elasticity with temperature change is shown below.

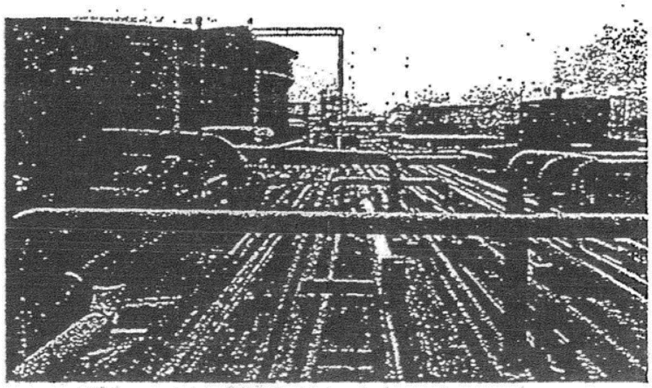
Temperature °F	Modulus of Elasticity, psi
−20°	300,000
0°	260,000
32°	200,000
75°	130,000
100°	105,000
140°	60,000

Thermal Expansion and Contraction – Polyethylene, like other thermoplastics, has a coefficient of expansion higher than metals. This coefficient is usually determined by a standard test method which employs the use of molded specimens. Measurements are made with a quartz dilatometer while the test specimen is held at elevated temperature. Typical coefficient values by this method range from $.75 \times 10^{-4}$ for Driscopipe 8600 to $.83 \times 10^{-4}$ for Driscopipe 1000.

The coefficient of linear expansion may also be determined by measuring the change in length of unrestrained pipe samples at different temperatures. The calculated coefficient is somewhat higher on extruded pipe than on molded test specimens. This appears to be true for all polyethylene pipe. The average coefficient calculated from measurements made on Driscopipe in the temperature range 0°F to 140°F, is 1.2×10^{-4} in/in/°F.

The circumferential coefficient of expansion and contraction for Driscopipe is approximately $.6 \times 10^{-4}$ in/in/°F in the range of 0° to 140°F ... or about ½ the linear coefficient. This circumferential change with temperature rarely presents any problems in system design. There may be need to consider this factor if compression fittings are used.

The expansion or contraction for Driscopipe can be stated in an easy rule of thumb ... the pipe will expand or contract approximately 1.4" per 100 feet for each 10°F change in temperature. Thus a 1000 foot unrestrained line which undergoes a 20°F increase in temperature change will increase in length 28 inches. The relatively large amount of expansion and contraction of plastic pipe generally presents no real problems in installation. The pipe has a relatively low elastic modulus and consequently there is less stress build-up. These stresses, caused by temperature change, are easily dissipated due to the thermoplastic nature of the material which relaxes and adjusts with time.



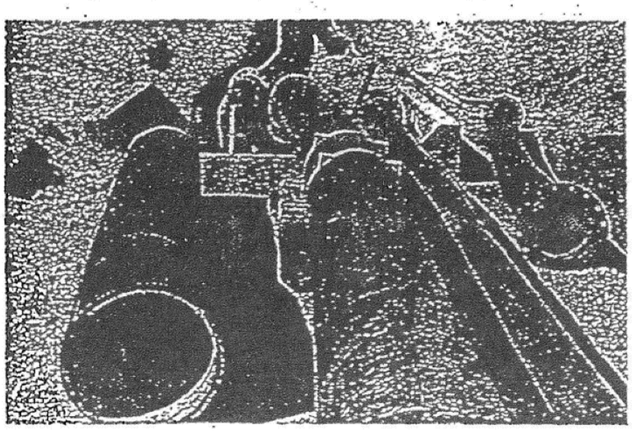
Tests have been conducted wherein the temperature of more than 100 feet of unrestrained pipe was changed 130°F in a period of a few minutes. The total force created by contraction was measured and proved to be about (½) one-half the theoretical calculated value. Thermoplastic materials are unique in their ability to stress-relieve themselves. Actual changes in temperature in most applications take place slowly over an extended period of time. The total stresses imposed will vary but are generally much lower than the calculated values.

Direct buried pipe will generally have ample soil friction and interference to restrain movement of the pipe under normal application temperature changes. It is a good idea to make the final tie-ins on a system at a temperature which is as close to operating temperature as possible. This is particularly true for insert liner systems where there is no soil restraint.

Normal good direct burial installation practices which include snaking the pipe in the ditch, proper backfill and compaction, making the tie-in at the proper temperature, etc. should be used at all times and will substantially reduce the possibility of pull out at tie-in connections on such installations. However, planning the transition tie-in becomes more important when Driscopipe is used for insert renewal inside another pipe because there is no restraint from earth loading. The contraction of the pipe due to reduction in temperature is freely transmitted to the transition connection and may result in pull-out if proper design precautions are not taken. In those cases, it may be necessary to provide additional anchoring at the terminations of the insert liner. Concrete anchors poured into undisturbed soil and cast around anchor projections in the Driscopipe line will restrict movement at the end of the line. Anchor projections on the Driscopipe liner can be made by fusing a blind tee into the line or by the use of two reducers, to the next larger size of pipe, fused together in the line.

Thermal Conductivity – This property of Driscopipe is lower than that for metals and can sometimes be exploited in the design of the system. It may eliminate or reduce the need for insulating pipe which carries water or other fluids through freezing temperatures. Thermal Conductivity of Driscopipe is 2.7 BTU per hour per sq. ft. per °F per inch of thickness. The slow heat transfer inhibits freezing and, if normal burial precautions are used, accidental freezing is usually eliminated. If the pipe does freeze, it does not fracture but fluid flow will be stopped. It will resume its function upon thawing. Direct application of intense heat should not be used to thaw a line. Antifreeze compounds such as methanol, isoproponol and ethylene glycol can be used without detrimental effect on the pipe.

Ignition Temperatures – The flash point for high density polyethylene using the Cleveland open cup method (ASTM D92) is 430°F. The flash ignition and self ignition temperatures using ASTM D1929 are 645°F and 660°F.



DRISCOPIPE

Weatherability

Two principal factors influence the weathering of plastic pipe in outside above ground applications ... temperature changes caused by seasonal variations and solar heating and solar radiation of ultraviolet rays. Effects of temperature variations on Driscopipe were discussed in the preceding section. Expansion and contraction of a line above ground, due to differential heating, will cause the line to move laterally, particularly if it is empty. This movement can easily be controlled within desired limits through the use of restraints.

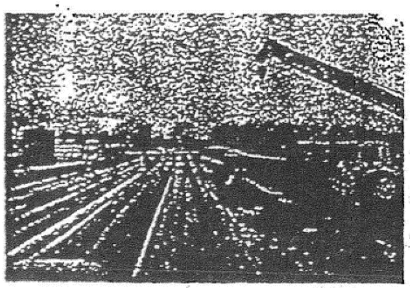
Driscopipe is also protected against degradation caused by ultraviolet rays when exposed to direct sunlight. The material contains 2½% of finely divided carbon black which also accounts for the black color of Driscopipe. Carbon black is the most effective single additive capable of enhancing the weathering characteristic of plastic materials. The protection even relatively low levels of carbon black impart to the plastic is so great that it is not necessary to use other light stabilizers or UV absorbers.

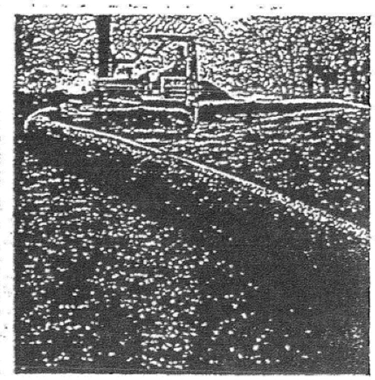
Weatherability tests indicate that Driscopipe can be safely used outside in most climates for periods of many years without danger of loss of physical properties due to UV exposure. Phillips has done extensive testing of polyethylene compounds containing 2 to 3% carbon black and compared these to other UV stabilizers to determine their effectiveness for protection against UV degradation in outdoor exposure. Samples were aged in outdoor exposure in three geographical locations: Phoenix, Arizona, Bartlesville, Oklahoma (Phillips 66 headquarters) and Akron, Ohio. From these actual tests, it was determined that one year exposure in Arizona was equivalent to at least two years in Bartlesville and greater than three and one-half years in Akron.

Weather-Ometer tests were run under standard conditions as set out in ASTM D 1499-64 and compared with the actual test samples in the three locations described above. From this test work, it was determined, conservatively, that 5000 hours (approximately 7 months) in the Weather-Ometer compares to greater than 42 months exposure in Arizona. Samples containing 2 to 3% carbon black and thermal stabilizers as used in Driscopipe have been tested for greater than 25,000 hours (2.85 years) in the Weather-Ometer without any brittleness or loss of physical properties. This is equivalent to over 17 years in Arizona and over 60 years in Akron, Ohio.

Permeability

The permeability of gases, vapors or liquids through a plastic membrane is generally considered to be an activated diffusion process. That is, the gas, vapor or liquid dissolves in the membrane and then diffuses to a position of lower concentration. The permeation rate is determined by the functional groups of the permeating molecules and by the density of the plastic ... the higher the density, the lower the permeability. Listed below are typical permeability rates for HDPE.





	Permeability Rate*
Carbon Dioxide	345
Hydrogen	321
Oxygen	111
Helium	247
Ethane	236
Natural Gas	113
Freon 12	95
Nitrogen	53

*Cubic centimeters per day per 100 sq. inches per mil thickness at atmospheric pressure differential.

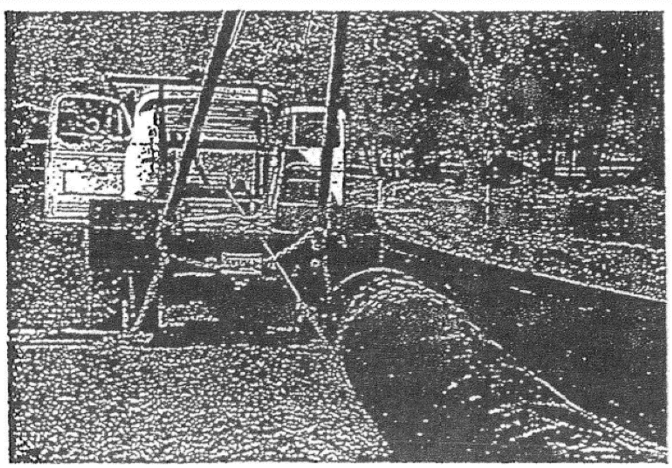
These permeation rates are considered very low. They result in negligible loss of product and create no hazard. For example, polyethylene piping systems are the predominant material used to construct new gas distribution systems and to renew old deteriorated systems. The permeation rate will vary in direct proportion to the differential pressure applied.

If the internal operating pressure is 60 psi, for example, the permeability rate would be approximately 4 times that shown above but volume losses would still be extremely low. Calculated volume loss in one mile of SDR 11 pipe (any size) in one day, for natural gas, would be ¼ of one cubic foot. At 120 psi, it would be ½ cubic foot per day.

Abrasion Resistance

One of the many outstanding characteristics of Driscopipe polyethylene is its resistance to abrasion. The inherent resilience and toughness of Driscopipe allows the mining industry to use this pipe in numerous surface applications where more conventional materials would be unsatisfactory, either because of the terrain encountered or the abrasiveness of the slurry to be moved. Quite often, a Driscopipe system offers substantial economic advantage as a means of transport over more conventional transportation methods used in the mining industry. Some of the more common applications include tailings lines and the transport of gypsum, limestone, sand, slimes and coal.

Due to its unique toughness, as indicated by low melt flow values, Driscopipe 8600 provides improved abrasion resistance over all other polyethylene piping materials. Controlled pipe loop pumping tests have demonstrated that Driscopipe can outlast steel pipe by as much as 4 to 1. One such test, performed by Williams Brothers Engineering, Tulsa, Oklahoma, compared Driscopipe to steel in pumping a coarse particle size magnetite iron ore slurry. At 13½ ft/sec velocity, Driscopipe was better by a factor of 4:1 and at 17 ft/sec by a factor of 3:1.



DRISCOPIPE

Heat Fusion Joining

The heat fusion joining technique has a long history of use for joining polyethylene pipe materials. The heat fusion method of joining PE pipe began shortly after the first commercial production of high density polyethylene in the early 1950s ... both developed by Phillips 66.

The integrity and superiority of heat fusion are now recognized universally. The modern day heat fusion joint is the same joint made in 1956 ... only the fusion equipment has evolved to gain efficiency, reliability and convenience. The principles learned on early equipment for making a successful joint are still in use today. Phillips designed, developed and built many models of heat fusion equipment from 1956 until the early 1970s. Since that time, Phillips has guided this development by others. The extensive line of high quality, efficient fusion equipment offered by McElroy Manufacturing, Inc., Tulsa, Oklahoma is one of the results of this long history of development. Phillips pioneered the idea and development of heat fusion and has used it exclusively in every high density polyethylene piping system sold by Phillips since 1956. There are millions of these joints in service today. In fact, 92% of all natural gas distribution pipe to homes, farms and factories is installed with polyethylene pipe and fittings. Heat fusion joints are industry accepted and field proven.

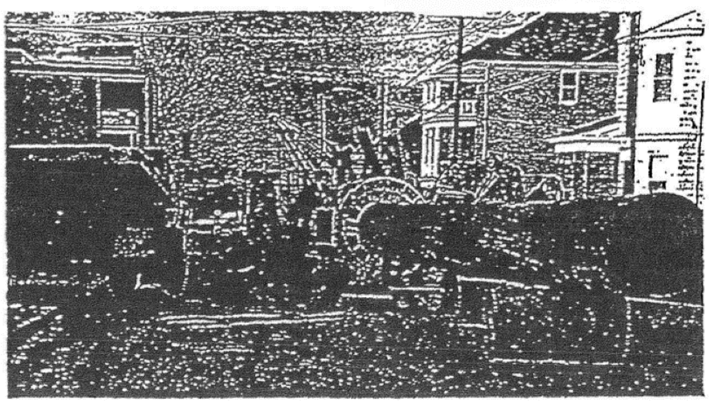
The heat fusion joining system has been so successful that it is the "standard" joining system for polyethylene. There are many reasons ... here are some.

Heat fusion joining ideally meets the requirements for a fast joining method to facilitate all phases of construction work in a safe and reliable manner.

The heat fusion joint is structurally superior to the socket fusion joint by configuration and, therefore, better meets the requirements of service. The heat joint configuration allows it to better disperse stresses initiated by pipe deflection and external loading. Stress concentration is minimized when the joint is placed in a strain and the joint is more "forgiving" when ground settlement occurs. In a socket joint, there is an extremely high ratio of "joint wall" to "pipe wall", resulting in stress intensification from external loading.

The Driscopipe heat fusion joining system is a simple, visual procedure with straight forward instructions. No "timing cycles" are necessary. The visual procedure allows the operator to concentrate on his work rather than a clock. Visually, he knows when the pipe ends have melted to the degree required to fuse them together. Visually, he observes and controls fusion pressure by observing the amount and configuration of the fusion bead as it is formed.

In the course of this work, the fusion operator is faced with a wide variety of job conditions. Changes in air temperature, material temperature, wind velocity, sun exposure, humidity, as well as condition of the terrain and the equipment all influence the joining requirements. Quality work under field conditions is more consistent with a simple, straight-forward, visual procedure.

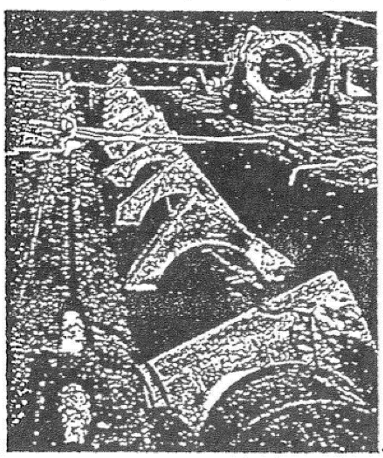


One heat fusion operator, with equipment, typically [illegible] the whole operation himself, sometimes using a [illegible] person as a helper. Pipe tolerances, ovality and curvature are no problem and "melt" is easily controlled by the visual procedure.

Heat fusion joints offer a large advantage over socket coupled joints for plow-in installation and for insert renewal applications. Socket coupled pipe requires larger size plow chutes and bore holes. Heat fused pipe one size larger can usually be handled and installed through bore holes and plow chutes selected for socket coupled pipe. Larger sizes of heat fused pipe can be used inside old mains for insert renewal because it does not require the extra space for the coupling.

Heat fusion joints may easily be cut out and re-done. This fact has a bearing on the quantity and quality of training necessary and favorably affects operator attitude toward quality in the field. These joints can be easily cut out and destructively tested in the field to check joining proficiency and equipment condition and it's inexpensive. There is no coupling to destroy and throw away.

The heat fusion joining system is especially effective with Driscopipe 8600. The melt of this material is very viscous and tough. The operator can apply ample pressure to form the heat fusion joint with little danger [illegible]rcing the molten material from between the two [illegible]ds of the joint, as can be done with the softer, less viscous, high density materials.



Driscopipe 8600 can be fusion joined to other polyethylene piping materials when necessary. Special joining techniques are required to achieve good joints. Phillips Driscopipe technical personnel are available to instruct and demonstrate the fusion joining procedure for joining Driscopipe to other polyethylene materials.

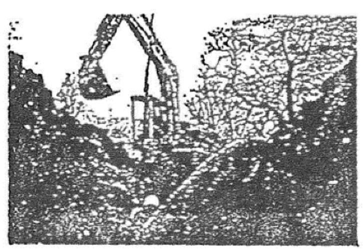
Fatigue Resistance

Driscopipe 8600 very high molecular weight, high density polyethylene has superior resistance to fatigue failure caused by cyclic loading. Independent laboratory tests were conducted to determine the suitability of Driscopipe 8600 for use as the cold water supply pipe and the barge mooring leg of the Mini-OTEC Project (Hawaii, 1979). In that application, 2150′ of 24″ 60 psi Driscopipe 8600 was deployed vertically in a deep ocean trench just offshore Keahole Point and was subject to cyclic distortion caused by wave action, current, and barge motion.

Cyclic tests showed that Driscopipe 8600 very high molecular weight PE could endure more than 100,000 cycles at a stress of 1800 psi without failure. Copies of this test report are avialable upon request.

Driscopipe 1000 offers good fatigue service life also, but not equal to 8600. Neither requires de-rating like PVC AWWA C-900 pipe. In fact, per AWWA C-906 for 4″ to 63″ HDPE pipe, no water hammer or fatigue de-rating factor need be applied to Driscopipe 8600 or Driscopipe 1000 ductile PE pipe.

The Driscopipe performance team offers you innovative solutions to your piping requirements. Contact your nearest Driscopipe Sales Representative. He'll give you personalized technical service, installation assistance and all the cost-saving advantages of a Driscopipe Piping System. Engineered for Performance!



DRISCOPIPE

Phillips Driscopipe, Inc.
A Subsidiary of Phillips 66 Company

To Secure Product Information or Leave a Message for a Sales Engineer or Technical Service Representative:

Mail:
Attn: Customer Service Department
P.O. Box 83-3866
2929 North Central Expressway
Suite 100
Richardson, Texas 75083

Phone:
U.S. Domestic Toll Free (800) 527-0662

TWX:
910-867-4818

Fax:
214-783-2689

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1774-90 A 01

butane may condense and liquefy in the pipe. Such liquefied fuel gasses are known to permeate polyethylene pipe, and result in unreliable heat fusion or electrofusion joints.

In potable water applications, permeating chemicals could affect the pipe or water in the pipe. ANSI/AWWA standards provide the following guidance for potable water applications:

> "The selection of materials is critical for water service and distribution piping where there is likelihood the pipe will be exposed to significant concentrations of pollutants comprised of low molecular weight petroleum products or organic solvents or their vapors. Research has documented that pipe materials such as polyethylene, polybutylene, polyvinyl chloride, and asbestos cement, and elastomers, such as used in jointing gaskets and packing glands, may be subject to permeation by lower molecular weight organic solvents or petroleum products. If water pipe must pass through such a contaminated area or an area subject to contamination, consult with the manufacturer regarding permeation of pipe walls, jointing materials, and so forth, *before* selecting materials for use in that area."[1]

Chemical Attack

A direct chemical attack on the polymer will result in permanent, irreversible polymer damage or chemical change by chain scission, cross-linking, oxidation, or substitution reactions. Such damage or change cannot be reversed by removing the chemical.

Chemical Resistance Information

The following chemical resistance guide, Table 5-1 (next page), presents immersion test chemical resistance data for a wide variety of chemicals.

- ❑ This data may be applicable to gravity flow and low stress applications.
- ❑ It may not be applicable when there is applied stress such as internal pressure, or applied stress at elevated temperature.

Unless stated otherwise, polyethylene was tested in the relatively pure, or concentrated chemical.

It is generally expected that dilute chemical solutions, lower temperatures, and the absence of stress have less potential to affect the material. At higher temperature, or where there is applied stress, resistance may be reduced, or polyethylene may be unsuitable for the application. Further, combinations of chemicals may have effects where individual chemicals may not.

Testing is recommended where information about suitability for use with chemicals or chemical combinations in a particular environment is not available. PLEXCO cannot provide chemical testing services.

1 *ANSI/AWWA C906-90, Section 1.2; ANSI/AWWA C901-96, Section 4.1.*

Table 5-1 Chemical Resistance

Because the particular conditions of each application may vary, Table 5-1 information should be used only as a preliminary guide for PLEXCO and SPIROLITE polyethylene pipe materials. This information is offered in good faith, and is believed to be accurate at the time of publication, but it is offered without any warranty, expressed or implied. Additional information may be required, particularly in regard to unusual or special applications. Determinations of suitability for use in particular chemical or environmental conditions may require specialized laboratory testing.

Additional information on chemical compatibility may be found in PPI TR-19, *Thermoplastic Piping for the Transport of Chemicals.*

Chemical Resistance Key

Key†	*Meaning*
X	resistant (swelling <3% or weight loss <0.5%; elongation at break not substantially changed)
/	limited resistance (swelling 3 - 8% or weight loss 0.5 - 5%; elongation at break reduced by <50%)
—	not resistant (swelling > 8% or weight loss >5%; elongation at break reduced by >50%)
D	discoloration
*	aqueous solutions in all concentrations
**	only under low mechanical stress

† Where a key is not printed in the table, data is not available.

Medium	*73°F*	*140°F*	*Medium*	*73°F*	*140°F*
Acetaldehyde, gaseous	X	/	Ammonia, liquid (100%)	X	X
Acetic acid (10%)	X	X	Ammonium chloride	*X	X
Acetic acid (100%) (Glacial acetic acid)	X	/D	Ammonium flouride, aqueous (up to 20%)	X	X
Acetic anhydride	X	/D	Ammonium nitrate	*X	X
Acetone	X	X	Ammonium sulphate	*X	X
Acetylene tetrabromide	**/ to —	—	Ammonium sulfide	*X	X
Acids, aromatic	X	X	Amyl acetate	X	X
Acrylonitrile	X	X	Aniline, pure	X	X
Adipic acid	X	X	Anisole	/	—
Allyl alcohol	X	X	Antimony trichloride	X	X
Aluminum chloride, anhydrous	X	X	Aqua regia	—	—
Aluminum sulphate	*X	X	Barium chloride	*X	X
Alums	X	X	Barium hydroxide	*X	X

Medium	73°F	140°F
Beeswax	X	**/ to —
Benzene	/	/
Benezenesulphonic acid	X	X
Benzoic acid	*X	X
Benzyl alcohol	X	X to /
Borax, all concentrations	X	X
Boric acid	*X	X
Brine, saturated	X	X
Bromine	—	—
Bromine vapor	—	
Butanetriol	X	X
Butanol	X	X
Butoxyl	*X	/
Butyl acetate	X	/
Butyl glycol	X	X
Butyric acid	X	/
Calcium chloride	*X	X
Calcium hypochlorite	*X	X
Camphor	X	/
Carbon dioxide	X	X
Carbon disulphide	/	
Carbon tetrachloride	**/ to —	—
Caustic potash	X	X
Caustic soda	X	X
Chlorine, liquid	—	—
Chlorine bleaching solution (12% active chlorine)	/	—
Chlorine gas, dry	/	—
Chlorine gas, moist	/	—
Clorine water (disinfection of mains)	X	
Chloroacetic acid (mono)	X	X
Chlorobenzene	/	—
Chloroethanol	X	XD
Chloroform	**/ to —	—
Chlorosulphonic acid	—	—
Chromic acid (80%)	X	—D
Citric acid	X	X
Coconut oil	X	/
Copper salts	*X	X
Corn oil	X	/
Creosote	X	XD
Creosol	X	XD
Cyclohexane	X	X
Cyclohexanol	X	X

Medium	73°F	140°F
Cyclohexanone	X	X
Decahydronaphthalene	X	/
Desiccator grease	X	/
Detergents, synthetic	X	X
Dextrin, aqueous (18% saturated)	X	X
Dibutyl ether	X to /	—
Dibutyl phthalate	X	/
Dichloroacetic acid (100%)	X	/D
Dichloroacetic acid (50%)	X	X
Dichloroacetic acid methyl ester	X	X
Dichlorbenzene	/	—
Diclolorethane	/	/
Dicloroethylene	—	—
Diesel oil	X	/
Diethyl ether	X to /	/
Diisobutyl ketone	X	/ to —
Dimethyl formamide (100%)	X	X to /
Dioxane	X	X
Emulsifiers	X	X
Esters, aliphatic	X	X to /
Ether	X to /	/
Ethyl acetate	/	—
Ethyl alcohol	X	X
Ethyl glycol	X	X
Ethyl hexanol	X	X
Ethylene chloride (dichlorothene)	/	/
Ethylene diamine	X	X
Fatty acids (>C^6)	X	/
Feric chloride*	X	X
Fluorine	—	—
Fluorocarbons	/	—
Fluorosilic acid, aqueous (up to 32%)	X	X
Formaldehyde (40%)	X	X
Formamide	X	X
Formic acid	X	
Fruit juices	X	X
Fruit pulp	X	X
Furfuryl alcohol	X	XD
Gelatine	X	X
Glucose	*X	X
Glycerol	X	X
Glycerol chlorohydrin	X	X
Glycol (conc.)	X	X

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Medium	73°F	140°F
Glycolic acid (50%)	X	X
Glycolic acid (70%)	X	X
Halothane	/	/
Hydrazine hydrate	X	X
Hydrobromic acid (50%)	X	X
Hydrochloric acid (all concentrations)	X	X
Hydrocyanic acid	X	X
Hydrofluoric acid (40%)	X	/
Hydrofluoric acid (70%)	X	/
Hydrogen	X	X
Hydrogen chloride gas, moist and dry	X	X
Hydrogen peroxide (30%)	X	X
Hydrogen peroxide (100%)	X	
Hydrogen sulfide	X	X
Iodine, tincture of, DAB 7 (German Pharmacopoeia)	X	/D
Isooctane	X	/
Isopropanol	X	X
Isopropyl ether	X to /	—
Jam	X	X
Keotones	X	X to /
Lactic acid	X	X
Lead acetate	*X	X
Linseed oil	X	X
Magnesium chloride	*X	X
Magnesium sulphate	*X	X
Maleic acid	X	X
Malic acid	X	X
Menthol	X	/
Mercuric chloride (sublimate)	X	X
Mercury	X	X
Methanol	X	X
Methyl butanol	X	X
Methyl ethyl ketone	X	/ to —
Methyl glycol	X	X
Methylene chloride	/	/
Mineral oils	X	X to /
Molasses	X	X
Monochloroacetic acid	X	X
Monochloroacetic ethyl ester	X	X
Monochloroacetic methyl ester	X	X
Morpholine	X	X
Naptha	X	/
Naphthalene	X	/
Nickel salts	*X	X
Nitric acid (25%)	X	X
Nitric acid (50%)	/	—
Nitrobenzene	X	/
o-Nitrotoluene	X	/
Octyl cresol	/	—
Oils, ethereal	/	/
Oils, vegetable & animal	X	X to /
Oleic acid (conc.)	X	/
Oxalic acid (50%)	X	X
Ozone	/	—
Ozone, aqueous solution (Drinking water purification)	X	
Paraffin oil	X	X
Perchloric acid (20%)	X	X
Perchloric acid (50%)	X	/
Perchloric acid (70%)	X	—D
Petrol	X	X to /
Petroleum	X	/
Petroleum ether	X	/
Petroleum jelly	**X to /	/
Phenol	X	XD
Phosphates	*X	X
Phosphoric acid (25%)	X	X
Phosphoric acid (50%)	X	X
Phosphoric acid (95%)	X	/D
Phosphorus oxychloride	X	/D
Phosphorus pentoxide	X	X
Phosphorus trichloride	X	/
Photographic developers, commecial	X	X
Phthalic acid (50%)	X	X
Polyglycols	X	X
Potassium bichromate (40%)	X	X
Potassium borate, aqueous (1%)	X	X
Potassium bromate, aqueous (up to 10%)	X	X
Potassium bromide	*X	X
Potassium chloride	*X	X
Potassium chromate, aqueous (40%)	X	
Potassium cyanide	*X	X
Potassium hydroxide (30% solution)	X	X
Potassium nitrate	*X	X
Potassium permanganate	X	XD
Propanol	X	X
Propionic acid (50%)	X	X
Propionic acid (100%)	X	/

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VOLUME 1

Medium	*73°F*	*140°F*
Propylene glycol	X	X
Pseudocumene	/	/
Pyridine	X	/
Seawater	X	X
Silicic acid	X	X
Silicone oil	X	X
Silver nitrate	X	X
Soduim benzoate	X	X
Sodium bisulphite, weak aqueous solutions	X	X
Sodium carbonate	*X	X
Sodium chloride	*X	X
Sodium chlorite (50%)	X	/
Sodium hydroxide (30% solution)	X	X
Sodium hypochlorite (12% active chlorine)	/	—
Sodium nitrate	*X	X
Sodium silicate	*X	X
Sodium sulfide	*X	X
Sodium thiosulphate	X	X
Spermaceti	X	/
Spindle oil	X to /	/
Starch	X	X
Steric acid	X	/
Succinc acid (50%)	X	X
Sugar syrup	X	X
Sulfates	*X	X
Sulfur	X	X
Sulfur dioxide, dry	X	X
Sulfur dioxide, moist	X	X
Sulfur trioxide	—	—
Sulfuric acid (10%)	X	X
Sulfuric acid (50%)	X	X
Sulfuric acid (98%)	/	—
Sulfuric acid, fuming	—	—
Sulfurous acid	X	X
Sulfuryl chloride	—	
Tallow	X	X
Tannic acid (10%)	X	X
Tartaric acid	X	X
Tetrachloroethane	**X to /	—
Tetrahydrofurane	**X to /	
Tetetrahydronapthalene	X	/
Thionyl chloride	—	—

Medium	*73°F*	*140°F*
Thiophene	/	/
Toluene	/	—
Transformer oil	X	/
Tributyl phosphate	X	X
Trichloroacetic acid (50%)	X	X
Trichloroacetic acid (100%)	X	/ to —
Trichloroethylene	**X to /	—
Triethanolamine	X	X
Turpentine, oil of	x to /	/
Tween 20 and 90 (Atlas Chemicals)	X	X
Urea	*X	X
Vinegar (commecial conc.)	X	X
Viscose spinning solutions	X	X
Waste gases containing		
carbon dioxide	X	X
carbon monoxide	X	X
hydrocloric acid (all conc.)	X	X
hydrogen fluoride (traces)	X	X
nitrous vitriol (traces)	X	X
sulfur dioxide (low conc.)	X	X
sulphuric acid, moist (all conc.)	X	X
Water gas	X	X
Xylene	—	—
Yeast, aqueous preparations	X	X
Zinc chloride	*X	X

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ATTACHMENT III.3.F

BASIN DIPOSAL WASTEWATER LABORATORY RESULTS

GE Infrastructure
Water & Process Technologies

WATER ANALYSIS REPORT

BASIN DISPOSAL
Aztec, NM

Sampled: 04-AUG-2006
Reported: 16-AUG-2006
Field Rep: Lambert, John W
91000497

	POST FILT PROD. WTR Q0808025
Particle Size Distribution	A
Ammonia, Free And Fixed, as N, ppm	35
pH	6.9
Specific Conductance, at 25°C, µmhos	22400
Alkalinity, "P" as $CaCO_3$, ppm	0
Alkalinity, "M" as $CaCO_3$, ppm	1370
Sulfur, Total, as SO_4, ppm	978
Chloride, as Cl, ppm	7600
Hardness, Total, as $CaCO_3$, ppm	497
Calcium Hardness, Total, as $CaCO_3$, ppm	347
Magnesium Hardness, Total, as $CaCO_3$, ppm	129
Barium, Total, as Ba, ppm	3.1
Strontium, Total, as Sr, ppm	16.5
Copper, Total, as Cu, ppm	< 0.05
Iron, Total, as Fe, ppm	6.9
Sodium, as Na, ppm	4970

GE imagination at work

GE Infrastructure
Water & Process Technologies

WATER ANALYSIS REPORT

BASIN DISPOSAL
Aztec, NM

Sampled: 04-AUG-2006
Reported: 16-AUG-2006
Field Rep: Lambert, John W
91000497

	POST FILT PROD. WTR Q0808025
Potassium, as K, ppm	571
Aluminum, Total, as Al, ppm	0.1
Manganese, Total, as Mn, ppm	0.47
Nitrate, as NO_3, ppm	< 1
Phosphate, Total, as PO_4, ppm	5.3
Silica, Total, as SiO_2, ppm	22
Fluoride, as F, ppm	< 0.1
Lead, Total, as Pb, ppm	0.019
Mercury, Total, as Hg, ppb	1.0
Carbon, Total Organic, as C, ppm	549
Turbidity, NTU	47
Hexane Extractable Material, mg/l	48

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WATER ANALYSIS REPORT

BASIN DISPOSAL
Aztec, NM

Sampled: 04-AUG-2006
Reported: 16-AUG-2006
Field Rep: Lambert, John W
91000497

Result Legend

A - This test was aborted for cause. More detail is provided below.

Comments

Sample Name: POST FILT PROD. WTR Lab ID: Q0808025

The Particle Size Distribution report will be sent at a later date under separate cover. For any questions or concerns, please contact Roberto Dominguez at 281-681-5270.

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Water & Process Technologies

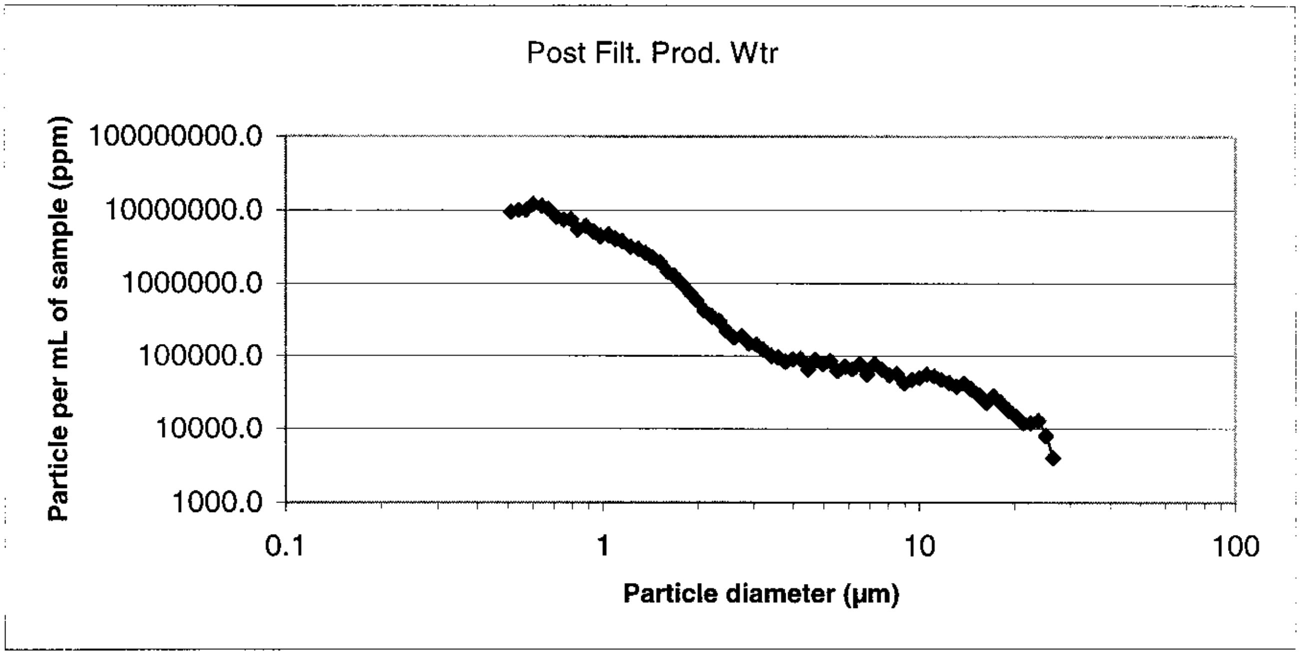
Customer Services Analytical Laboratories 9 669 Grogans Mill Road The Woodlands, TX 77380 (281) 681-5270

Date: August 22, 2006

Customer Name **Basin Disposal**
Address
Aztec, NM

Ship To#
Field Rep: **John W Lambert**
PE # **91000497**
Sample Date: April 8, 2006
Sample Point: **Post Filt. Prod. Wtr**

Particle Size (microns)	Particles per mL	% of Total Particles	Volume ppm	% of Total Volume	Particle Volume
0.5-1.0	107361999.1	75.6%	20.2208	0.72%	2.02E+08
1.0-2.0	30551000.0	21.5%	39.3963	1.39%	3.94E+08
2.0-4.0	2446000.0	1.7%	27.2570	0.96%	2.73E+08
4.0-6.0	541000.0	0.4%	35.5571	1.26%	3.56E+08
6.0-8.0	343000.0	0.2%	59.1686	2.09%	5.92E+08
8.0-10.0	250000.0	0.2%	95.9334	3.39%	9.6E+08
10.-15.0	314000.0	0.2%	314.9535	11.14%	3.15E+09
15.0-20.0	121000.0	0.1%	317.7735	11.24%	3.18E+09
20.0-30.0	70000.0	0.0%	470.5920	16.64%	4.71E+09
30.0-40.0	14000.0	0.0%	297.2424	10.51%	2.97E+09
40.0-50.0	4000.0	0.0%	173.8154	6.15%	1.74E+09
50-100	1000.0	0.0%	79.0452	2.80%	7.91E+08
100-200	1000.0	0.0%	896.4909	31.71%	8.97E+09
Total	142017999.0	100%	2827.4463	100%	



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LIST OF ATTACHMENTS

Attachment No.	Title
III.4.A	NEW MEXICO STATE HIGHWAY AND TRANSPORTATION DEPARTMENT DRAINAGE MANUAL
III.4.B	NOAA POINT PRECIPITATION FREQUENCY ESTIMATES (OCTOBER 1, 2019)

1.0 INTRODUCTION

Basin Disposal, Inc. (BDI) is an existing Surface Waste Management Facility (SWMF) providing oil field waste liquids (OFWL) disposal services. The existing BDI facility is subject to regulation under the New Mexico Oil and Gas Rules, specifically 19.15.36 NMAC, administered by the Oil Conservation Division (OCD) of the NM Energy, Minerals, and Natural Resources Department (NMEMNRD). This document is a component of the "Application for Permit Renewal" that proposes continued operations of the existing approved waste processing and disposal capabilities. The Facility is designed in compliance with 19.15.36 NMAC, and is operated in compliance with a Surface Waste Management Facility Permit issued by the OCD. The Facility is owned and operated by Basin Disposal Inc.

BDI only accepts liquid waste from the production and exploration of oil fields in northwest New Mexico and the surrounding areas. The existing facility is organized in a pattern that allows for specific liquid waste acceptance, treatment, evaporation, or injection of clean liquid.

1.1 Site Location

BDI is located in unincorporated San Juan County on 27.77 acres entirely within Section 3, Township 29 North, Range 11 West approximately 3 miles north of the intersection of Highway 550 and 64 (**Figure II.1.1**). Coordinates for the approximate center of the BDI site are Latitude 36°45'19.92" and Longitude -107°58'58.73". The site is situated approximately 4 miles north of the San Juan River, and about 4.7 miles south of the Animas River on Crouch Mesa, about 500 feet and 400 feet in elevation above these respective river plains. The site occupies the West Fork of Bloomfield Canyon, an ephemeral drainage channel that drains south to the San Juan River. The site slopes gently to the east and southeast, from a maximum elevation of 5,750 feet to less than 5,700 feet. Detailed site characterization documentation is provided in **Volume IV**.

1.2 Facility Description

The existing BDI facility is comprised of 27.7 acres and is comprised of the following:

- 2 existing evaporation ponds (1 pending construction)
- 12 existing receiving tanks (6 pending construction)
- 4 existing oily water receiving tanks
- 3 existing skimmed oil tanks
- 3 oil heating tanks
- 3 existing settling tanks
- 7 existing oil sales tanks (2 pending construction)
- 3 existing filtered water tanks
- 4 existing bleach tanks
- 1 existing concrete sludge solidification basin
- 2 existing covered below grade tanks (containment sumps)
- 1 UIC Class II injection well for disposal of produced water
- 2 existing separation tanks
- Various support facilities including an office, a maintenance building, roads, and a storm water detention basin.

Oil field wastes are delivered to the BDI SWMF from oil and gas exploration and production operations in northwestern New Mexico and southwest Colorado. The Site Plan provided as **Figure II.1.2** identify the locations of the Disposal facilities, evaporation/storage ponds, and all structures. Perimeter of the site is surrounded by commercial/industrial businesses on three sides and buffered by a bluff on the west side of the Facility.

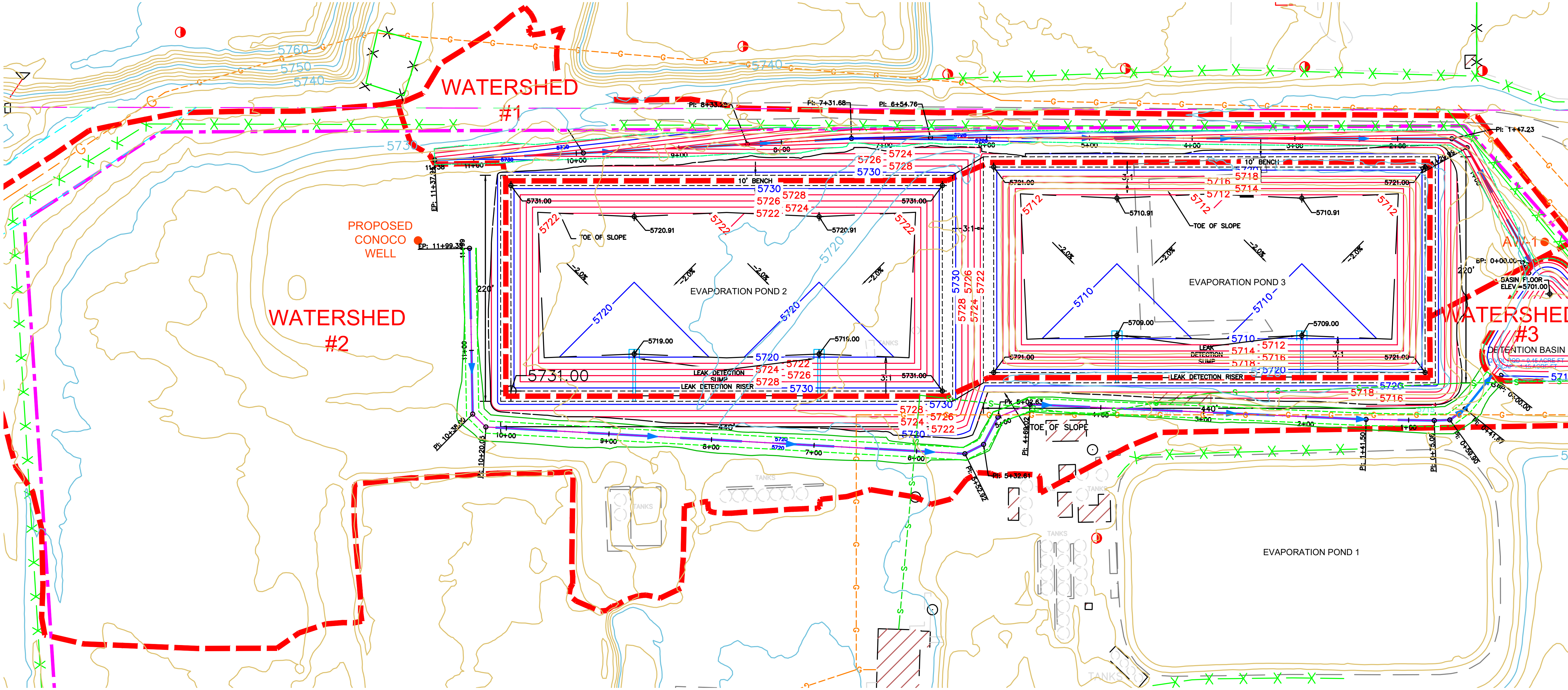
1.3 Site Conditions

Existing topography for the site generally drains to the east/southeast at 2% to 5% slopes. The northern boundary of the site is contiguous with commercial properties, portions of which contribute run-on to the stormwater management footprint (Watershed #1, **Figure III.4.1**). On-site run-off (Watersheds #2 and #3) will be controlled, along with run-on, by the Stormwater Detention Basin located east of existing Evaporation Pond 3. Site drainage is conveyed by two perimeter channels; one to the north of planned Evaporation Pond 2 and existing Evaporation Pond 3, and one to the south of the Ponds (**Figure III.4.1**).

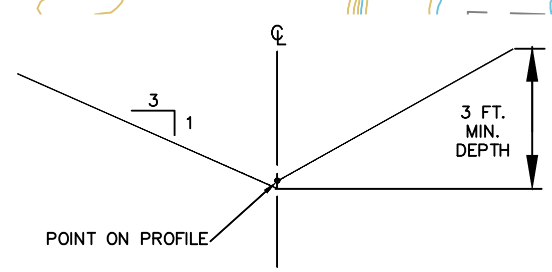
2.0 DESIGN CRITERIA

The stormwater management systems for the Basin Disposal, Inc. Evaporation Ponds are designed to meet the requirement of the regulatory standards identified in the Oil Conservation Division 19.15.36 NMAC (Regulations), New Mexico Energy, Minerals, and Natural Resources Department. More specifically, 19.15.36.8.C.(11) NMAC requires:

> *a plan to control run-on water onto the site and run-off water from the site that complies with the requirements of Subsection M of 19.15.36.13 NMAC;*

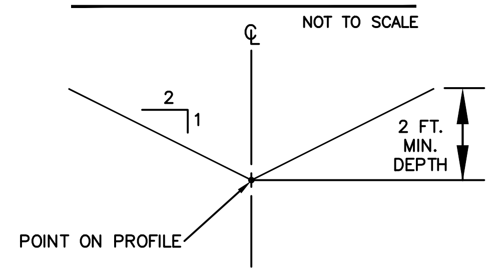


WATERSHED	AREA (ACRES)	CURVE NUMBER	$P_{25-YR\ 24-HR}$ (INCHES)	Q_{25} (CFS)	Q_{25} VOLUME (ACRE–FT)
#1	1.93	77	2.1	1.93	0.08
#2	7.52	77	2.1	6.62	0.32
#3	0.28	—	—	—	0.05
				TOTAL VOLUME	0.45
25 YEAR 24 HOUR POINT PRECIPITATION FREQUENCY ESTIMATED FROM NOAA ATLAS					



SOUTH CHANNEL TYPICAL SECTION

NOT TO SCALE

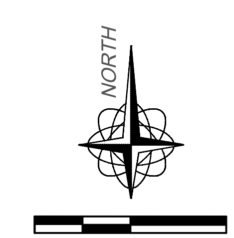


NORTH CHANNEL TYPICAL SECTION

NOT TO SCALE

LEGEND

- SITE BOUNDARY
- DRAINAGE DIVIDE
- 2' CONTOUR (EXISTING)
- 5700 — 10' CONTOUR (EXISTING)
- 5720 — 10' MAJOR CONTOUR
- 5716 — 2' MINOR CONTOUR
- 5711.04 — SPOT ELEVATION (DESIGN)
- GHP — 3" GAS LINE (EXISTING)
- S — SEWER LINE (EXISTING)
- G — GAS LINE (EXISTING)
- UTILITY EASEMENT
- UNPAVED ROADWAY (EXISTING)
- X—X—X — FENCE (EXISTING)
- AW-1 — ASSESSMENT WELL
- LIGHT POLE (EXISTING)
- STRUCTURE



NOTES:

1. LOCATION OF SITE UTILITIES IS APPROXIMATE. LOCATIONS OF SITE UTILITIES WILL BE FIELD VERIFIED PRIOR TO CONSTRUCTION.
2. NOT FOR CONSTRUCTION

DRAINAGE PLAN

SURFACE WASTE MANAGEMENT
BASIN DISPOSAL, INC.
BLOOMFIELD, NEW MEXICO

Parkhill
333 Rio Rancho Blvd. NE
Suite 400
Rio Rancho, New Mexico,
Phone: 505-867-6990
Fax: 505-867-6991
www.parkhill.com

DATE: 07/05/2022	CAD: DRAINAGE.dwg	PROJECT #: 1657.22
DRAWN BY: DMI	REVIEWED BY: MWK	FIGURE III.4.1
APPROVED BY: MWK		

Drawing:A:\2022\1657.22\03_DSGN\01_DWG\050_CIVIL\02_CONTENT\FIGURES\DRAINAGE FIG.dwg
Date/Time:Jul. 07, 2022-10:22:54

and further 19.15.36.13.M NMAC specifics that:

Each operator shall have a plan to control run-on water onto the site and run-off water from the site, such that:

(1) the run-on and run-off control system shall prevent flow on the surface waste management facility's active portion during the peak discharge from a 25-year storm; and

(2) run-off from the surface waste management facility's active portion shall not be allowed to discharge a pollutant to the waters of the state or United States that violates state water quality standards.

3.0 METHODOLOGY

The approach for the calculation of run-on and run-off stormwater flows was based on the Drainage Manual (New Mexico State Highway and Transportation Department, "Drainage Manual, Volume 1, Hydrology; **Attachment III.4.A**). The Drainage Manual specifies that the Simplified Peak Flow method should be used to compute run-off from watersheds less than 5 square miles. The total drainage basin acreage for the project area is determined to be approximately 10 acres (**Table III.4.6**), when the area of existing Pond 3 and undeveloped Pond 2 are subtracted out.

4.0 SURFACE WATER CALCULATIONS

Site conditions at BDI have developed in accordance with the 2009 Permit Modification and Renewal. Evaporation Pond 3, the Detention Basin, and the stormwater channels north and south of Evaporation Ponds 2 and 3 have been constructed. The construction of Evaporation Pond 2 is pending at the date of this application for permit renewal. Therefore, the method of drainage calculations used in the 2009 permit renewal remain consistent with existing and planned site conditions.

The Simplified Peak Flow method was used to determine run-on surface water flow rates. The Simplified Peak Flow method estimates the peak rate of run-on and run-off volume from small to medium watersheds. This method was developed by the Soil Conservation Service (SCS) and revised for use in New Mexico. Infiltration and other losses are estimated using the SCS Curve Number (*CN*) methodology. Input parameters are consistent with those used in the SCS Unit Hydrograph Method. The Simplified Peak Flow method is used for New Mexico basins less than 5 square miles in area and is used when the time of concentration is expected not to exceed 8.0 hours. The Simplified Peak Flow method is described as follows:

TABLE III.4.1 - Drainage Calculations

1. Establish the appropriate Design Frequency for analysis: Per Regulations the Design Storm is the 25-year, 24-hour event. Updated NOAA Atlas 14 Point Precipitation Frequency Estimates for New Mexico estimate a 25-year, 24-hour event to be equal to 2.02 inches **(Attachment III.4.B).** For the purposes of conservatively estimating a 25-year, 24-hour event, the previous 2009 permit renewal 25-year, 24-hour event estimate of 2.10 inches was used.
2. Estimate the drainage area, A, in Acres:
    a. Run-on Watershed #1 = 1.93 acres
    b. Run-off Watershed #2 = 7.52 acres
    c. Detention Basin Watershed #3 = 0.28 acres
3. Compute the Time of Concentration, T_c, in hours.
4. Determine Curve Number: From **Figure 402-2** "Run-off curve Numbers for Urban Areas" in **Attachment III.4.A**; Developing urban areas; newly graded; Soil type A; *CN*=77.
5. Because the watershed is less than 1.0 square miles, transmission losses were considered.
6. The average run-off depth, Q_d, is obtained from **Equation 404-1, Attachment III.4.A pg. 4-88**.
$Q_d = \frac{[P_{24} - (200/CN) + 2]^2}{P_{24} + (800/CN) - 8}$ Where: P_{24} = 24-hour rainfall depth (in) and *CN*= curve number.
7. Compute the design frequency peak flow by the following (**Equation 404-2, Attachment III.4.A pg. 4-88**): Q_p = (Acres)(Q_d)(q_u) cfs
8. Compute the stormwater volume (**Equation 404-3, Attachment III.4.A pg. 4-89**): $Q_v = \frac{Q_d \bullet A}{12}$.
9. Stormwater that falls within the footprint of the two new Evaporation Ponds (10 ac ±) is accommodated within the freeboard calculation (**Volume III.5**).

The Simplified Peak Flow methods used to determine stormwater flow at the Basin Disposal, Inc. site are identified as follows:

TABLE III.4.2 - Watershed #1 Calculations

Watershed #1: Discharge point at north side of detention pond (25-year, 24-hour storm event; conservatively estimated at 2.1 inches).

1. Area = 1.93 acres
2. Longest travel distance = 156' (overland flow) + 1039' (channel flow).
3. Average slope = 0.128 ft/ft (overland flow) and 0.016 ft/ft (channel flow).
4. Velocity = 3.5 ft/s (**Figure 402-15, Attachment III.4.A pg. 4-47**; overland flow).
5. $T_{c1} = \left[\frac{156 ft}{3.5 ft/s}\right]\left(\frac{1}{60}\right)$ = 0.74 min (**Equation 402-3, Attachment III.4.A pg. 4-39;** overland flow).
6. T_{c2} = 0.0078($1039^{0.77}$)($0.016^{-0.385}$) = 8 min (**Equation 403-2, Attachment III.4.A pg. 4-66;**channel flow).
7. $T_c = T_{c1} + T_{c2}$ = 0.74 + 8 = 8.74 min. = 0.15 hours.
8. Curve Number = 77 (**Table 402-2, Attachment III.4.A pg. 4-28**) for soil group A, newly graded areas.
9. Unit peak discharge $q_u = 0.543(T_c^{-0.812})10^{-\frac{(|\log(T_c)+0.3|-\log(T_c)-0.3)^{1.5}}{10}}$ cfs/ac-in = 1.98 cfs/ac-in.
10. Average Run-off Depth = $Qd = \frac{[2.1-(200/77)+2]^2}{2.1+(800/77)-8}$ = 0.503 inches (**Equation 404-1**, **Attachment III.4.A pg. 4-88**).
11. Design Frequency Peak Flow (**Equation 404-2**, **Attachment III.4.A pg. 4-88**) Q_p = (1.93 acres)(0.503in.)(1.98 cfs/ac-in.) = 1.93 cfs (This flow volume is used in sizing the channel north of Evaporation Ponds 2 and 3 which will convey the run-off from Watershed #1).
12. Stormwater volume (**Equation 404-3**, **Attachment III.4.A pg. 4-89**) Q_v = [(Q_d) (Acres)]/12 = 0.08 acre-ft (This volume is used in sizing the detention basin located east of Evaporation Pond 3 (see **Figure III.4.1**)).

TABLE III.4.3 - Watershed #2 Calculations

Watershed #2: Discharge point at southwestern side of detention pond (25-year, 24-hour storm event; conservatively estimated at 2.1 inches).

1. Area = 7.52 acres
2. Longest travel distance = 555' (overland flow) + 1123' (channel flow).
3. Average slope = 0.0468 ft/ft (overland flow) and 0.015 ft/ft (channel flow).
4. Velocity = 3.2 ft/s (**Figure 402-15, Attachment III.4.A pg. 4-47**; overland flow).
5. $T_{c1} = \left[\frac{555\,ft}{3.2\,ft/s}\right]\left(\frac{1}{60}\right)$ = 2.89 min (**Equation 402-3, Attachment III.4.A pg. 4-39;** overland flow).
6. T_{c2} = 0.0078($1123^{0.77}$)($0.015^{-0.385}$) = 8.77 min (**Equation 403-2, Attachment III.4.A pg. 4-66;** channel flow).
7. $T_c = T_{c1} + T_{c2}$ = 2.89 + 8.77 = 11.66 min. = 0.19 hours.
8. Curve Number = 77 (**Table 402-2, Attachment III.4.A pg. 4-28**) for soil group A, newly graded areas.
9. Unit peak discharge $q_u = 0.543(T_c^{-0.812})10^{-\frac{(|\log(T_c)+0.3|-\log(T_c)-0.3)^{1.5}}{10}}$ cfs/ac-in = 1.75 cfs/ac-in.
10. Average Run-off Depth = $Qd = \frac{[2.1-(200/77)+2]^2}{2.1+(800/77)-8}$ = 0.503 inches (**Equation 404-1, Attachment III.4.A pg. 4-88**).
11. Design Frequency Peak Flow (**Equation 404-2**, **Attachment III.4.A pg. 4-88**) Q_p = (7.52 acres)(0.503in.)(1.75 cfs/ac-in.) = 6.62 cfs (This flow volume is used in sizing the channel south of Evaporation Ponds 2 and 3 which will convey run-off from Watershed #2).
12. Stormwater volume (**Equation 404-3**, **Attachment III.4.A pg. 4-89**) Q_v = [(Q_d)(Acres)]/12 = 0.32 acre-ft (This volume is used in sizing the detention basin located east of Evaporation Pond 3 (see **Figure III.4.1**)).

TABLE III.4.4 - Watershed #3 Calculations (Detention Basin)

Watershed #3 (Pond): Assume all rainfall is contained within the Basin area and losses are negligible (25-year, 24-hour storm event; conservative estimated at 2.1 inches).

1. Area = 0.28 acres
2. Q_v = [(2.1 in.)(0.28 acres)]/12 = 0.05 acre-ft.

5.0 DRAINAGE CHANNEL DESIGN

The design frequency peak flow (Q_p) is used to size perimeter drainage channels. Drainage channels are sized to convey the volume of runoff from Watersheds #1 and #2, and sizing is based on Hydraflow Express Extension for AutoCAD Civil 3D. Hydraflow Express Extension software computes the velocity, depth based on the input values of flowrate, slope, and channel dimensions.

TABLE III.4.5 - Channel Calculations

Channel	Q_{25} (cfs)	Slope (ft/ft)	Velocity (ft/s)	Water Depth (ft)	Freeboard (ft)
North	1.93	0.016	2.97	0.57	1.43
South	6.62	0.015	3.63	0.78	2.22

6.0 DETENTION BASIN DESIGN

The Stormwater Detention Basin is designed to store the volume of runoff from Watershed #1 (**Table III.4.2**), Watershed #2 (**Table III.4.3**), and Watershed #3 (**Table III.4.4**) as calculated in Section 4.0. The Detention Basin controls the flow from the North Channel and the South Channel, as well as rainfall within the Basin area. To determine the volume required of the basin the Simplified Peak Flow method is used from the NMSHTD Drainage Manual. The Simplified Peak Flow method calculates volume in acre-ft as follows:

TABLE III.4.6 - Detention Basin Summary

Watershed	Area (acres)	Curve No.	$P_{25\text{-yr } 24\text{-hr}}$ (inches)*	Q_{25} Volume (acre-ft)
#1	1.93	77	2.1	0.08
#2	7.52	77	2.1	0.32
#3	0.28	NA	2.1	0.05
Total	**9.73**	**-**	**2.1**	**0.45**

Notes:
**Conservative Estimate*
NA = Not Applicable

Based on the available volume in the basin compared to the incoming flow, peak storage in the Detention Basin is assumed to be at elevation 5709.5. At this elevation, available volume = 1.15 acre-ft and the peak inflow from the 25-year 24-hour storm event is 0.45 acre-ft., therefore the current Detention Basin size is more than sufficient to detain the stormwater runoff as a result of the design storm event.

ATTACHMENT III.4.A

NEW MEXICO STATE HIGHWAY AND TRANSPORATION DEPARTMENT

DRAINAGE MANUAL

DRAINAGE DESIGN MANUAL

New Mexico
Department of Transportation

July 2018

Drainage Design Manual

New Mexico Department of Transportation

Prepared by:

Smith Engineering Company

Occam Engineers Inc.

Edited by:

New Mexico Department of Transportation

Drainage Design Bureau Staff

and

Thompson Engineering Consultants, Inc.

July 2018

New Mexico Department of Transportation

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July 2018

Foreword

The New Mexico Department of Transportation Drainage Design Bureau is pleased to present this updated comprehensive Drainage Design Manual (July 2018). This Manual provides the drainage criteria, standardized drainage analysis methods and many related references to be applied for New Mexico Department of Transportation Projects. This Manual supersedes the previous drainage criteria and drainage manuals listed here.

Drainage Design Criteria, Fourth Revision, June 2007.
New Mexico Department of Transportation.

Drainage Manual Volume 1, Hydrology, 1995.
New Mexico State Highway and Transportation Department.

Drainage Manual Volume II, Hydraulics, Sedimentation and Erosion, November 1998.
New Mexico State Highway and Transportation Department.

Comments regarding the content of this Manual are welcomed and should be addressed to:

Bureau Chief, Drainage Design Bureau
New Mexico Department of Transportation
P.O. Box 1149
Santa Fe NM 87504-1149

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100 INTRODUCTION

101 Drainage Design Manual Purpose and Use

The New Mexico Department of Transportation (NMDOT) is responsible for the construction and maintenance of a vast network of roads throughout the State of New Mexico. Public safety and prudent investment of public funds in the road network requires that each facility be both reasonably protected from damaging floods and able to safely carry traffic during most rainfall events. Standard methods of analyses and design are continually evolving largely due to the availability of improved technology and greatly expanded digital databases of watershed land use and related data, hydrologic data, topography and aerial photography. The purpose of this manual is to document and standardize, to the greatest practical extent, the state of the practice for hydrologic, hydraulic, and related drainage analyses, as these are the basis for drainage design for New Mexico roadways. This Drainage Design Manual is an update to the previous manuals and documents that are briefly described here.

Previous Manuals and Documents

Volume 1 - Hydrology, (NMSHTD, 1995) and Volume II - Hydraulics, Sedimentation, and Erosion (NMSHTD, 1998) were developed based on the Department's needs and the state of the practice of highway drainage design current in 1995 and 1998. The Drainage Design Criteria document was last updated in 2007 (NMDOT, 2007).

Many of the best practices presented in the previously referenced documents have been retained in this update. The impetus to supplement and update the previous 1995 and 1998 manuals and also update the criteria presented in the 2007 document is due to:

- The Drainage Design Bureau's desire to provide "state of the art" analysis methods appropriate for the NMDOT and New Mexico
- Changes in the type and quantity of data available (particularly digital) such as rainfall, stream gage, soils, aerial photography, topography, etc.
- Advances in desktop computing and geographic information systems (GIS), coupled with computer software

Hotlinks and Cross-References

This Manual contains many hotlinks to referenced source documents. A hotlink (or hyperlink) is a connection or direct link to the referenced source document that is available on another server website, through the internet. In cases when external guidance documents or references are updated after the publication of this Manual, the latest version of those documents will be considered the effective document. References with hotlinks (where available) are provided for the reader to review the source documents.

The hotlinks in this document should be updated regularly since hotlinks can become inactive when the source websites are modified. If a hotlink becomes inactivated, the reader should type in the source document title into an internet browser, and the document should be found. Hotlinks to external documents are shown in blue and underlined. Cross-references to figures, tables, equations, sections, appendices and example problems within this document are shown in **bold text**.

Drainage Design Manual Update

Many of the design procedures and computation methods have been adopted and extracted directly from updated analysis and design guidance documents published by federal agencies. The two most referenced agencies in this Manual are listed here.

Federal Highway Administration (FHWA) for hydraulics, erosion, sediment transport, scour and countermeasure design (for erosion and scour). The FHWA website hotlink listed here provides a full index of all current and archived FHWA publications.
https://www.fhwa.dot.gov/engineering/hydraulics/library_listing.cfm?archived=false

Natural Resources Conservation Service (previously the Soil Conservation Service) Part 630, Hydrology, National Engineering Handbook, Chapters 1-22. Note that various Chapters have different dates. The Natural Resources Conservation Service (NRCS) website hotlink listed here will access this document.
https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/manage/hydrology/?cid=stelprdb1043063

Limitations on the use of each analysis method have been included where applicable. This Drainage Design Manual does not include descriptions of the development of, or derivation of analyses methods except by reference.

This manual is not intended to replace the technical manuals referenced or hotlinked, or to be a textbook for hydrology, hydraulics erosion/sediment transport or scour. It is intended to guide engineers new to highway drainage analysis and design, and those more experienced, with the goal of standardizing the analysis and design process given the extremely variable rainfall, elevations, slopes, and soils in New Mexico.

Contact the NMDOT Drainage Design Bureau (DDB) to request spreadsheets developed by the DDB to assist in various calculations.

The Drainage Analysis and Design Process Basics

These questions should be considered before a project begins, and should be addressed and incorporated into every drainage analysis and design:

- How much analysis is warranted for the drainage structure given the size, cost, importance, availability, and quality of data, and consequence of a failure?
- How are failure and non-failure defined?
- What is the probability of failure?
- Are the costs associated with this solution consistent with the benefits?
- Does the solution make sense?
- Will the solution work?
- Can the proposed solution(s) and improvement(s) be practically maintained?

The results should be verified by considering the history and experience as reported by the local patrol foreman, local records, high water marks, historic aerial photography, “rules of thumb”, and other computational methods. Conducting many drainage analyses will provide the experience that leads to developing good judgment, and will assist in exercising prudent engineering practice.

Drainage Infrastructure Past Performance

The methods prescribed in the previous manuals have adequately met the need for a balance between prudent and appropriate design and the capital improvement costs. This statement is based on discussions with the NMDOT Drainage Design Bureau engineers and general observations of highway drainage structures around New Mexico, since the publication of the previous NMDOT drainage manuals and documents.

Summary of Research

During the development of this update, drainage manuals from ten western states excluding New Mexico, were reviewed to determine the current state of the practice of hydrology and hydraulics. The purpose of the review was to discover if other states have developed methods and/or procedures that would be better suited for New Mexico roadways than those in current use. The review and evaluation of those ten drainage manuals revealed that the NMDOT's previous analyses/methods are best suited for New Mexico's needs. However, there are some analyses and design approaches as well as improved methods, that are borrowed from other states and adapted to New Mexico. **APPENDIX 10** contains the Summary of Research that was conducted prior to the preparation of this Drainage Design Manual.

Hydrology

The standard hydrologic analyses methods presented in this Drainage Design Manual should be applied for all NMDOT projects (except in special circumstances as noted). Use of these standard methods will ensure consistency of analysis and design. A brief description of each analysis method is included in this Drainage Design Manual, followed by a step-by-step procedure to apply the method. In many instances, a brief description of the method has been excerpted from its source. In those cases, a hotlink to the source document is provided. Example hydrologic analyses problems are included in **APPENDIX 6.**

This Drainage Design Manual specifies which hydrologic analysis method should be the best choice for use at a particular drainage structure based on drainage area size, location, available data, and physical circumstances. By standardizing the process for choosing hydrologic analysis methods, a consistent and appropriate type and level of analysis is assured for every drainage structure, large and small. However, despite these efforts to standardize both the selection of methods and their reasonable application, proper drainage analysis and design requires experience and competent engineering judgment. Drainage engineers working on NMDOT projects are expected to seek the advice of more experienced engineers when needed and to apply sound engineering judgment throughout the analysis and design process.

Hydraulics

The previous Volume II (1998) manual was developed during a period when there was a nationwide push to convert highway design to metric standards. Since that time, the universal metrification effort has been largely abandoned in most DOTs around the United States including the NMDOT. Many of the updates in this Drainage Design Manual with respect to Volume II, are related to conversion to English standard units from metric units.

This Manual presents more information and references than the 1998 Manual, specifically many more hydraulic equations and analysis methods regarding, sediment transport, scour and erosion countermeasures. Example hydraulic analysis problems are included in **805APPENDIX 7** and example sediment transport and scour analysis problems are included in **APPENDIX 8**.

102 Acronyms

AASHTO – American Association of State Highway and Transportation Officials

ADT – Average Daily Traffic

AMAFCA – Albuquerque Metropolitan Arroyo Flood Control Authority

BFE – Base Flood Elevation (FEMA term for the 100-year water surface elevation illustrated on a Flood Insurance Rate Map)

BLM – Bureau of Land Management

BMP – Best Management Practice

CoCoRAS – Community Collaborative Rainfall, Hail and Snow Network

CFR – Code of Federal Regulations

COA – City of Albuquerque

CWA – Clean Water Act

DACFC – Doña Ana County Flood Commission

DDB – Drainage Design Bureau

DOT – Department of Transportation

EBID – Elephant Butte Irrigation District

EDAC – Earth Data Analysis Center

EPA – Environmental Protection Agency

ESCAFCA – Eastern Sandoval County Arroyo Flood Control Authority

FEMA – Federal Emergency Management Agency

FHWA – Federal Highway Administration

FIRM – Flood Insurance Rate Map

FIS – Flood Insurance Study

GI – Green Infrastructure

GIS – Geographic Information System

LID – Low Impact Development

LIDAR – Light Detection and Ranging

MRCOG – Mid-Region Council of Governments

MRGCD – Middle Rio Grande Conservancy District

MS4s – Municipal Separate Storm Sewer Systems

NEXRAD – Next Generation Radar

NMDGF – New Mexico Department of Game and Fish

NMDOT – New Mexico Department of Transportation
NMED – New Mexico Environment Department
NMIMT – New Mexico Institute of Mining and Technology
NMOSE – New Mexico Office of the State Engineer
NOAA – National Oceanic and Atmospheric Administration
NPDES – National Pollution Discharge Elimination System
NRCS – Natural Resources Conservation Service
NWS – National Weather Service
PDE – Project Development Engineer
RGIS – Resource Geographic Information System (New Mexico) National Weather Service
ROW – Right-of-Way
RSE – Relative Standard Error
SCS – Soil Conservation Service (now the NRCS)
SSCAFCA – Southern Sandoval County Arroyo Flood Control Authority
SWMP – Storm Water Management Plan
TESCP – Temporary Erosion and Sediment Control Plan
TMDL – Total Maximum Daily Load
USACE – U.S. Army Corps of Engineers
USBLM – U.S. Bureau of Land Management
USBR – U.S. Bureau of Reclamation
USDA – U.S. Department of Agriculture
USEPA – U.S. Environmental Protection Agency
USFS – U.S. Forest Service
USFWS – U.S. Fish and Wildlife Service
USGS – U.S. Geological Survey
USWB – U.S. Weather Bureau

103 References

Federal Highway Administration (FHWA), Website. A full index of all current and archived FHWA publications are located at the following website.
https://www.fhwa.dot.gov/engineering/hydraulics/library_listing.cfm?archived=false

NMSHTD, December 1995, "Drainage Manual, Volume 1, Hydrology", Easterling & Associates, Inc.
http://dot.state.nm.us/content/dam/nmdot/Infrastructure/NMHydrologyManual.pdf

NMSHTD, November 1998, "Drainage Manual, Volume II, Hydraulics, Sedimentation and Erosion", Resource Technology, Inc.
http://dot.state.nm.us/content/dam/nmdot/Infrastructure/NMHydraulicManual.pdf

NMDOT, June 2007, "Drainage Design Criteria for New Mexico Department of Transportation Projects, Fourth Revision", Smith Engineering Company and the NMDOT Drainage Design Bureau Engineers.
http://dot.state.nm.us/content/dam/nmdot/Infrastructure/drainageDesignCriteria.pdf

NRCS, "Part 630 Hydrology, National Engineering Handbook". Note that various Chapters have different dates.
https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/manage/hydrology/?cid=stelprdb1043063

200 DRAINAGE CRITERIA

201 Introduction

This section establishes minimum recommended criteria for drainage structure analyses and design for NMDOT projects. This section also addresses the NMDOT's principles and guidelines related to drainage structure analysis and design criteria. The design criteria were developed based on highway or road classification, Average Daily Traffic (ADT), location (urban or rural), public safety and protection, property protection, public funds availability and economic impacts.

The design criteria must be applied in conjunction with current NMDOT documents and drawings that include the "Standard Specifications for Highway and Bridge Construction" and the "Standard Drawings". These may be obtained from the following hotlinks:

http://dot.state.nm.us/content/dam/nmdot/Plans_Specs_Estimates/2014_Specs_For_Highway_And_Bridge_Construction.pdf

http://dot.state.nm.us/content/nmdot/en/Standards.html

Design variances may be required as a result of budget impacts, right-of-way limitations, environmental and property impacts, or other constraints. Refer to the NMDOT document titled "Design Exception, Design Variance & ADA Design Variance Procedures", November 8, 2016. Refer to the following hotlink to obtain design variance information from that document.

http://dot.state.nm.us/content/dam/nmdot/Plans_Specs_Estimates/Design_Directives/2016/IDD-2016-11_(Design_Exception_Variance_and_ADA_Design_Variance.pdf

Such variances are only allowed when all other options have been considered and found inadequate. If departure from the criteria and design standards for major drainage structures or systems is necessary, a risk assessment may be required. **Section 408** describes the risk assessment procedure. If a jurisdiction or organization has more stringent criteria than the NMDOT drainage criteria, those criteria shall govern the hydrologic analyses, hydraulic analyses and design.

202 Drainage Principles, Guidelines and Definitions

Principles and Guidelines

Drainage system design must consider the following principles and guidelines:

- Preserve, as best possible, the existing drainage path
- Minimize adverse hydraulic affects upstream and downstream of the watercourse crossing
- Minimize the effect on adjacent properties
- Preserve, as best possible, the existing floodplains
- Promote the passage of sediment and debris as much as possible
- Minimize the effects to the environment including impact on fish, wildlife, and wetlands
- Consider safety and welfare of the traveling public

- Protect historic properties and archaeological sites
- Consider and plan for context sensitive design
- Adhere to EPA Permit requirements for Municipal Separate Storm Sewer Systems (MS4s)
- Consider Green Infrastructure (GI) and Low Impact Development (LID) in MS4 areas
- The drainage system design must be in compliance with all environmental regulations and permit requirements
- The design must also plan for maintenance access operations

Definitions

Definitions of terms included in this Drainage Criteria **Section 200** are included in **APPENDIX 1**. Many of these terms are also presented in other Sections of this Manual.

203 Storm Duration and Frequency Criteria

The 24-hour duration storm shall be adopted for all hydrologic analyses.

Minor Arterials, Collectors and Local Roads

Table 203-1 presents the "Storm Frequency Criteria" associated with the Design Flood and Check Flood for various drainage design items with respect to urban and rural locations and ADT ranges for Minor Arterials, Collectors, and Local Roads.

Interstate Highways and Principal Arterials

Table 203-2 presents the "Storm Frequency Criteria" associated with the Design Flood and Check Flood for various drainage design items for Interstate Highways and Principal Arterials. The criteria are applicable to all ADT ranges.

Table 203-1 Storm Frequencies for Minor Arterials, Collectors and Local Roads

	All Urban and Rural >= 400 ADT		Rural < 400 ADT	
	Design Flood	**Check Flood**	**Design Flood**	**Check Flood**
	Storm Frequency in years "y"			
Bridge Freeboard	50 y	100 y	25 y	50 y
Bridge Scour (a)	100 y	500 y	50 y	100 y
Existing Culverts	50 y	100 y	25 y	50 y
New Culverts	50 y	100 y	25 y	50 y
Sidewalk Culverts	50 y	100 y	25 y	50 y
Bridge Deck Drains	50 y	100 y	25 y	50 y
Roadside Ditches and Inlets	50 y	100 y	10 y	25 y
Median Ditches and inlets	50 y	100 y	10 y	25 y
Concrete Channels	50 y	100 y	10 y	25 y
Trunk Lines	50 y	100 y	10 y	25 y
Curb Drop Inlets (b)	50 y	100 y	10 y	25 y
Concrete Wall Barrier (c)	50 y	100 y	10 y	25 y

a - Check other flood frequencies as appropriate for greater scour depths

b - Curb Drop Inlets criteria apply to curbs and similar vertical barriers up to 8" height; also applies to slotted drains

c - Concrete Wall Barrier criteria also apply to Concrete Barrier Railing and vertical barriers greater than 8" height

Table 203-2 Storm Frequencies for Interstate Highways and Principal Arterials

	ADT Range - All	
	Design Flood	Check Flood
	Storm Frequency in years "y"	
Bridge Freeboard	50 y	100 y
Bridge Scour (a)	100 y	500 y
Existing Culverts	50 y	100 y
New Culverts	50 y	100 y
Sidewalk Culverts	50 y	100 y
Bridge Deck Drains	50 y	100 y
Roadside Ditches and Inlets	50 y	100 y
Median Ditches and inlets	50 y	100 y
Concrete Channels	50 y	100 y
Trunk Lines	50 y	100 y
Curb Drop Inlets (b)	50 y	100 y
Concrete Wall Barrier (c)	50 y	100 y

a - Check other flood frequencies as appropriate for greater scour depths

b - Curb Drop Inlets criteria apply to curbs and similar vertical barriers up to 8" height, also applies to slotted drains

c - Concrete Wall Barrier criteria also apply to Concrete Barrier Railing and vertical barriers greater than 8" height

204 Hydraulic Criteria for Drainage Structures

Figure 204-1 and **Figure 204-2** present typical roadway sketches to define the basic roadway and drainage related features listed in the criteria tables.

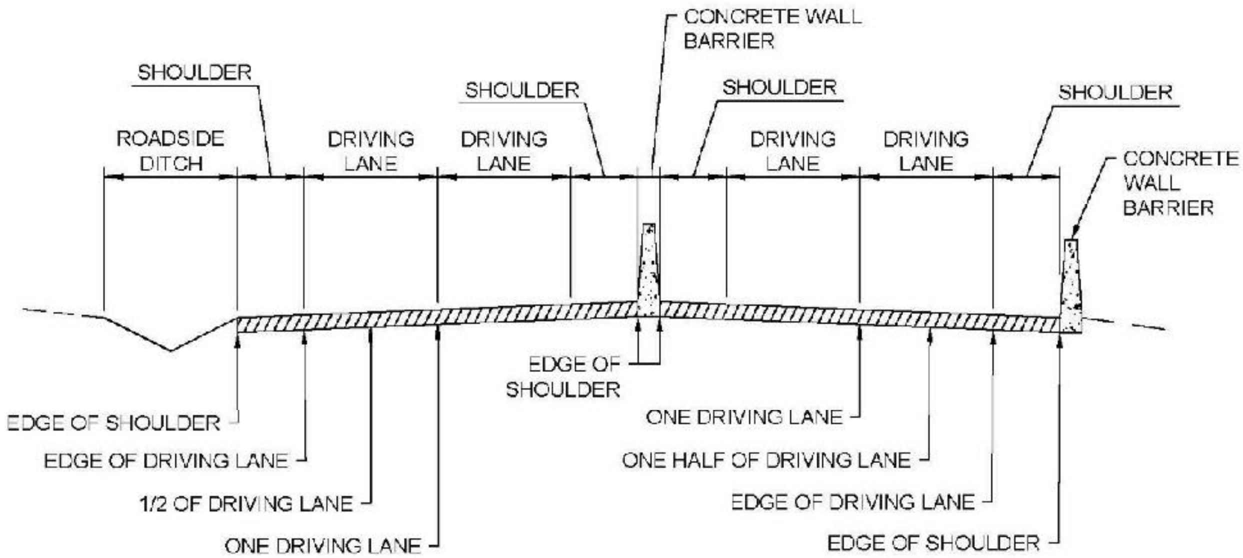


Figure 204-1 Typical Roadway Schematic:
Section with Roadside Ditch and Concrete Wall Barrier

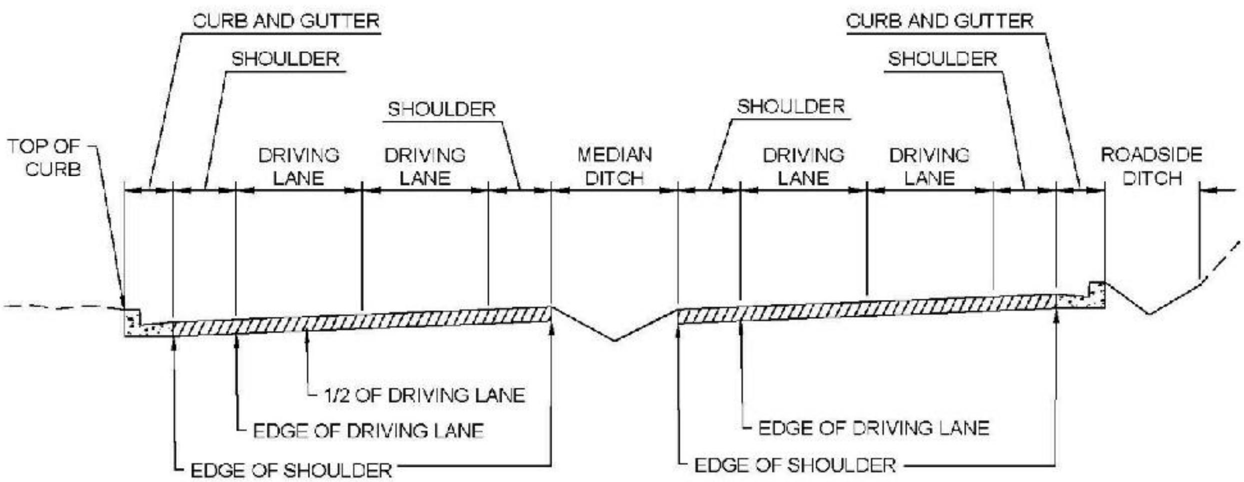


Figure 204-2 Typical Roadway Schematic:
Section with Median Ditch and Curb and Gutter

Table 204-1 Design Flood Hydraulic Criteria for Drainage Structures

Design Flood (c)	Two, Four and Six Lane Roads	Interstate
Bridge Freeboard	Minimum of 2 feet	Minimum of 2 feet
Existing Culverts	Limit headwater spread to edge of driving lane	Limit headwater spread to edge of driving lane
New Culverts	Ratio of headwater depth to culvert rise shall not exceed 1.5 and limit headwater to edge of shoulder	Ratio of headwater depth to culvert rise shall not exceed 1.5 and limit headwater to edge of shoulder
Sidewalk Culverts	Limit headwater depth to top of sidewalk	Not applicable
Bridge Deck Drains	Limit water spread to edge of driving lane	Limit water spread to edge of driving lane
Roadside Ditches and Inlets	Limit water spread to edge of shoulder	Limit water spread to edge of shoulder
Median Ditches and Inlets	Limit water spread to edge of shoulder	Limit water spread to edge of shoulder
Concrete Channels	Compute freeboard with equations in Section 204	Compute freeboard with equations Section 204
Trunk Lines	Limit hydraulic grade line to 1 foot below top of grate elevation	Limit hydraulic grade line to 1 foot below top of grate elevation
Curb Drop Inlets (a)	Two Lane - Limit water spread to half of driving lane Four and Six Lane - Limit water spread to 1 driving lane	Limit water spread to edge of driving lane
Concrete Wall Barrier (b)	Two Lane - Limit water spread to half of driving lane Four and Six Lane - Limit water spread to 1 driving lane	Limit water spread to edge of driving lane

a - Curb Drop Inlets criteria apply to curbs and similar vertical barriers up to 8" height
b - Concrete Wall Barrier criteria also apply to Concrete Barrier Railing and vertical barriers greater than 8" height
c - Criteria for both the Design Flood and Check Flood must be achieved

Table 204-2 Check Flood Hydraulic Criteria for Drainage Structures

Check Flood (c)	Two Lane Roads	Four and Six Lane Roads	Interstate
Bridge Freeboard	Below the low chord	Below the low chord	Below the low chord
Existing Culverts	Limit headwater spread to one half of a driving lane	Limit headwater spread to one driving lane	Limit headwater spread to edge of driving lane
New Culverts	Limit headwater spread to one half of a driving lane	Limit headwater spread to one driving lane	Limit headwater spread to edge of driving lane
Sidewalk Culverts	Overtopping the sidewalk is allowed	Overtopping the sidewalk is allowed	Not applicable
Bridge Deck Drains	Limit water spread to one half of a driving lane	Limit water spread to one driving lane	Limit water spread to edge of driving lane
Roadside Ditches and Inlets	Limit water spread to one half of a driving lane	Limit water spread to one driving lane	Limit water spread to edge of driving lane
Median Ditches and Inlets	Limit water spread to edge of driving lane	Limit water spread to edge of driving lane	Limit water spread to edge of driving lane
Concrete Channels	Maximum water surface below top of channel	Maximum water surface below top of channel	Maximum water surface below top of channel
Trunk Lines	Limit hydraulic grade line to the top of grate	Limit hydraulic grade line to the top of grate	Limit hydraulic grade line to the top of grate
Curb Drop Inlets (a)	Limit water depth to top of curb	Limit water depth to top of curb	Limit water spread to edge of driving lane
Concrete Wall Barrier (b)	Limit water spread to one half of a driving lane	Limit water spread to one driving lane	Limit water spread to edge of driving lane

a - Curb Drop Inlets criteria apply to curbs and similar vertical barriers up to 8" height
b - Concrete Wall Barrier criteria also apply to Concrete Barrier Railing and vertical barriers greater than 8" height
c - Criteria for both the Design Flood and Check Flood must be achieved

Peak Discharge Computation at Culverts and Bridges

When roadside ditches or storm drains add flow to the upstream side of a culvert or bridge, peak flow from the ditch/storm drain must be added to the peak flow rate of the arroyo to determine the appropriate flow rate to model through the culvert or bridge. Except in unusual situations and as approved by the NMDOT Drainage Design Bureau, differences in Time of Concentration (Tc) will not be used in this calculation, and the respective peak flows will be simply added together.

Bridge Scour

Calculate the maximum bridge scour depths at piers and abutments. Refer to **Section 607** for scour computation methods. The maximum scour depth may occur during more frequent, less intense storm events than the frequencies for the Design Flood or Check Flood. Evaluate scour for more frequent events if warranted for the circumstance, and then compare to the Design Flood and Check Flood scour results.

Bridge foundations should be designed by an interdisciplinary team of hydraulic, geotechnical, and structural engineers. Bridge foundations shall be designed to withstand the effects of estimated/calculated total scour that is comprised of long-term channel degradation, contraction scour, abutment scour and pier scour (if piers are present).

Concrete Channels

Rectangular channels should be avoided if possible due to additional structural design and construction costs since the walls act as retaining walls. In addition, the vertical walls (depending on channel depth) may be difficult to climb out of during a flood, and therefore present safety issues. Trapezoidal shaped channels are preferred because the problems described for rectangular channels are minimized.

Channel Freeboard

Channel freeboard is the additional wall height applied to a calculated water surface. Concrete channel freeboard shall be computed based on the Design Flood. Freeboard computations are not required for the Check Flood; however, the Check Flood water surface must remain below the top of the channel. The City of Albuquerque Development Process Manual (DPM) (City of Albuquerque, October 2008) criteria and related equations for trapezoidal and rectangular channels are adopted by the NMDOT. The hotlink to the DPM main document is provided below.

http://library.amlegal.com/nxt/gateway.dll/New Mexico/albuqdpm/albuquerquenewmexicodevelopmentprocessma?f=templates$fn=default.htm$3.0$vid=amlegal:albuquerque_nm_mc$anc=JD_DPM

If further DPM information is required from the website, please follow these instructions. After the DPM opens, perform a search for “freeboard,” then select “Chapter 22 Drainage, Flood Control, and Erosion Control”, and the appropriate page will be obtained that contains the trapezoidal and rectangular channel equations and criteria listed below.

Trapezoidal Channels

Adequate channel freeboard above the Design Flood water surface must be provided and shall not be less than determined by the following:

where:

V = velocity, ft/s

d = flow depth, ft

D_c = critical depth, ft

1. For flow rates of less than 100 cfs and average flow V of less than 35 ft/s:
   Freeboard (ft) = $1.0 + 0.025\ V\ d^{1/3}$
2. For flow rates of 100 cfs or greater and average flow velocity (V) of 35 ft/s or greater:
   Freeboard (ft) = $0.7\ (2.0 + 0.025\ V\ d^{1/3})$
3. For supercritical flow where the specific energy is equal to or less than 1.2 of the specific energy at Dc, the wall height will be equal to the sequent depth, but not less than the heights required above. This condition should be avoided.

http://library.amlegal.com/nxt/gateway.dll/New Mexico/albuqdpm/albuquerquenewmexicodevelopmentprocessma?f=templates$fn=default.htm$3.0$vid=amlegal:albuquerque_nm_mc$anc=JD_DPM

Rectangular Channels (not used except with NMDOT Drainage Design Bureau approval)

1. For flow depths of 1.0 ft or less and average flow velocities less than 35 ft/s, add 1.0 ft
2. For flow depths of 1.0 ft or less and average flow velocities greater than 35 ft/s, add 1.5 ft
3. For flow depths of greater than 1.0 ft and average flow velocities less than 35 ft/s, add 2.0 ft
4. For flow depths of greater than 1.0 ft and average flow velocities greater than 35 ft/s, add 3.0 ft
5. For supercritical flow where the depth is between critical depth (D_C) and 0.80 D_C, the wall height must be equal to the sequent depth (depth after a hydraulic jump), but not less than the heights required above. This condition should be avoided.

Summary

Freeboard, as determine from the previous equations, will be in addition to any super-elevation of the water surface, standing waves, and/or other water surface disturbances. When the total expected height of disturbances is less than 0.5 ft, disregard their contribution.

Unlined portions of the drainage way may not be considered as freeboard unless specifically approved by the NMDOT Drainage Design Bureau.

205 Additional Criteria for Bridges, Channels, Culverts, Inlets, Concrete Wall Barriers and Other Considerations

Table 205-1 Additional Criteria for Bridges, Channels, Culverts, Inlets, Concrete Wall Barriers and Other Considerations

Bridges - Debris	Estimate pier (if present) debris width and depth and account for conveyance loss in the hydraulic and scour analyses. Estimate based on urban or rural location, watershed and watercourse conditions.
Bridges - Sedimentation	Evaluate the structure and mitigate effects with respect to - significant changes to channel velocity, aggradation or degradation, scour, head cutting, and conveyance.
Culverts - Bulking and Debris Factor	Urban and Rural – For clear water calculations apply a 20% factor. For flows determined by regression equations or a USGS Bulletin 17C analysis of stream gage data, no additional bulking factor should be applied. Refer to **Section 402.11** for bulking factors.
Pipe (storm drain and culvert) - Material and Wall Thickness	Select wall thickness based on Corrosion Resistance Number – **Section 800** (NMDOT Spec. 570.2.3.1) and cover height.
Curb & Median Drop Inlet Grates - Clogging Factor	Inlet Grates on Grade - assume a 25% minimum grate clogging factor.
	Inlet Grates in Sag - assume a 50% clogging factor. Inlet grates in sag will require a minimum of one flanking inlet (an inlet near to and upstream of the sag inlet).
	Median Inlet Grates - assume a 50% grate clogging factor.
Concrete Wall Barrier - Clogging Factor (drainage slots)	Assume a 50% clogging factor due to minimal opening size. Wall barrier in sag will require a minimum of one flanking inlet (an inlet near to and upstream of the sag inlet).
Detour Drainage Structures	Shall be designed to convey the 2-year flood as a minimum. However, some circumstances listed here may require larger flood events. Consult with the Drainage Design Bureau. - A long construction period (longer than 9 months) - Safety concerns due to roadway overtopping - Environmental concerns and potential for environmental damage - Potential for property damage and related economic consequences
Waterstops/turnout humps	All turnouts to NMDOT ROW must be constructed with waterstops (humps), matching the height of the existing curb and gutter or having a minimum height of 4" if curb and gutter is not present. If full-height waterstops are not geometrically feasible, consult with the NMDOT Drainage Engineer for alternative configurations. Turnouts or driveways may discharge runoff to the NMDOT ROW provided that the contributing runoff is included in design calculations for the roadway and storm drain system. If NMDOT will discharge roadway runoff to private property, drop inlets, or other methods to reduce the runoff down the turnout should be installed immediately upstream of the turnout.
Adjacent Properties	Consider and avoid detrimental effects - flooding, sedimentation, or erosion - on adjacent property.
Irrigation Ditches	Ensure that the proposed design does not adversely affect irrigation ditches.
Channel or Stream Deterioration and Modifications	Evaluate the proposed structure and mitigate effects with respect to channel velocity, aggradation or degradation, scour, head cutting, and conveyance. Make allowance in channels for conveyance loss due to debris, vegetation and sedimentation.
Regulatory Requirements	Evaluate proposed structure/project and ensure that any channel or stream modifications meet the requirements of the U.S. Army Corps of Engineers, the NM Environment Department, U.S. Fish & Wildlife Service, U.S. EPA, FEMA, and other agencies.

206 Design Criteria for Storm Drains and Culverts

Table 206-1 Design Criteria for Storm Drains and Culverts

Design Criteria for Storm Drains and Culverts	
Item	**Design Criteria**
STORM DRAINS	
Minimum diameter trunk line	24 inch
Minimum diameter laterals	24 inch
Maximum distance between manholes:	
24 inch storm drain	300 feet
27-36 inch storm drain	400 feet
42-54 inch storm drain	500 feet
60 inch or greater storm drain	600 feet
Minimum cover on pipe	See NMDOT Standard Drawings
Minimum storm drain slope	0.3%
Minimum velocity (trunk and laterals)	2.5 ft/s
Manhole location	Not within an intersection for linear storm drains, may be at an intersection for two trunk lines intersecting at an intersection
CULVERTS	
Minimum diameter turnout culverts	18 inch
Minimum diameter non-turnout culverts	24 inch
Minimum cover on pipe	See NMDOT Standard Drawings
Minimum slope	0.5%
Slope	Match existing slope if steeper than 0.5%
Minimum velocity	3 ft/s
TEMPORARY CULVERTS	
Minimum diameter culverts	12 inch (18 inch is preferable)
Minimum diameter highway culverts	24 inch
Minimum cover on pipe	See NMDOT Standard Drawings and account for load during construction
Minimum slope	0.5%
Slope	Match existing slope if steeper than 0.5%
Minimum velocity	3 ft/s

207 Design Criteria for Detention and Retention Ponds

Jurisdictional Dams and Non-Jurisdictional Dams

Refer to **APPENDIX 1** for definitions as obtained from the following document.

NMOSE Dam Safety Bureau, December 2010, "Rules and Regulations Governing Dam Design, Construction and Dam Safety".

Design of jurisdictional dams shall be avoided for all NMDOT projects.

DETENTION AND RETENTION PONDS

Refer to New Mexico Environment Department (NMED) for Retention Pond definition, stormwater infiltration description, and permitting requirements, if any.

NMDOT Requirement - Infiltration losses, considered in retention pond volume computations, must be documented by infiltration test data or by a qualified reference.

Pond Design Criteria (Detention and Retention Ponds)

- Sediment Bulking
    - Computed/simulated clear water hydrographs shall be increased by a sediment bulking factor to account for sediment volume within the water volume
    - Bulking factors will typically range from about 1.0 for a 100 percent urban impervious watershed including hard lined conveyance systems (no exposed soil or landscape areas), to a maximum factor of about 1.25 for a rural undeveloped or damaged watershed. **Section 402.11** presents more information and items to consider regarding determination of sediment bulking factors. **Figure 402-19** presents a range of bulking factors for various return period floods.
    - Obtain approval from the Drainage Design Bureau regarding sediment bulking factor assumptions and computed or selected values applied for pond analysis and design
    - Sediment bulking factors shall be applied in addition to the dead storage volume requirement (see **Table 207-1**). Dead storage design provides for additional design storage volume due to sediment deposition, and accounts for either lack of maintenance (sediment removal to maintain the design storage volume) and/or storage volume loss from frequent floods/sediment deposition between maintenance activities.
    - A maintenance schedule may be warranted, depending on accumulated sediment loads (volumes) and available storage space.

- Principal Spillways
    - Minimum outfall conduit diameter shall be 24 inches
    - Outfall conduit design maximum pressure and allowable joint pressure capacity shall be documented
    - Detention Ponds - spillways shall provide for floatable debris retention
    - Retention Ponds – do not have principal spillways
    - Outfall design shall include erosion/scour and energy dissipation structures

  - Outfall conduit shall be oriented in the direction of, and outfall to, the natural watercourse
  - Include water quality features as appropriate (e.g., trash racks, perforated riser)
  - Outfall conduit through an embankment shall have piping protection

- Emergency Spillways
  - Detention Ponds - shall have an emergency spillway with sufficient capacity to pass the Check Flood without overtopping the embankment
  - Retention Ponds - shall have an emergency spillway with sufficient capacity to pass the Check Flood without overtopping the embankment
  - Spillways shall be directed to the natural watercourse
  - Spillway approach, crest, chute, and toe design shall include erosion/scour and energy dissipation structures

- Pond Embankments
  - Maximum pond side slopes and embankment slopes shall be 1 vertical to 3 horizontal (1V:3H) if an approved "seeded gravel mulch" is applied. Otherwise maximum slopes of 1V:6H or flatter are required to minimize rill/gulley erosion.
  - Maximum embankment height is defined as the vertical distance from the lowest point on the downstream embankment toe to the lowest point on the embankment crest as defined by the NM Office of the State Engineer Dam Safety Bureau (NMOSE, December 2010). This definition shall also apply to NMDOT pond embankments.
  - Embankment crest width shall be:
    - 12 feet minimum width if a maintenance access road on crest is required by NMDOT Drainage Design Bureau
    - Crest width may be less than 12 feet if a maintenance access road is not required, but not less than 3 feet. Crest widths less than 12 feet must be approved by the NMDOT Drainage Design Bureau
    - Crest width shall be designed in conjunction with embankment design and documented by geotechnical specifications and recommendations
    - Crest width requirements do not apply to retention ponds excavated below ground on all sides

- Maintenance Access Road to Pond Bottom
  - Required – maximum slope allowed shall be 1V:8H (12.5%)
  - Road surface shall be designed to ensure access and may include crushed gravel, base course, or other approved materials and design as required
  - Road should lead to principal spillway structure if possible

- Miscellaneous Pond Requirements
  - An approved permanent sediment stage indication marker (marked in 1 ft increments) shall be installed in all ponds and shall be located near the embankment toe and near the principal spillway
  - Grade detention pond bottoms to drain at minimum 0.5% slope towards the principal spillway. Retention pond bottoms may have 0% slope.

- Fencing shall be installed along the perimeter of all ponds as required. A variance to the fence requirement may be possible based on specific circumstances. For example, a shallow 1 ft maximum depth pond in a gore area

All designs must be approved by the NMDOT.

Refer to **Table 207-1** for additional pond design criteria including:

- Dead storage
- Freeboard
- Allowable peak water surface elevation
- Drain time

Table 207-1 Criteria for Detention and Retention Ponds

Flood		**Design Flood**	**Check Flood**
Storm Frequency		**50-year 24-hour**	**100-year 24-hour**
	Design Item		
DETENTION PONDS (Non-Jurisdictional) (b) (c)	Dead Storage	Rural - Use Check Flood	Rural - provide additional storage volume equal to 20% of inflow hydrograph volume
		Urban - Use Check Flood	Urban - provide additional storage volume equal to 10% of inflow hydrograph volume
	Freeboard	Rural and Urban - 2 ft of freeboard to top of embankment	Rural and Urban - 1 ft of freeboard to top of embankment
	Allowable Peak Water Surface	Rural and Urban - Water surface elevation at or below emergency spillway	Rural and Urban - Emergency spillway may flow with 1 ft of freeboard to top of embankment
	Drain Time	Rural and Urban - must drain in less than 96 hours (a)	Rural and Urban - must drain in less than 96 hours (a)
RETENTION PONDS (Non-Jurisdictional) (b) (c)	Dead Storage	Rural - Use Check Flood	Rural - provide additional storage volume equal to 30% of inflow hydrograph volume
		Urban - Use Check Flood	Urban - provide additional storage volume equal to 20% of inflow hydrograph volume
	Freeboard	Rural and Urban - 2 ft of freeboard to top of embankment	Rural and Urban - 1 ft of freeboard to top of embankment
	Allowable Peak Water Surface	Rural and Urban - Water surface elevation at or below emergency spillway	Rural and Urban - Emergency spillway may flow with 1 ft of freeboard to top of embankment
	Drain Time	Rural and Urban - must infiltrate/evaporate in less than 96 hours (a)	Rural and Urban - must infiltrate/evaporate in less than 96 hours (a)
MS4 Permit Requirements		See **Section 207** text and **Section 700** for more information	
JURISDICTIONAL DAMS		(a)	
a - See **APPENDIX 1** for definitions of non-jurisdictional and jurisdictional dams. Refer to NMOSE Dam Safety Bureau, December 2010, "Rules and Regulations Governing Dam Design, Construction and Dam Safety".			
b - Design all ponds with stormwater quality improvement features. See **Section 506.6.1** for ported principal spillway concepts and **Section 700** for stormwater quality permitting guidance.			
c - See **Section 207** text for further design requirements including sediment bulking factors only for Detention Ponds.			

Stormwater Quality MS4 Requirements

All projects and ponds shall be designed with stormwater quality improvement features. See **Section 700** for permit requirements, additional information regarding stormwater quality design criteria and Green Infrastructure (GI)/Low Impact Development (LID) information.

Municipal Separate Storm Sewer System (MS4) Permit considerations, computations and designs shall be addressed in the Preliminary and Final Drainage Reports. The EPA has a Draft MS4 Permit and a Middle Rio Grande Watershed Based Permit. Note that as the various permittees begin to implement the permit conditions, it is likely that new best management practices suited to New Mexico will be developed, and it is possible that the permit conditions may change. Consult with the Drainage Design Bureau at project inception regarding the latest permit and design requirements.

(Note – Hotlinks for the referenced documents previously located on the EPA website, were not available during the preparation of this Drainage Design Manual.)

<u>Pond Design Criteria</u>

MS4 ponds shall be designed for the clear water runoff volume. Sediment bulking factors are not required unless special circumstances exist. Dead storage volume is not required but is recommended if special circumstances exist. Verify pond design criteria with the Drainage Design Bureau.

Controlling Runoff from New Development and Re-development

One requirement from the Draft MS4 Permit and the existing Middle Rio Grande Watershed Based MS4 Permit, is that Green Infrastructure (GI) and Low Impact Development (LID) practices and control measures shall be implemented under the Post-Construction Stormwater Management, for New Development and Re-development. Permit conditions also include requiring controls that mimic pre-development runoff. For purposes of the MS4 Permit, the pre-development hydrology can be met by retention of the storm volume associated with the 90th percentile storm event for new development sites, and the 80th percentile storm event for re-development sites.

The 90th and 80th percentile storm depths may be computed by following instructions in the Draft Permit and related technical document, or the values in the following table may be adopted by selection of the nearest location given in the table. **Table 207-2** values were obtained from the Draft MS4 Permit.

Table 207-2 80th and 90th Percentile Rainfall Events (inches)

Source: USEPA, March 2015, EPA Publication Number 832-R-15-009, "Estimating Pre-Development Hydrology for Urbanized Areas in New Mexico".

LOCATION NAME	80^{th} Percentile	90^{th} Percentile
Albuquerque International Airport	0.48	0.65*
Farmington Agricultural Science Center	0.40	0.53
Los Alamos	0.53	0.69
Los Lunas 3 SSW	0.48	0.71
Santa Fe 2	0.50	0.68
State University (Las Cruces)	0.55	0.78
El Paso Airport	0.54	0.82

*Use 0.615 inches per the following paragraph.

Notes related to **Table 207-2** and information for the Albuquerque area follow.
The previous predevelopment runoff study (Kosco, et al., 2014) used data from the Albuquerque International Airport for the period 1950-2012. Because rainfall data for the other stations studied in the 2015 report did not extend back to 1950, the 2015 report used the most recent 30-year period of record (1983-2013) for all stations which resulted in a slightly higher 90_{th} percentile event for Albuquerque. For all NMDOT projects within the small MS4 permit areas, use the values in **Table 207-2**.

For the Albuquerque urban area, the following rainfall depth data should be applied from the previous predevelopment runoff study (Kosco, et al., 2014): 0.48 inches = 80^{th} %, 0.615 inches = 90^{th} %. This study is referenced specifically in the Middle Rio Grande Watershed MS4 Permit, and the 0.615 inches shown in this report is the value the EPA has directed to be used.

Alternatively, values may be estimated through site specific pre-development hydrology and associated storm event discharge volume using the methodology specified in the 2015 USEPA Technical Report "Estimating Predevelopment Hydrology for Urbanized Areas in New Mexico".

(Note – Hotlinks for the referenced documents previously located on the EPA website, were not available during preparation of this Drainage Design Manual.)

The pre-development hydrology requirement may be achieved by retaining the increase in runoff that will occur from the added impervious area, computed as follows:

1. New Development –The 90^{th} percentile rainfall depth (inches) multiplied by the new development impervious area, or,
2. Re-development - The 80^{th} percentile rainfall depth (inches) multiplied by the additional re-development impervious area. The retained runoff volume = (post-construction impervious area – pre-construction impervious area) * (80^{th} percentile rainfall depth).

Refer to **Section 700** for more information.

208 References

AASHTO, 2001, “A Policy on Geometric Design of Highways and Streets, Fourth Edition”.
http://nacto.org/docs/usdg/geometric_design_highways_and_streets_aashto.pdf

AASHTO, 2011, “A Policy on Geometric Design of Highways and Streets, 6th Edition”.

AASHTO, 2014, “AASHTO Drainage Manual, Chapter 11”.

City of Albuquerque, October 2008, “Development Process Manual, Chapter 22, Drainage, Flood Control and Erosion Control”.
http://library.amlegal.com/nxt/gateway.dll/New Mexico/albuqdpm/albuquerquenewmexicodevelopmentprocessma?f=templates$fn=default.htm$3.0$vid=amlegal:albuquerque_nm_mc$anc=JD_DPM

EPA, Region 6, “Current Internet Download – Region 6 sMS4 General Permit, NMR04000 Stormwater General Permit for Small Municipal Separate Storm Sewer Systems (MS4s)”.
(Note – Hotlinks for the referenced document previously located on the EPA website, were not available during preparation of this Drainage Design Manual.)

EPA, March 2015, Publication Number 832-R-15-009, “Estimating Pre-Development Hydrology for Urbanized Areas in New Mexico”.
(Note – Hotlinks for the referenced document previously located on the EPA website, were not available during preparation of this Drainage Design Manual.)

FHWA, December 1995, “Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation’s Bridges”.
https://www.fhwa.dot.gov/bridge/mtguide.pdf

NMDOT Website, “Standard Specifications for Highway and Bridge Construction”.
http://dot.state.nm.us/content/dam/nmdot/Plans_Specs_Estimates/2014_Specs_For_Highway_And_Bridge_Construction.pdf

http://dot.state.nm.us/content/nmdot/en/Standards.html

NMDOT Website, “Standard Drawings”.
http://dot.state.nm.us/content/nmdot/en/Standards.html

NMDOT, November 8, 2016, “Design Exception, Design Variance & ADA Design Variance Procedures”, Infrastructure Design Directive IDD-2016-11.
http://dot.state.nm.us/content/dam/nmdot/Plans_Specs_Estimates/Design_Directives/2016/IDD-2016-11_(Design_Exception_Variance_and_ADA_Design_Variance.pdf

NMOSE, December 31, 2010, “Rules and Regulations Governing Dam Design, Construction and Dam Safety”, New Mexico Office of the State Engineer Dam Safety Bureau.
http://www.ose.state.nm.us/DS/Regs/19-25-12-NMAC-2010.pdf

300 NMDOT DRAINAGE ANALYSES CHECKLISTS, REPORT AND CONSTRUCTION PLAN REQUIREMENTS

301 Introduction

This Section presents guidance, information, data sources, and lists most topics that should be considered for field work and for inclusion into NMDOT Drainage Report submittals. Adherence to direction provided in this section will promote reports that lead to a holistic evaluation of drainage and design issues and will minimize the review effort by the NMDOT Drainage Design Bureau, and will minimize report re-submittals. The ultimate goal is to promote economic design, constructability, and sustainability of proposed drainage structures.

Questions that should be asked during the drainage analysis and design and be addressed or answered in the drainage report include:

- Is the design buildable?
- Was maintenance access considered and included in the design? Is the design maintainable?
- Was sustainability considered in the planning and design?
- Were location and related issues considered such as:
    - high mountains (snow and ice accumulations, freeze/thaw, perennial streams, fish habitat and environmental issues, brush and tree debris at culverts and bridges, erosion and sedimentation);
    - desert areas (blowing sand, brush debris, erosion and sedimentation);
    - irrigated valleys or low-lying areas (saturated soils)
- Are the subgrade soils and soil profile appropriate for infiltration and recharge?
- Are the subgrade soils expansive or collapsible that requiring special attention to protect the subgrade from water?
- Will the design enhance, be protective of, or adversely impact wetlands or valuable habitat?
- Will the ditches and shoulders likely be vegetated?
- Is there a high probability of large volumes of debris, brush, trash impacting drainage structures?
- Would acquiring more right-of-way make the project easier to maintain and/or construct? (reducing erosion, avoiding retaining walls, and reducing the sizes of headwalls)
- Did the Engineer consider that in urban areas, as Average Daily Traffic (ADT) increases, so does highway generated pollution?
- Where would the water discharge if the structure was overtopped or partially clogged?
- What impact will the project have on existing wetlands, sensitive or critical habitat?
- Are there opportunities to create stormwater mitigation areas or credits within or in association with the project?
- How does the design impact adjacent properties?

- Are there known water quality issues/limitations (303(d) listed receiving waters – Clean Water Act Section 303(d) Impaired Waters and Total Maximum Daily Loads (TMDLs))? https://www.epa.gov/tmdl
- Have stormwater quality improvement features been considered at all locations?

302 Supplemental Data Sources

Supplemental data sources to obtain drainage, flood and water resource information, master drainage and development plans/record drawings (as-built plans), geographic information system (GIS) data, mapping, satellite imagery include but are not limited to the following:

Government Agencies:

- NMDOT maintenance patrol records/verbal information
- NMDOT Maps and Records – record drawings (as-built plans)
- Albuquerque Metropolitan Arroyo Flood Control Authority (AMAFCA)
- Southern Sandoval County Arroyo Flood Control Authority (SSCAFCA)
- Doña Ana County Flood Commission (DACFC)
- Federal Emergency Management Agency (FEMA), Flood Insurance Study (FIS) Reports and Flood Insurance Rate Maps (FIRMs)
- NOAA Atlas 14 (rainfall data server)
- Next Generation Radar (NEXRAD)
- Community Collaborative Rainfall, Hail and Snow Network (CoCoRAS) (volunteer rainfall data network, managed by the National Weather Service)
- National Weather Service (NWS) (rainfall data)
- Natural Resources Conservation Service (NRCS) (cover type and soils data)
- U.S. Army Corps of Engineers (USACE)
- U.S. Bureau of Reclamation (USBR)
- U.S. Fish and Wildlife Service (USFWS)
- U.S. Geological Survey (USGS) (on-line stream gage data)
- Mid-Region Council of Governments (MRCOG) (current and historic aerial photographs and mapping)
- Cities, towns, and villages
- Local community officials – city and county (public works directors and city engineers)
- New Mexico State Police
- County Sheriffs

Irrigation Districts:

- Elephant Butte Irrigation District (EBID) – operates and maintains many irrigation canals, drains and dams between Percha Dam (below Caballo Dam) and the New Mexico/Texas state line
- Middle Rio Grande Conservancy District (MRGCD) – operates and maintains many irrigation canals and drains between Cochiti Dam and the north boundary of the Bosque Del Apache National Wildlife Refuge

Other Sources:

- Earth Data Analysis Center (EDAC) – maintains a large repository of historical and recent aerial photography and contour mapping

- Google Earth and Bing Maps (current and historical aerial photography and street view)
- Internet search for flood or rainfall reports
- New sources, as methods and technologies develop and supersede others
- Individuals that live near the location
- Newspaper records

303 Field Inspection Checklists

Preparation is required prior to a field visit. During the field visit, various items/tasks must be observed, measured and documented. **APPENDIX 1** contains a Field Trip Preparation Checklist and a Field Trip Observations and Measurements Checklist. Each checklist should be copied, reviewed, and completed as appropriate. The Observations and Measurements Checklist and associated information obtained during the field trip will provide necessary data required for hydrologic and hydraulic analyses. These checklists will guide the engineer to include all items that should be addressed and may help avoid the need for an additional field visit.

304 Drainage Analysis Requirements

Each drainage study will result in one or more required drainage report(s), each report will document all analyses and recommended drainage related improvements. Other tasks that may be required include preparation of drainage and project related permits and coordination with agencies such as:

- U.S. Environmental Protection Agency (EPA) for: sediment/erosion control and stormwater quality issues
- U.S. Army Corps of Engineers (USACE) for: stormwater quality and environmental related issues
- U.S. Fish and Wildlife Service (USFWS) for: biological assessments, stream and riparian area wildlife habitat issues
- Federal Emergency Management Agency (FEMA) for: floodplain related issues
- New Mexico Environment Department (NMED) for: stormwater quality and related environmental issues, infiltration permits
- New Mexico Office of the State Engineer (NMOSE) for: water rights issues and jurisdictional dam determination (for detention ponds)

The engineer may be required to prepare a Temporary Erosion and Sediment Control Plan (TESCP). In addition, coordination with other NMDOT Sections and District offices may be required.

Project Development and Drainage Tasks

NMDOT projects include a standard set of project development tasks and milestones. The standard project tasks and milestones are listed below with drainage related tasks shown in bold text.

Typical Project Development Schedule and Milestones

- Preliminary Scoping Report
- Preliminary Field Review
- **Drainage Field Inspection***
- 30% Plan Review
- 60% Plan Review
- **Preliminary Drainage Report**
- Temporary Erosion and Sediment Control Plan
- **Draft Final Drainage Report**
- 90% Plan Review
- **Revised Final Drainage Report**
- Final Design Review
- Plans, Specifications, and Estimates

*The Drainage Field Inspection is sometimes combined with the 30% Plan Review.

305 Drainage Reports and Submittal Format

Preliminary Drainage Report

The Preliminary Drainage Report should summarize the results of the preliminary drainage analyses. Structure size recommendations will be reviewed by the NMDOT Drainage Design Bureau and will be used for design plans by the NMDOT Highway Design Regions. The Preliminary Drainage Report is prepared concurrently with the 60% plan preparation. Basic elements which should be included in the Preliminary Drainage Report are listed below. A much more detailed Drainage Report Checklist and a Drainage Report Table of Contents Template are included in **APPENDIX 3** and should be used for the actual development of the scope of analyses and report preparation. The following is a brief list of the requirements for preparing Preliminary and Final Drainage Reports:

Items Required on the Cover Include:

- Project Number
- Project Control Number
- Date
- Route Number
- Beginning Milepost Number
- Ending Milepost Number
- Bridge Number(s)
- Document Type: example - Final Drainage Report
- Document Description

Other Items Within the Report Include:

- Professional Engineer - signature, stamp and date
- Drainage design criteria
- Drainage area topographic map with structure locations identified
- Identify soil types, vegetation and land use distribution
- Runoff Curve Number (CN) or Rational Formula Method (C) calculations

- Rainfall tables
- Time of Concentration calculations
- Summarize the drainage field inspection results
- Document the Patrol Foreman interview
- Drainage Structure Field Inspection forms
- Summary Table of existing and recommended drainage structure sizes and types
- Identify data sources and references used in the analysis

The Preliminary Drainage Report typically does not include detailed output from hydrologic or hydraulic analyses, however, data and electronic models generated in the analyses process should be kept on file and submitted with the Preliminary Drainage Report.

Final Drainage Report

The Final Drainage Report is a refinement of the Preliminary Drainage Report. Preparation of the hydrologic and hydraulic calculations and models occurs concurrently with the development of the project design and plan sets. In order to facilitate timely technical review of the drainage assumptions, analysis, and design, a Draft Final Drainage Report should be developed and submitted prior to the 90% Plan Review. This allows time for any necessary changes to the analysis or design. A Revised Final Drainage Report can be submitted after the 90% Plan Review.

The highway design data must include: plan and profile sheets (with grades), typical roadway sections, toe of slope lines, and drainage structure survey data. Modifications to the preliminary hydrologic analyses are completed as required, and final structure sizes are established. A detailed hydraulic analysis (backwater profiles, flow velocities, etc.) is required for bridge structures and for some large culvert locations. Analysis of scour depths at critical locations is required to assist in the design of permanent erosion countermeasure design. At bridge watercourse crossings with unprotected (unlined) beds/overbanks/abutments/piers, a sediment transport and sediment continuity analyses upstream and downstream of the bridge will usually be required.

Drainage Report Checklist

Please refer to **APPENDIX 3** for a Drainage Report Checklist that presents a comprehensive drainage report outline which will serve as a guide during drainage report preparation. This Checklist will assist both the engineer in preparing the scope of the drainage report, and the NMDOT reviewer.

Drainage Reports may not require every item in the Checklist as some items may not be relevant to the analysis or design. The Checklist is provided as a reminder to consider these items during analysis, design, and report development. A Drainage Report Table of Contents Template is also included in **APPENDIX 3**.

Drainage Reports Submittal Format

The NMDOT Drainage Design Bureau will require the following items:

- A digital PDF copy of the stamped and signed drainage report text and appendices
- A digital submission of the hydrologic and hydraulic models
- A digital submission of spreadsheets and other relevant supporting computations and documents

- Quality Assurance and Quality Control (QA/QC) documentation, including written responses to all comments on Plan Sets, Preliminary and Final Drainage Reports

The NMDOT will typically not require a paper submittal, unless specifically requested. Coordinate with the NMDOT Drainage Design Bureau regarding additional or specific information and the format required to assist in the NMDOT review of the preliminary and final drainage analyses, models, recommendations, and reports.

Municipal Separate Storm Sewer Systems (MS4s)

For projects within a USEPA designated MS4, the requirements, applicable data, information and calculations shall be included in the Drainage Report(s). Refer to **Section 700** for permitting requirements.

306 Temporary Erosion and Sediment Control Plans

Design of temporary erosion and sediment control measures or plans are not included in the Preliminary or Final Drainage Reports. The drainage design for erosion and sediment control features and Best Management Practices requires the engineer to refer to the document "National Pollutant Discharge Elimination System Manual (Stormwater Management Guidelines for Construction and Industrial Activities, Revision 2)", NMDOT, August 2012, or current version. The Drainage Design Bureau or the Bureau consultants, prepare Final Stabilization, Erosion and Sediment Control Plans (post construction conditions), while it is the construction contractors' responsibility to prepare Temporary Erosion and Sediment Control Plans for construction phase activities.

NMDOT, August 2012, "National Pollutant Discharge Elimination System Manual - Stormwater Management Guidelines for Construction and Industrial Activities, - Revision 2". http://dot.state.nm.us/content/dam/nmdot/Infrastructure/NPDESM.pdf

307 Construction Plan Drainage Requirements

The following information must be included in the NMDOT construction plans, typically within the 10-Series.

Bridges - Annotate the plans with the following information:

a. DA = drainage area in acres or square miles
b. Qx = design peak flow rate in cfs = Design Flood flow; with "x" representing the Design Flood recurrence interval
c. HWx = headwater in feet; listed as either depth from the upstream bridge invert to water surface at the upstream bridge deck, or the elevation of water surface; with "x" representing the recurrence interval

Through Culverts - Annotate the plans with the following information:

d. DA = drainage area in acres or square miles
e. Qx = design peak flow rate in cfs = Design Flood flow; with “x” representing the Design Flood recurrence interval
f. HWx = headwater in feet; listed as either depth from the culvert invert to water surface, or the elevation of water surface; with “x” representing the recurrence interval

Drop Inlets - Annotate the plans with the following information:

g. DA = drainage area in acres or square miles
h. Qx = design peak flow rate in cfs = Design Flood flow; with “x” representing the Design Flood recurrence interval
i. HGLx = hydraulic grade line shown in profile; with “x” representing the recurrence interval

Storm Drain Network Pipes - Annotate the plans with the following information:

j. Vx = velocity in ft/s for the Design Flood flow; with “x” representing the Design Flood recurrence interval
k. Qx = Design peak flow rate in cfs = Design Flood flow; with “x” representing the Design Flood recurrence interval
l. HGLx = hydraulic grade line shown in profile; with “x” representing the recurrence interval

308 References

NMDOT, August 2012, “National Pollutant Discharge Elimination System Manual - Stormwater Management Guidelines for Construction and Industrial Activities, - Revision 2”. http://dot.state.nm.us/content/dam/nmdot/Infrastructure/NPDESM.pdf

U.S. Environmental Protection Agency, current internet site, “Clean Water Act Section 303(d): Impaired Waters and Total Maximum Daily Loads (TMDLs)”. https://www.epa.gov/tmdl

400 HYDROLOGY

The standard methods of hydrologic analyses presented in this Drainage Design Manual should be used for all New Mexico Department of Transportation (NMDOT) structure analyses and design projects. Use of these standard methods will ensure consistency of analysis and design methods to the greatest extent possible. A brief description of each analysis method is included, followed by a step by step procedure to apply the method. **APPENDIX 6** contains example problems to assist the drainage engineer. Note, that for the purposes of water quality protection within a designated Municipal Separate Storm Sewer System (MS4), methods other than the standard methods are prescribed in **Section 700.**

This Drainage Design Manual specifies which hydrologic analysis method should be applied for use at a particular drainage structure based on drainage area size, location, available data, and physical circumstances. By standardizing the process for choosing hydrologic analysis methods, the intent is that a consistent, appropriate type, and level of analysis is assured for every drainage structure, large and small. Despite the efforts to standardize both the selection of methods and their reasonable application, proper drainage analysis and design is not complete without the inclusion of competent engineering judgement. Drainage engineers working on NMDOT projects are expected to apply sound engineering judgement and/or to seek the counsel of more experienced engineers when questions or uncertainty exists throughout the analysis and design development process.

Questions such as these should be considered in every drainage analysis:

- How much analysis effort is warranted for this structure given the size, cost, importance, and consequences of a failure?
- How are failure and non-failure defined?
- What is the probability of failure?
- What are the consequences of a failure?
- Do the analyses results make sense?
- Are the costs associated with the proposed structure(s) consistent with the benefits?
- Will the proposed structure(s) be functional?
- Can the proposed improvement(s) be practically maintained?

Checking the analyses results against experience reported by the local patrol foreman, local records, high watermarks, historic aerial photography, “rules of thumb”, and other computational methods are all part of gaining experience that leads to developing good judgment, and the exercising of prudent engineering practice.

401 NMDOT Approach to Hydrologic Analyses

The NMDOT is tasked with providing transportation facilities that are reasonably safe for the public within the realities of budget and widely varying soils, topography and climate conditions. A safe roadway environment includes proper roadway drainage, and properly designed drainage structures. The NMDOT’s goal is to design and construct roadways and drainage structures that meet minimum design standards and do so within the realities of budgetary constraints. **Section 200** of this Manual presents the current minimum drainage criteria that shall be applied for NMDOT projects.

The NMDOT also recognizes that the effort associated with the design and analysis of drainage structures and roadways must be commensurate with the importance of the transportation facility. Small culverts on low volume roads in remote areas normally do not require exhaustive analyses. For this reason, the NMDOT has established a hierarchy of drainage analysis methods to ensure that appropriate design methods are available and applied.

The goal of the NMDOT Drainage Design Bureau is to standardize the hydrologic analysis methods applied on NMDOT projects, which have a demonstrated performance record in New Mexico. Many hydrologic analysis methods have been used in New Mexico with widely varying results. Some of these methods do not work well in this state, or perhaps are valid only for a particular region of New Mexico. Furthermore, within each hydrologic analysis method, there is some range of judgement or interpretation needed and allowed.

By standardizing hydrologic analysis methods, drainage analysis confusion and debate will be minimized. This Manual provides guidelines for the use of NMDOT approved hydrologic analysis methods, along with visual aides to promote consistency in the selection of parameters which describe physical characteristics such as Runoff Curve Numbers.

The hydrologic methods presented in this manual (with exception of the Rational Formula Method) are based almost entirely on the three publications by the Natural Resources Conservation Service (NRCS), formerly the Soil Conservation Service (SCS). These three document titles and hotlinks as available are listed here.

NRCS, "Part 630 Hydrology, National Engineering Handbook". Note that various Chapters have different dates.
https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/manage/hydrology/?cid=stelprdb1043063

NRCS, June 1986, "TR-55, Urban Hydrology for Small Watersheds".
https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044171.pdf

SCS, February 1985, "Peak Rates of Discharge for Small Watersheds, Chapter 2, Engineering Field Manual for Conservation Practices".
(Not available on the NRCS website or the internet)

The most pertinent sections from these references have been excerpted directly for ease of use. If further explanation or background information is required, the engineer is directed to the NRCS website where the complete National Engineering Handbook and TR-55 may be found. **APPENDIX 5** contains a copy of the February 1985 document as it is not available on the NRCS website or the internet.

Organization of the Hydrology Section of this Manual

Section 402 provides material that is foundational to the understanding and use of the hydrologic methods which follow in **Section 403** through **Section 408.** However, to facilitate the use of this Manual, sufficient information is provided within each of the method specific sections for the experienced practitioner to be able to perform analyses without having to reference material outside that section. As a result, there is necessarily some repetition of material from

Section 402 in the sections that follow. If, when needing a refresher or clarification of foundational principles, the material and references are provided in **Section 402**.

401.1 Purposes Served by Hydrologic Analyses

Hydrologic analyses are required in both the evaluation of the hydraulic and scour design adequacy of existing drainage structures and to appropriately size and protect proposed new structures. These analyses also serve to determine the drainage impacts that existing and proposed facilities will have on upstream and downstream properties and facilities.

Hydrologic analysis considers the physical processes in a watershed that convert precipitation to runoff. The hydraulic analysis and drainage structure design is dependent on the hydrologic analysis results.

The analyses and design of drainage facilities requires the engineer to:

- Select the appropriate design storms and level of protection desired, specified in terms of the probability of the facility's capacity being exceeded
- Determine the flow rate and/or volume
- Compute in many cases, the corresponding water surface elevation, sediment transport, and scour for that particular stream reach and structure

Peak runoff or discharge in cubic feet per second (cfs) is generally all that is needed in the design of facilities such as storm drain systems, culverts, and sometimes bridges. Hydrographs (flow rate as a function of time) are required for systems that are designed to detain or retain a specified runoff volume, such as detention storage facilities, pump stations, flood routing through culverts/bridges, or when sediment transport analyses are required. Thus, depending on the needs of a particular project, the hydrology study may provide:

- A flow rate for which a return period is specified
- A volume of runoff expected with a specified storm duration, for which the storm return period is specified
- A hydrograph (flow rate as a function of time) for a specified return period. The addition of time allows for determining the effects of storage and/or hydrologic routing from one analysis point to another, and is required for sediment transport analyses

Several methods are provided for use in hydrologic analyses in New Mexico, which are discussed in more detail in **Section 401.2**. A summary of these methods is provided below.

- <u>Rational Formula Method</u> – This Method is appropriate for simple watersheds of 160 acres or less and where only a peak runoff rate is needed, however is not to be used for runoff volume computations. **Section 403** describes the use of the Rational Formula Method.

- <u>NRCS Simplified Peak Discharge Method</u> – This Method is based on the SCS, February 1985 document titled, "Peak Rates of Discharge for Small Watersheds, Chapter 2, Engineering Field Manual for Conservation Practices", and in watersheds with areas up to 10 square miles. Refer to **Section 404.2** for limitations that must be observed with this Method. **Section 404** describes the NRCS Simplified Peak Discharge Method.

- NRCS (SCS) Unit Hydrograph Method within U.S. Army Corps of Engineers "HEC-HMS (Hydrologic Modeling System)" – The HEC-HMS program is a very robust modeling tool and is applicable, but perhaps not most appropriate for all applications. **Section 405** describes the use of the NRCS Unit Hydrograph Method within HEC-HMS.
- USGS Regional Regression Equations – The U.S. Geological Survey, in cooperation with the NMDOT, updated estimates of peak-discharge magnitude for individual gaging stations in the region and updated regional equations for estimation of peak discharge and frequency at ungaged sites. Equations were developed for estimating the magnitude of peak discharges for recurrence intervals of 2-, 5-, 10-, 25-, 50-, 100-, and 500-years at ungaged sites by use of data collected through 2004 for 293 gaging stations on unregulated streams that have 10 or more years of record. **Section 406** describes the use of the USGS Regional Regression Equations. StreamStats is a web-based tool that provides stream flow statistics, drainage basin statistics and other useful information for USGS stream gaging stations and for user selected ungaged steam site locations.
- Watersheds with Stream Gage Data – Performing hydrologic analyses on watersheds with stream gage data is described in **Section 406**.
- Statistical Methods in Watersheds without Stream Gage Data – This topic is described in **Section 407**.
- Risk and Uncertainty in Hydrologic Analyses and Design – This topic is described in **Section 408**.
- Hydrologic Information Required for Water Quality Protection – This topic is described in **Section 700**.

401.2 Selection of Hydrologic Method

The NMDOT Drainage Design Bureau has established specific hydrologic analysis methods to be used on NMDOT projects. The appropriate method is initially selected based on study requirements and the level of effort required as defined by the Drainage Design Bureau. Then the method selected is based on drainage area size and whether the highway facility is located in an urban or rural area. In general, NMDOT personnel and consultants to the NMDOT are required to use the hydrologic methods specified below. The NMDOT Drainage Design Bureau may allow or require other hydrologic analysis methods to be used, depending on project specific circumstances. Contact the Drainage Design Bureau and obtain approval if there appears to be a conflict between methods required by this Manual and local methods before using a method other than those specified below.

Figure 401-1 and **Figure 401-2** are used to select the appropriate hydrologic method for rural watersheds or urban conditions for a particular drainage structure. In areas where a local government agency has a drainage policy which mandates a specific hydrologic analysis method, consult with the NMDOT Drainage Design Bureau to determine the appropriate analysis method. For example, the City of Las Cruces specifies the use of the NRCS Simplified Peak Discharge Method for all projects except those requiring a hydrograph (ponds). Also, when a drainage basin size is on the border (plus or minus 10%) between two size categories, the more detailed analysis method shall generally be used. At the discretion of the engineer and approval of the NMDOT Drainage Design Bureau, the Unit Hydrograph Method may be substituted for the Simplified Peak Discharge Method and the Simplified Peak Discharge Method may be substituted for the Rational Formula Method.

Given the wide range of Standard Error of Estimates of peak discharges found in the USGS Regional Regression Equations, the use of this approach as the sole source of estimates of peak discharge is only allowed with the approval of the NMDOT Drainage Design Bureau. With the availability of public Geographic Information System (GIS) based aerial photography, soils data, and the ease by which this data can be collected and incorporated into both the NRCS Simplified Peak Discharge Method and the NRCS Unit Hydrograph Method in HEC-HMS, these methods should be used to develop the primary hydrology on basins exceeding the 160 acre Rational Formula Method limit. The USGS Regression Equations should generally be limited to confirming order of magnitude validations of deterministic methods and only for very preliminary estimating.

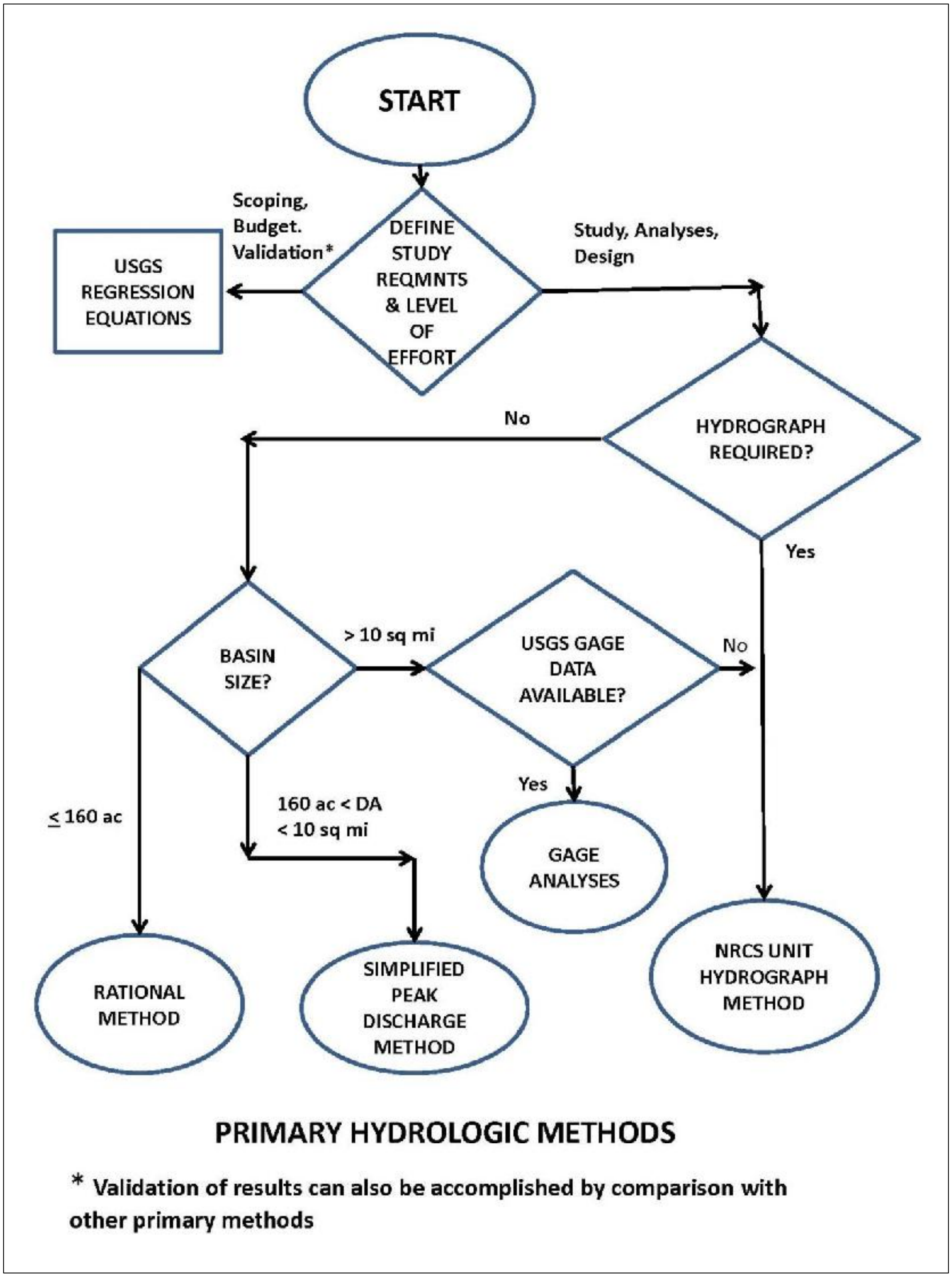
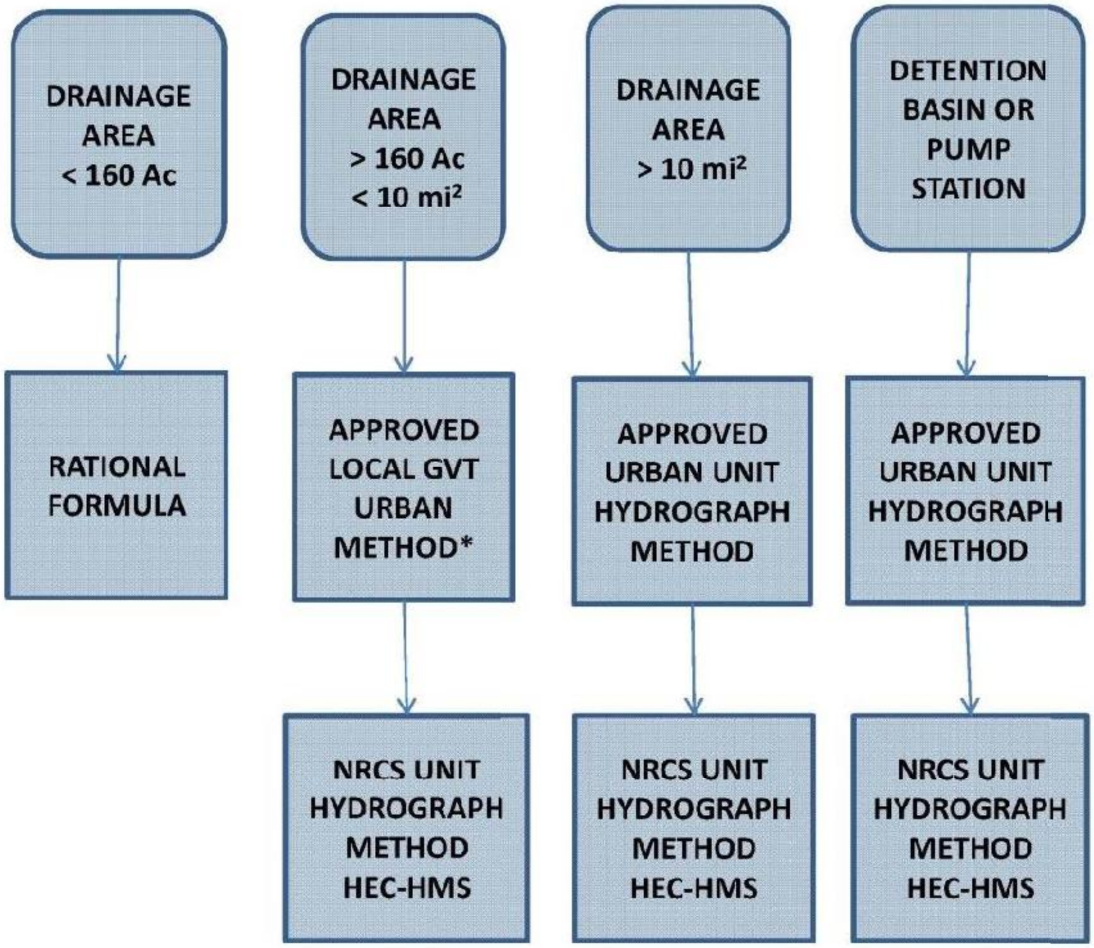


Figure 401-1 Hydrologic Method Selection – Rural Watersheds



HYDROLOGIC METHOD SELECTION

URBAN CONDITIONS

* "Approved local government urban methods" are those which are specified by local governments and the use of which NMDOT has approved for a specific project application

Figure 401-2 Hydrologic Method Selection – Urban Conditions

401.3 Basic Requirements for Drainage Studies

This Section describes the basic requirements of a drainage study and schedule for a NMDOT project. NMDOT projects that require drainage studies and drainage reports must identify the drainage criteria applied, and the hydrologic and hydraulic methods/analyses applied to develop the drainage structure design requirements. Most projects require two or more drainage reports that summarize the required drainage improvements for the project. The drainage engineer's responsibility typically does not end with the drainage report.

The NMDOT Drainage Design Bureau staff engineers prepare drainage reports and provide support to the NMDOT Environmental Bureau for obtaining permits (EPA, USACE, FEMA). NMDOT Drainage Design Bureau engineers also develop Sediment and Erosion Control Plans, and coordinate with other NMDOT sections. Similar responsibilities may be required of NMDOT consultants. No matter how limited or broad the project scope of services, a drainage study and associated drainage report(s) will be required.

Most NMDOT projects include a standard set of project development milestones within the NMDOT project development schedule. These standard milestones including drainage elements are shown in bold below.

<u>Typical Project Development Schedule and Milestones</u>

- Preliminary Scoping Report
- Preliminary Field Review
- **Drainage Field Inspection***
- 30% Plan Review
- 60% Plan Review
- **Preliminary Drainage Report**
- Temporary Erosion and Sediment Control Plan
- **Draft Final Drainage Report**
- 90% Plan Review
- **Revised Final Drainage Report**
- Final Design Review
- Plans, Specifications and Estimates

*The drainage field inspection is sometimes combined with the 30% Plan Review.

401.4 Drainage Field Inspection and Drainage Reports

Drainage Field Inspection

Field inspection of the project from a drainage perspective is a critical element of the drainage study process. A thorough inspection will often reveal design considerations which cannot be deduced from aerial photography and available topographic mapping. The drainage field inspection should be performed in the preliminary drainage report phase of the project, after basic data collection and after the preliminary hydrologic analysis has been performed. In this sequence, the field inspection can be used to verify design assumptions, locate and size existing structures, and evaluate the potential impacts of proposed drainage improvements. This is an opportunity to field verify preliminary design assumptions. A list of questions/items should be developed during the preliminary hydrologic analysis which need field verification.

A Field Observation and Measurements Checklist is located in **APPENDIX 3.** A checklist may be used as a reminder of features to observe and quantify in the field. The checklist forms should be completed in the field for all existing drainage structures. Be sure to allow adequate time for the drainage field inspection, particularly if field surveys of structure inlet/outlet conveyances are planned.

Preliminary and Final Drainage Reports

Refer to **Section 305** for more information regarding drainage reports and report submittal requirements.

401.5 References

NRCS, June 1986, "TR-55, Urban Hydrology for Small Watersheds".
https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044171.pdf

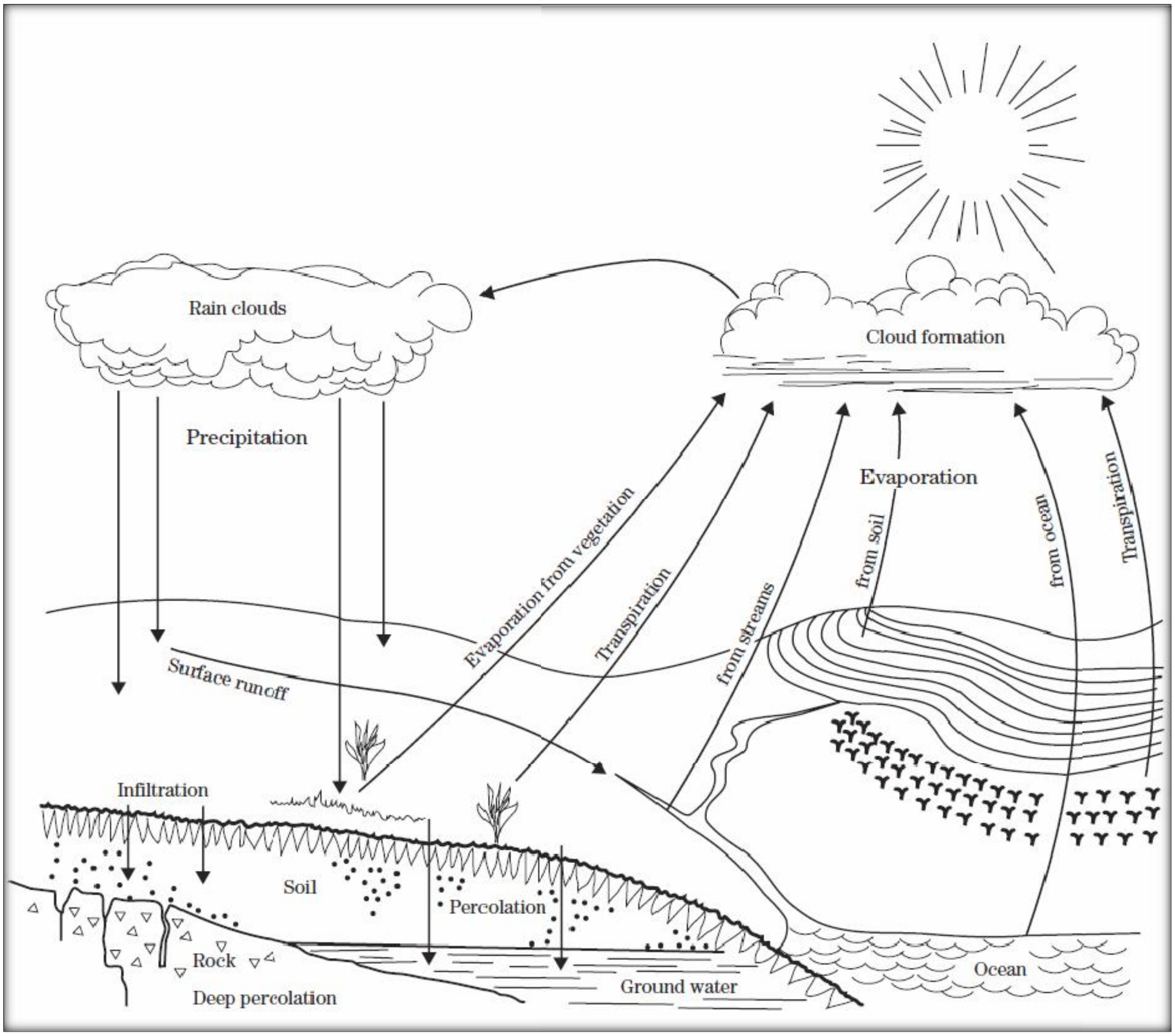
NRCS, "Part 630 Hydrology, National Engineering Handbook". Note that various Chapters have different dates.
https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/manage/hydrology/?cid=stelprdb1043063

Soil Conservation Service (NRCS), 1973, Rev. ed. February 1985, Rev. ed. 2014, "Peak Rates of Discharge for Small Watersheds, Chapter 2, Engineering Field Manual for Conservation Practices".
(Not available on the NRCS website or the internet, **APPENDIX 5** contains a copy)

U.S. Army Corps of Engineers Hydrologic Modeling System HEC-HMS, 2015.
http://www.hec.usace.army.mil/software/hec-hms/

402 General Data Requirements for Hydrologic Analyses

To properly prepare hydrologic analyses, it is fundamental to have a solid grasp of the major physical processes, especially, between precipitation and the earth upon which it falls. **Figure 402-1** depicts the hydrologic cycle in schematic form illustrating the processes and interactions.



Source: NRCS, 1997, "Part 630 Hydrology, National Engineering Handbook, Chapter 1 Introduction", Cover Page.
http://www.wcc.nrcs.usda.gov/ftpref/wntsc/H&H/NEHhydrology/ch1.pdf

Figure 402-1 Hydrologic Cycle

Hydrologic analyses are generally data intensive. Unlike structural and pavement design with known loads, the design discharges are unknown, and must be determined for each design project for each component within a project. No two drainage structures share exactly the same circumstances (drainage area, shape, slope, soils, land use, rainfall, and design criteria), the specifics drive the design analysis.

The basic assumptions which are the foundation of each of the hydrologic analysis methods described in this Manual are:

- Rainfall is distributed uniformly over the basin (or subbasin in very large models)
- The rainfall/runoff derivation (Runoff Curve Number (CN), Rational Formula Method Runoff Coefficient (C)) is representative of the average runoff conditions in the basin or subbasin
- The basin Time of Concentration (Tc) represents the time it takes for runoff to reach the analysis point from the most *hydraulically remote* location in the basin or subbasin
- The basin or subbasin slope is relatively uniform throughout the basin or subbasin

When these assumptions are not met, the results are less likely to be accurate or reproducible. Most often, the solution is to subdivide the basin further (within reason).

402.1 Record Drawings and Planned Improvements Information

The hydrologic analysis method selection process begins with the specific project and structure requirements which are determined by the current and/or planned importance of the highway facility it supports. If the project involves existing drainage structures, it is critical to obtain the record drawings (as-built drawings) and ideally, the drainage report which supported the original design. If the project involves new construction, schematic design plans should be available for use in locating and sizing structures. See **Section 200** for more discussion on drainage design criteria related to roadway classification and other parameters.

402.2 Basin and Subbasin Delineation

Regardless of the hydrologic analysis selected, the drainage basin area is always required. Basic to all hydrologic methods is the assumption that the basin or subbasin can be reasonably characterized by one set of hydrologic parameters (soils, slope, rainfall, vegetative cover, and land use). The further from this assumption and the parameters within a basin and subbasin vary, the less accurate and reproducible the results of the analyses will be.

Good "rules of thumb" to follow regarding basin and subbasin sizing are that the length of a basin or subbasin should not exceed 4 times its width and that no subbasin should be more than 10 times larger than the smallest subbasin (NRCS, 2007, "Part 630 Hydrology, National Engineering Handbook, Chapter 16 Hydrographs").
http://www.wcc.nrcs.usda.gov/ftpref/wntsc/H&H/NEHhydrology/ch16.pdf

Basins should be delineated so that soils, cover, land use, slope, and size allow each subbasin to be relatively homogeneous within itself rather than being driven or limited strictly by the location and/or number of analyses points (points of interest) within the basin. These limitations will generally lead to the creation of smaller subbasins that is sometimes dictated by the number and/or location of analysis points. Subbasin size delineation (small, medium, large) within a basin, is based on judgment and experience, and these can be gained by regularly analyzing several different subbasin sizes and configurations, and comparing the results. This sensitivity analysis should be developed early in the hydrologic analysis in order to select the appropriate size subbasins. Experience will lead to confidence in knowing how to delineate and size subbasins correctly. **Figure 402-2** is an example of the subbasin delineation process.

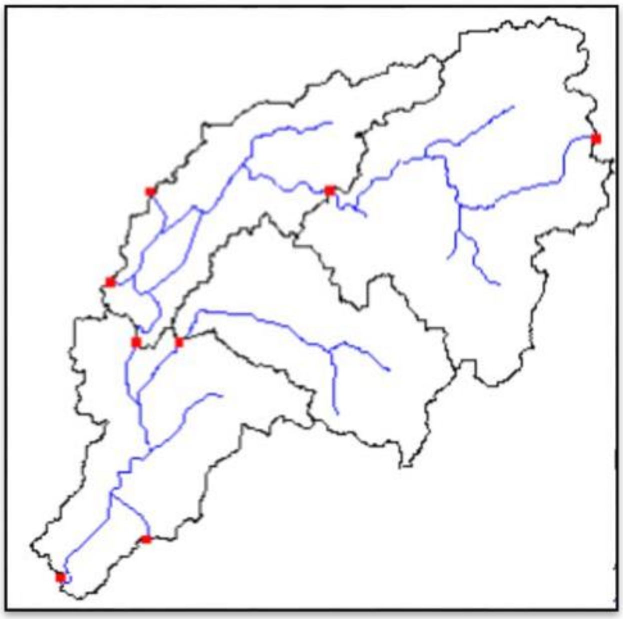


Figure 402-2 Basin Delineation

Drainage basins and subbasins are typically defined graphically using the best available topographic mapping, supplemented with aerial photography and when possible, field verification. USGS topographic maps at 1:24,000 scale provide adequate detail for most rural NMDOT projects and are available for all areas of New Mexico digitally from New Mexico Resource Geographic Information System (RGIS) at: http://rgis.unm.edu/getdata/#. In addition, LIDAR topography is available for many parts of the state in digital form, and the LIDAR coverage area is ever increasing.

Drainage structures crossing roadways are typically located at low spots in the terrain and are always provided where a watercourse crosses or impacts the roadway. Drainage basin boundaries are drawn from the drainage structure location(s), on topographic maps, proceeding uphill such that the boundary encompasses all land which can drain to the crossing structure location. A simple test is to imagine a drop of rain falling on the ground and to follow the path it takes as it flows downhill. Drainage basin boundary lines are drawn perpendicular to the topographic contour lines, following the ridgetops.

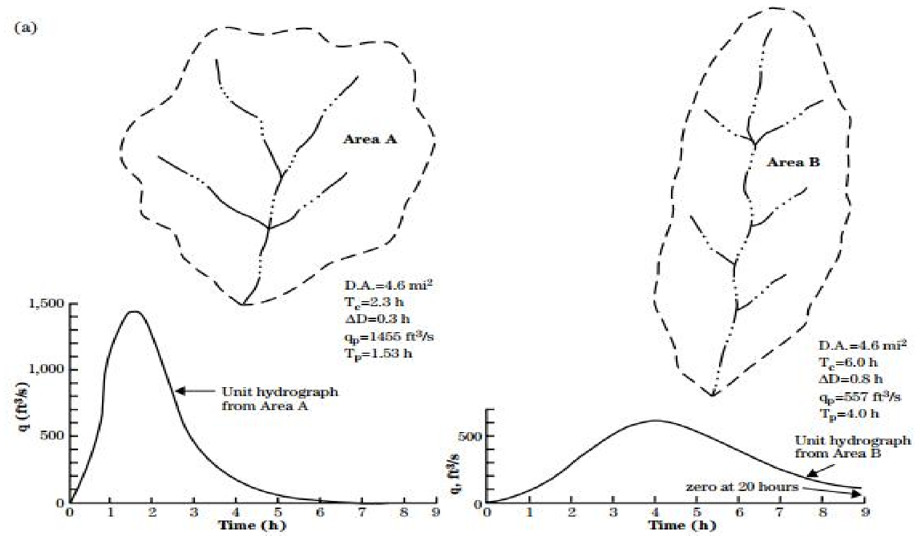
The total basin drainage area can be measured after the drainage basin has been defined. USGS maps are now available in digital format so that this measurement can be made with a GIS tool. A simple guideline should be employed to crosscheck the total drainage area by multiplying the average watershed length by the average watershed width.

Each drainage basin should be qualitatively assessed by the following:

- What hydrologic analysis method is required based on drainage basin size? This may be an iterative process since some methods have size limitations. (e.g. Rational Formula Method ≤ 160 acres, NRCS Simplified Peak Discharge Method ≤ 10 square miles).
- Is the overall drainage basin shape somewhat consistent with implicit assumptions built into the analytical design methods? (i.e., length/width ratio, size relative to other subbasins in the watershed model).
- Subbasins should be sized as uniformly as possible (don't mix 0.5 square mile subbasins with 20 square mile subbasins). The guideline is that no subbasin should be more than 10 times larger than the smallest one in the basin.
- Subbasins should have fairly homogeneous soils, land use, topographic characteristics, and drainage network patterns within themselves. For example, significant areas of mountains, foothills, alluvial plains, and valleys should be in separate subbasins where possible.
- Subbasins should be delineated for each significant tributary at the confluence with the major waterscourse where possible.
- Check to see if roads, diversions, ponds, or other features within the subbasin(s) prevent it from behaving as a uniform, homogeneous watershed. Determine if these features alter flow paths or velocities, create significant storage, or contribute to directly connected imperviousness determinations.
- In flat terrain, are there roads, railroad fill, irrigation facilities or other development features which act as drainage divides or diversions?
- Are there effects of storm drainage networks within urban areas?

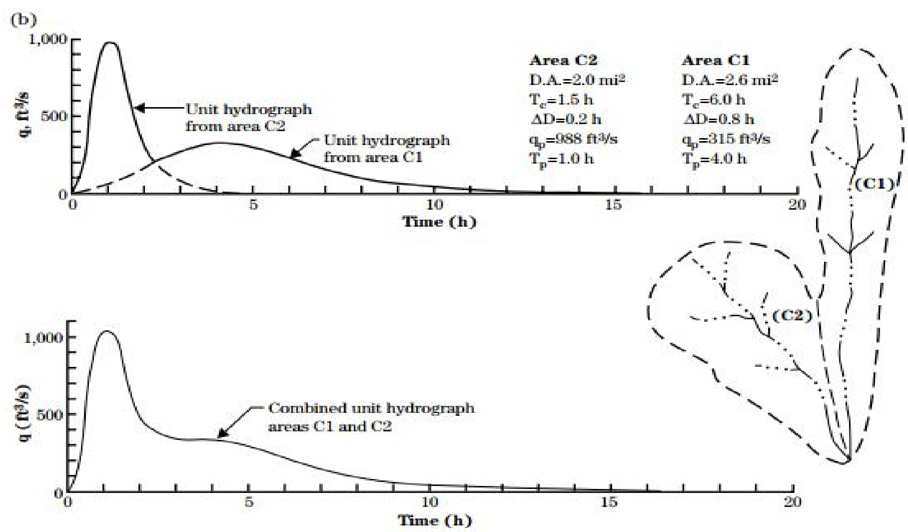
When these factors are accounted for, parameters such as Time of Concentration (Tc), Runoff Curve Number (CN) and Rational Formula Method (C), will more accurately portray the basin runoff response.

An additional consideration when delineating basins is the recognition of the effect that the basin shape can have on the shape (and peak rate) of the resulting hydrograph. **Figure 402-3** and **Figure 402-4** show the effects on the shape of the resultant hydrograph from different shaped drainage basins. Avoid delineating drainage subbasins which are particularly elongated or short and wide. Consider redelineating the subbasins to generally follow the "rules of thumb" (**Section 402.2**).



Source: NRCS, 2007, "Part 630 Hydrology National Engineering Handbook, Chapter 16 Hydrographs", Figure 16-2(a), p. 16-5.
http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17755.wba

Figure 402-3 Basin Shape Effects on Hydrograph Shape



Source: NRCS, 2007, "Part 630 Hydrology National Engineering Handbook, Chapter 16 Hydrographs", Figure 16-2(b), p. 16-6.
http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17755.wba

Figure 402-4 Combined Basin Effects on Shape of Hydrograph

402.3 Rainfall Volume and Temporal Distribution Data

Rainfall data is a necessary input parameter for all peak rate computations performed on NMDOT projects (except statistical). The total rainfall volume and the time distribution of the rainfall will both affect the resulting runoff volume and peak runoff rate.

The return frequency of the Design Flood and Check Flood to be used for a particular project or drainage structure must be determined. Design frequency floods are listed in **Section 200.** Note that design criteria and standards are subject to change. Verify that the latest drainage design criteria are applied, and that these criteria are appropriate for the specific roadway classification and design circumstances before proceeding with analysis and design.

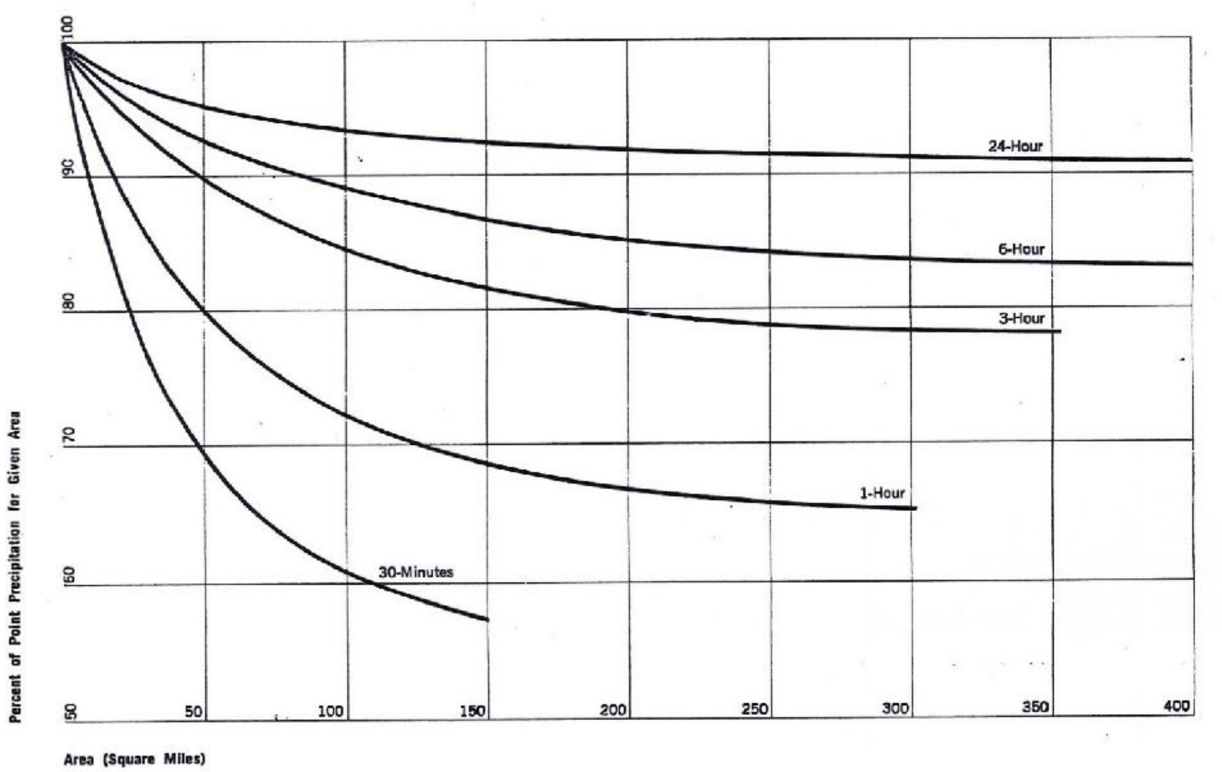
For NMDOT projects, the assumption is made that rainfall frequencies produce equivalent flood frequencies, i.e., the 50-year rainfall event will produce the 50-year runoff event. This assumption is generally valid when all other factors remain reasonably constant (antecedent moisture, etc.), particularly for ephemeral stream systems. There are some situations where this assumption may not be correct. In regions of New Mexico where the seasonal snowpack is significant or that have been affected by severe wildfire, contact the NMDOT Drainage Design Bureau for guidance prior to commencing work.

With the advent of digital rainfall data from NOAA Atlas 14 (2011), rainfall data acquisition is both simpler and more accurate than in the past when only large-scale paper copies of rainfall atlases were available (NOAA Atlas 2, 1973). The NOAA Atlas 14 rainfall data sets are more extensive and more accurate than what was available with NOAA Atlas 2. The NOAA Atlas 14 data has its limitations that should be recognized. Refer to the NOAA Atlas 14 text for a complete discussion of the limitations. It is strongly recommended that the NOAA Atlas text be reviewed and occasionally revisited. New Mexico is covered by *NOAA Atlas 14 Precipitation-Frequency Atlas of the United States Volume 1, Version 5.0 (Rev. ed. 2011)* which is available at:
http://www.nws.noaa.gov/oh/hdsc/PF_documents/Atlas14_Volume1.pdf.

Rainfall data is also available in digital form for any point in New Mexico from the NOAA Hydrometeorological Design Studies Center Precipitation Frequency Data Server (PFDS) at: http://hdsc.nws.noaa.gov/hdsc/pfds/

On all but the largest watersheds (those greater than 10 square miles) and some basins with significant mountain face contributing areas, the rainfall amounts given at the centroid of the basin are appropriate for hydrologic analyses. When performing hydrologic modeling on large watersheds (greater than 10 square miles) and mountain face areas, the rainfall amounts may vary significantly from the furthest downstream point to the most upstream point and, therefore, may be significantly different between subbasins within the model. Subbasin rainfall variations may be simulated within the model.

NOAA Atlas 14 has not yet developed rainfall areal reduction factors (at the time of this Drainage Design Manual preparation). For large basins, NOAA Atlas 14 refers users to NOAA Atlas 2 (1973) that provides guidance on rainfall areal reduction factors. See **Figure 402-5** for NOAA Atlas 2 (1973) area reduction factors for New Mexico. HEC-HMS will accept separate rainfall point amounts for subbasins.



Source: NOAA, 1973, Atlas 2 (not available in digital format)

Figure 402-5 Area Reduction Factors for New Mexico

The NOAA Precipitation Frequency Data Server now provides all the data needed to produce a Precipitation-Intensity Curve for use in the Rational Formula Method. This process is described in **Section 403.2.**

A temporal (time) distribution of rainfall, in addition to the volume, is required for NMDOT designs and Drainage Reports that require a unit hydrograph based modeling effort. The NRCS recommends that a Type II-a design storm distribution be used in New Mexico. The NRCS previously had developed (with the aid of the National Weather Service) a family of temporal distributions that further subdivided the Type II-a storm family for specific parts of New Mexico (i.e.-Type II 60-75). Since the publication of NOAA Atlas 14, tools are available to develop a site-specific distribution that generally follows the NRCS Type II-a distribution and is, therefore, compatible with the NRCS Unit Hydrograph Method. These tools are found in the NOAA Precipitation Frequency Data Server (PFDS) and HEC-HMS. Point rainfalls for various storm durations and frequencies from the PFDS are input into HEC-HMS with a temporal distribution specified to create the design storm distribution for use in developing hydrographs. A more detailed description is included in **Section 405.3**.

Before using rainfall data, read the text provided in NOAA Atlas 14 to gain a better understanding of the source of the data methods used in producing the precipitation frequency information, and the limitations inherent in its use.

402.4 Soils Data

This Section presents detailed soil descriptions and information as background to the Hydrologic Soil Groups (HSGs) as defined by the Natural Resources Conservation Service (NRCS). Note that with GIS tools, the detail presented here is generally not required when completing soils data collection and preparing the related hydrologic data based on the HSGs.

The texture, composition and density of soils have a direct impact on the amount and rate at which rainfall becomes runoff. Therefore, the determination of the soil type(s) is a critical in the development of rainfall/runoff calculations. In general, soils are classified as sandy, silty, loamy or clayey. There can be an infinite number of combinations of these characteristics. The NRCS has divided the extremely wide range of soil textures by their hydrologic (runoff producing) characteristics into four Hydrologic Soils Groups (HSG): Type A, B, C, and D. Type A being generally sandy soils and low runoff producers, and Type D being clayey soils and high runoff producers for a given rainfall volume. Type B and Type C soils have runoff characteristics that are subdivisions within the range of Type A to Type D soils as described below.

Group A

Soils in this group have low runoff potential when thoroughly wet. Water is transmitted freely through the soil. Group A soils typically have less than 10 percent clay and more than 90 percent sand or gravel and have gravel or sand textures. Some soils having loamy sand, sandy loam, loam or silt loam textures may be placed in this group if they are well aggregated, of low bulk density, or contain greater than 35 percent rock fragments.

The limits on the diagnostic physical characteristics of Group A are as follows. The saturated hydraulic conductivity of all soil layers exceeds 40.0 micrometers per second (5.67 inches per hour). The depth to any water impermeable layer is greater than 50 centimeters (20 inches). The depth to the water table is greater than 60 centimeters (24 inches). Soils that are deeper than 100 centimeters (40 inches) to a water impermeable layer are in Group A if the saturated hydraulic conductivity of all soil layers within 100 centimeters (40 inches) of the surface exceeds 10 micrometers per second (1.42 inches per hour).

Group B

Soils in this group have moderately low runoff potential when thoroughly wet. Water transmission through the soil is unimpeded. Group B soils typically have between 10 percent and 20 percent clay and 50 percent to 90 percent sand and have loamy sand or sandy loam textures. Some soils having loam, silt loam, silt, or sandy clay loam textures may be placed in this group if they are well aggregated, of low bulk density, or contain greater than 35 percent rock fragments.

The limits on the diagnostic physical characteristics of Group B are as follows. The saturated hydraulic conductivity in the least transmissive layer between the surface and 50 centimeters (20 inches) ranges from 10.0 micrometers per second (1.42 inches per hour) to 40.0 micrometers per second (5.67 inches per hour). The depth to any water impermeable layer is greater than 50 centimeters (20 inches). The depth to the water table is greater than 60 centimeters (24 inches). Soils that are deeper than 100 centimeters (40 inches) to a water impermeable layer or water table are in Group B if the saturated hydraulic conductivity of all soil layers within 100 centimeters (40 inches) of the surface exceeds 4.0 micrometers per second (0.57 inches per hour) but is less than 10.0 micrometers per second (1.42 inches per hour).

Group C

Soils in this group have moderately high runoff potential when thoroughly wet. Water transmission through the soil is somewhat restricted. Group C soils typically have between 20 percent and 40 percent clay and less than 50 percent sand and have loam, silt loam, sandy clay loam, clay loam, and silty clay loam textures. Some soils having clay, silty clay, or sandy clay textures may be placed in this group if they are well aggregated, of low bulk density, or contain greater than 35 percent rock fragments.

The limits on the diagnostic physical characteristics of Group C are as follows. The saturated hydraulic conductivity in the least transmissive layer between the surface and 50 centimeters (20 inches) is between 1.0 micrometers per second (0.14 inches per hour) and 10.0 micrometers per second (1.42 inches per hour). The depth to any water impermeable layer is greater than 50 centimeters (20 inches). The depth to the water table is greater than 60 centimeters (24 inches). Soils that are deeper than 100 centimeters (40 inches) to a restriction or water table are in Group C if the saturated hydraulic conductivity of all soil layers within 100 centimeters (40 inches) of the surface exceeds 0.40 micrometers per second (0.06 inches per hour) but is less than 4.0 micrometers per second (0.57 inches per hour).

Group D

Soils in this group have high runoff potential when thoroughly wet. Water movement through the soil is restricted or very restricted. Group D soils typically have greater than 40 percent clay, less than 50 percent sand, and have clayey textures. In some areas, they also have high shrink-swell potential. All soils with a depth to a water impermeable layer less than 50 centimeters (20 inches), and all soils with a water table within 60 centimeters (24 inches) of the surface are in this group. Although some may have a dual classification, as described in the next section, if they can be adequately drained.

The limits on the physical diagnostic characteristics of Group D are as follows. For soils with a water impermeable layer at a depth between 50 centimeters and 100 centimeters (20 and 40 inches), the saturated hydraulic conductivity in the least transmissive soil layer is less than or equal to 1.0 micrometers per second (0.14 inches per hour). For soils that are deeper than 100 centimeters (40 inches) to a restriction or water table, the saturated hydraulic conductivity of all soil layers within 100 centimeters (40 inches) of the surface is less than or equal to 0.40 micrometers per second (0.06 inches per hour).

Site-specific information regarding the hydrologic characteristics of the soils needed for analyses in a watershed has been surveyed by NRCS and other agencies for almost the entire country and state of New Mexico. This information is generally available from the NRCS by consulting the Natural Resources Conservation Service’s (NRCS) Field Office Technical Guide or the Web Soil Survey Website:
https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

Occasionally, when dealing with public lands (U.S. Forest Service, BLM, military bases), the soils information will not be shown in the NRCS database but may be available from the local office of the land management agency responsible for those lands.

It is important to recognize that the NRCS has classified thousands of soils with infinitely varying combinations of textures, thicknesses, and settings into just four Hydrologic Soils Groups (HSGs). Further, it needs to be recognized that within each family of soils there are soils with characteristics that justified them being classified as sub-sets within that family (all of which may not be in the HSG as the parent soil). The engineer may find that some soils do not exhibit the general characteristics of the HSG to which its family has been assigned. When this is observed, it may be helpful to investigate the text of the soil survey report information more thoroughly. An example of a real situation where this condition was found to exist and how it was resolved is provided in a technical paper titled “Hatch Site 6 Runoff Methods Revisited” (Easterrling, Charles, M., May 2004), this is located in Appendix 6 as **Example Problem 6-7.**

For more information on Hydrologic Soil Groups, refer to the following source.

NRCS, 2009, “Part 630 Hydrology, National Engineering Handbook, Chapter 7 Hydrologic Soils Groups”.
http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=22526.wba

402.5 Hydrologic Soil-Cover Complexes

A combination of a HSG (soil), land use, and treatment class (cover) is a hydrologic soil-cover complex. A range of Runoff Curve Numbers (CN) has been developed by the NRCS from empirical data and is published by the NRCS in their National Engineering Handbook, Chapter 9 as well as in multiple other locations. The CN represents the runoff potential of a particular soil/cover complex during periods when the soil is not frozen. A higher CN indicates a higher runoff potential, and logically, a lower CN indicates a lower runoff potential. Engineers are strongly encouraged to review and become familiar with the discussion provided in Chapter 9 (Soil-Cover Complexes) of NRCS Part 630 Hydrology, National Engineering Handbook and the academic papers referenced at the end of this Section.
http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17758.wba

The CN is an input to both the Simplified Peak Discharge Method and the NRCS Unit Hydrograph Method analyses. **APPENDIX 4** contains a series of photographs provided as an aid in the selection of hydrologic conditions as a supplement to the descriptions, figures, and table provided herein. Subbasin runoff volume is governed by the hydrologic soil-cover (vegetation) complexes and impervious surfaces.

402.5.1 Vegetation Effects

Vegetation affects runoff as described here:

- The foliage and its litter maintain the soil’s infiltration potential by preventing the sealing of the soil surface from raindrop impact
- Foliage and litter retain some of the raindrops, increasing their chance of being evaporated and/or infiltrated
- Some of the moisture is intercepted on the plant and withheld from the initial period of runoff

- Vegetation and litter transpire soil moisture leaving a greater void in the soil to be filled
- Vegetation, including its ground litter, forms numerous barriers along the path of the water flowing over the surface of the land (these can lengthen the travel time and increase opportunity for infiltration)

Table 402-1 contains information that can be used as a guide in determining the vegetative cover conditions for range sites. Grass cover is evaluated on plant basal area while trees and shrubs are evaluated using canopy cover.

Table 402-1 Vegetative Cover Classes – Grassland

Source: NRCS, 2002, Part 630 Hydrology, National Engineering Handbook, Chapter 8 Land Use and Treatment Classes, Table 8-1, p. 8-3
https://directives.sc.egov.usda.gov/viewerFS.aspx?hid=21422

Vegetative Condition	Hydrologic Condition
Heavily grazed—No mulch or has plant cover on < 0.5 of the area	Poor
Not heavily grazed—Plant cover on 0.5 to 0.75 of the area	Fair
Lightly grazed – Plant cover on > 0.75 of the area	Good

See **Figure 402-6** and **Figure 402-7** on the following pages for further explanation of the relationship between cover condition and Runoff Curve Number.

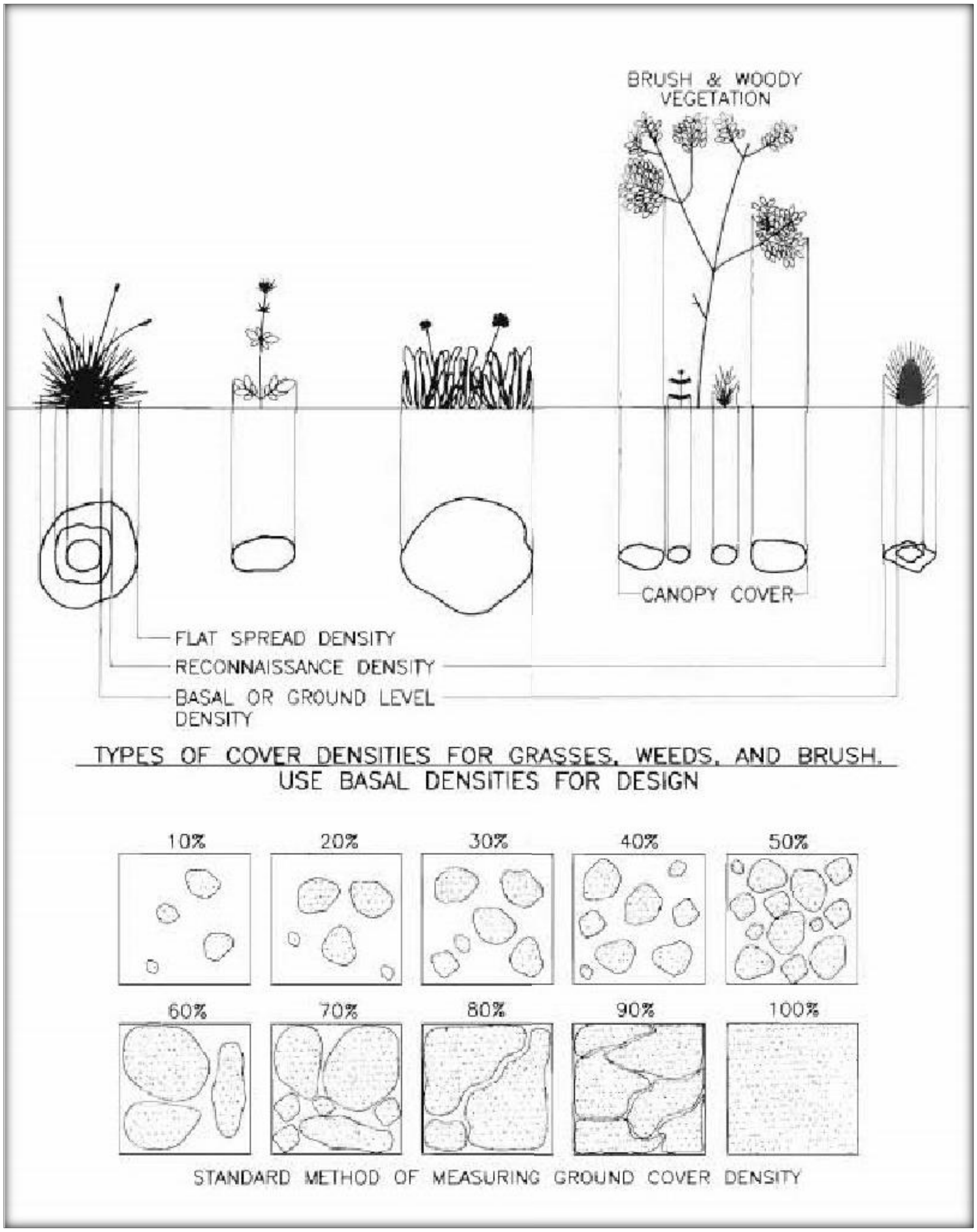
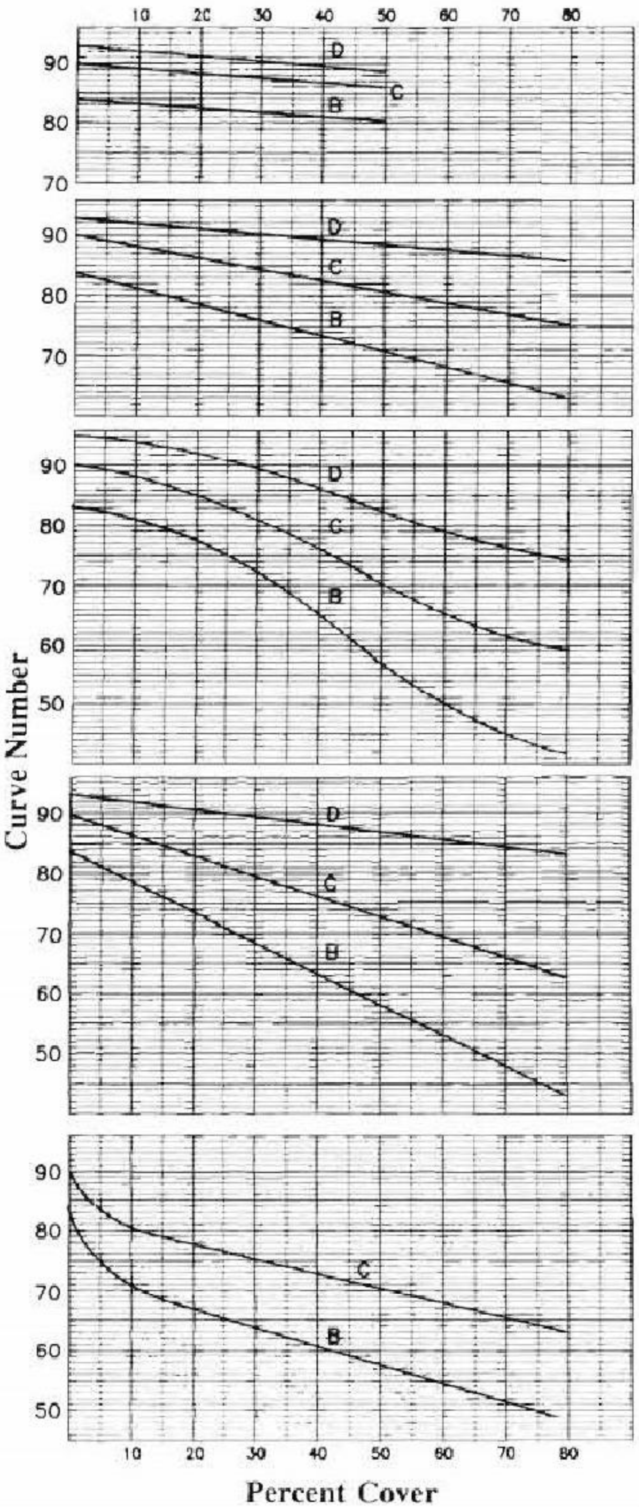


Figure 402-6 Determining Soil-Cover Complex – Vegetative Density



Desert Brush: Brush–weed and grass mixtures with brush the predominant element. Some typical plants are – Mesquite, Creosote, Yuccas, Sagebrush, Saltbush, etc. This area is typical of lower elevations of desert and semi–desert areas.

Herbaceous: Grass–weed–brush mixtures with brush the minor element. Some typical plants are – Grama, Tobosa, Broom Snakeweed, Sagebrush, Saltbush, Mesquite, Yucca, etc. This area is typical of lower elevations of desert and semi–desert areas.

Mountain Brush: Mountain brush mixtures of Oak, Mountain Mohagany, Apache Plume, Rabbit Brush, Skunk Brush, Sumac, Cliff Rose, Snowberry, etc. Mountain Brush is typical of intermediate elevations and generally higher annual rainfall than Desert Brush and herbaceous areas.

Juniper – Grass: These areas are mixed with varying amounts of juniper, piñon, grass, and cholla cover, or may be predominantly of one species. Grass cover is generally heavier than desert grasses due to higher annual precipitation. Juniper – Grass is typical of mountain slopes and plateaus of intermediate elevations.

Ponderosa Pine: These are forest lands typical of higher elevations where the principal cover is timber.

Hydrologic Soil – Cover Complexes and Associated Curve Numbers

Adapted from SCS, Chapter 2 for NM, 1985

Source: SCS, February 1985, Chapter 2 for NM.

Figure 402-7 Hydrologic Soil-Cover Complexes and Associated Curve Numbers

Figure 402-6 and **Figure 402-7** provide good guidance for determining the percentage of vegetative coverage and describe the five principle range and forest soil-cover complex conditions found in New Mexico. For a more complete guide to determining the percentage of vegetative cover, see "Sampling Vegetation Attributes", Interagency Technical Reference 1996 (Rev. ed. 1997 and 1999) at:
http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044175.pdf

Land use has a direct bearing on the amount and types of impervious surfaces that overlay the soils. The type and density of land use also affects the amount of initial abstraction losses that occur in the rainfall/runoff relationship. Most urban areas are only partially covered by impervious surfaces; therefore, the soil remains an important factor in runoff estimates. Urbanization has a greater effect on runoff in watersheds with soils having high infiltration rates (sands and gravels) than in watersheds predominantly of silts and clays, which generally have low infiltration rates. Whether or not impervious areas are directly connected to the stream can make a significant difference in transmission losses, particularly in the case of smaller, more frequent storm events.

Note that the Rational Formula Method Runoff Coefficient (C) is in itself a somewhat simplified term describing the relationship between rainfall and the impacts of soils and cover. Further discussion on this topic is found in **Section 403.3**.

402.6 Runoff Curve Number

The NRCS Runoff Curve Number (CN) (also called Curve Number) is a lumped watershed parameter. It often serves as a proxy for all losses from the beginning of precipitation until runoff reaches the point of interest in a hydrologic analysis. As such, it should not be interpreted as a point infiltration value but rather as representing all losses (initial abstraction, infiltration, transmission, evaporation, etc.) unless separate calculations are developed for ponding and transmission losses.

Methods for selecting a Runoff Curve Number and for making areal adjustments are described below. When carefully followed, these methods will yield a Curve Number which represents the runoff response of the basin or subbasin for the assumed watershed conditions. Seasonal changes in vegetation and ground cover density will occur in the watershed during the year that may cause CN value variations, and should be considered. However, in practice, normally only the largest CN value is adopted. The condition of the watershed may vary dramatically from the date of field reconnaissance to the annual season of largest historic runoff.

Note that NMDOT policies do not allow the analyses to be based on anticipated changes in development unless they are imminent. Check with the Drainage Design Bureau before proceeding regarding proposed development.

Variation in the CN is most evident in cultivated agricultural areas and heavily grazed rangeland where:

1. The land is planted in row crops that are short or tall depending on plant type and growing season, or
2. The crop has been harvested and the ground is plowed or fallow, or the crop type may be changed from year to year, or
3. The plant cover is severely impacted in times of drought.

Note that the rainfall/runoff relationship found in the Curve Number Method is not linear for the many CNs when coupled with design rainfall amounts in New Mexico. The effect is that a small change in CN can dramatically increase or decrease the amount of runoff that results under certain combinations of CN and rainfall as presented in **Figure 402-8.**

Therefore, engineering judgement must be exercised to determine the appropriate CN for a particular drainage basin or subbasin.

The following excerpts from Chapter 2 of "TR-55, Urban Hydrology for Small Watersheds", (NRCS, June 1986) provide a relatively complete and clear explanation of the Curve Number, its determination, and its use in hydrologic analyses. A hotlink to the document is provided below.
https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044171.pdf

Figure 402-8 describes the relationship of rainfall and runoff for the range of possible Runoff Curve Numbers based on the following equation:

$$Q = \frac{(P - 0.2\,S)^2}{P + 0.8\,S} \qquad \textbf{402-1}$$

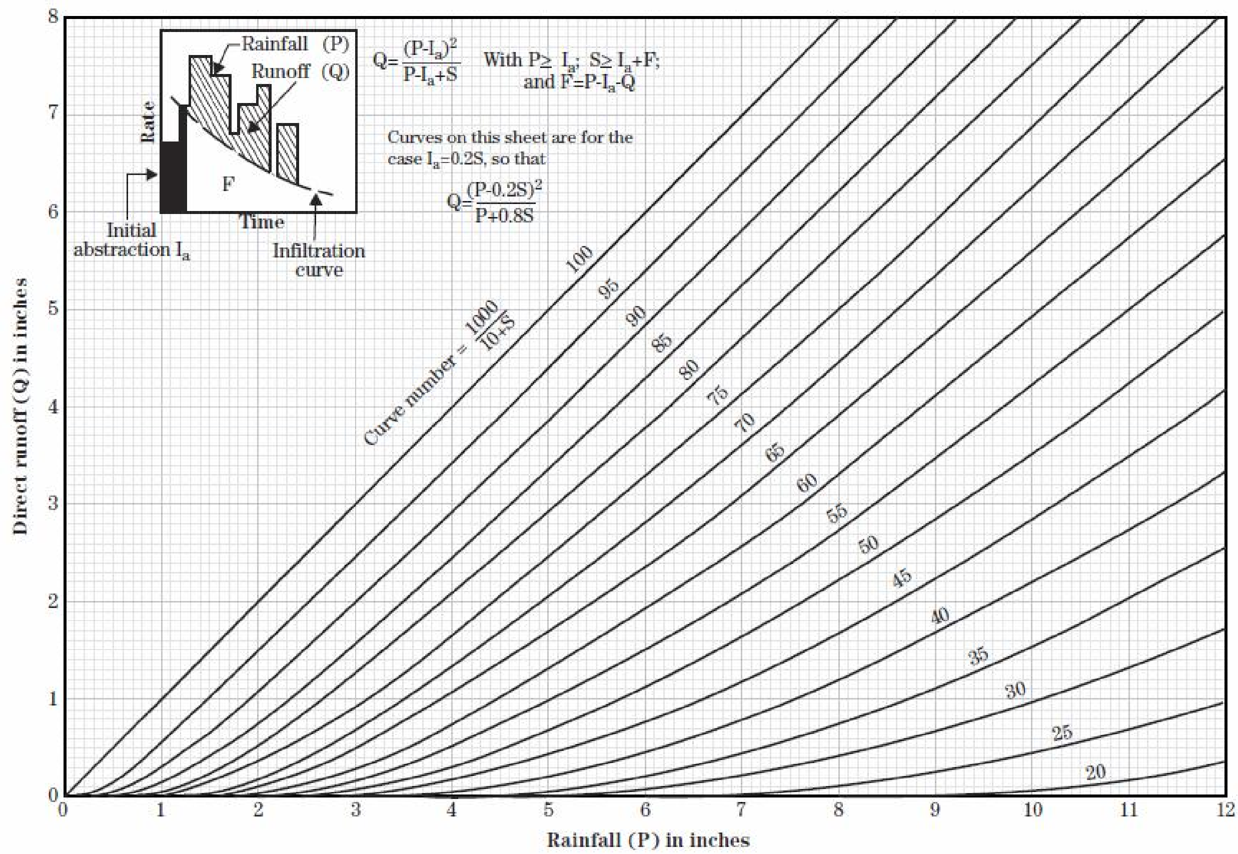
(NRCS, June 1986, "TR-55, Urban Hydrology for Small Watersheds", Eq. 2-3, p. 2-1)
https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044171.pdf

where:

Q	=	runoff, inches
P	=	rainfall, inches
S	=	potential maximum soil moisture retention after runoff begins
CN	=	Runoff Curve Number

$$S = \left(\frac{1000}{CN}\right) - 10 \qquad \textbf{402-2}$$

(NRCS, June 1986, "TR-55, Urban Hydrology for Small Watersheds", Eq. 2-4, p 2.1)
https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044171.pdf



Source: NRCS, 2004, "Part 630 Hydrology, National Engineering Handbook, Chapter 10 Estimation of Direct Runoff from Storm Rainfall", Figure 10-2, p. 10-4
https://directives.sc.egov.usda.gov/17752.wba

Figure 402-8 Solution of Runoff Equation

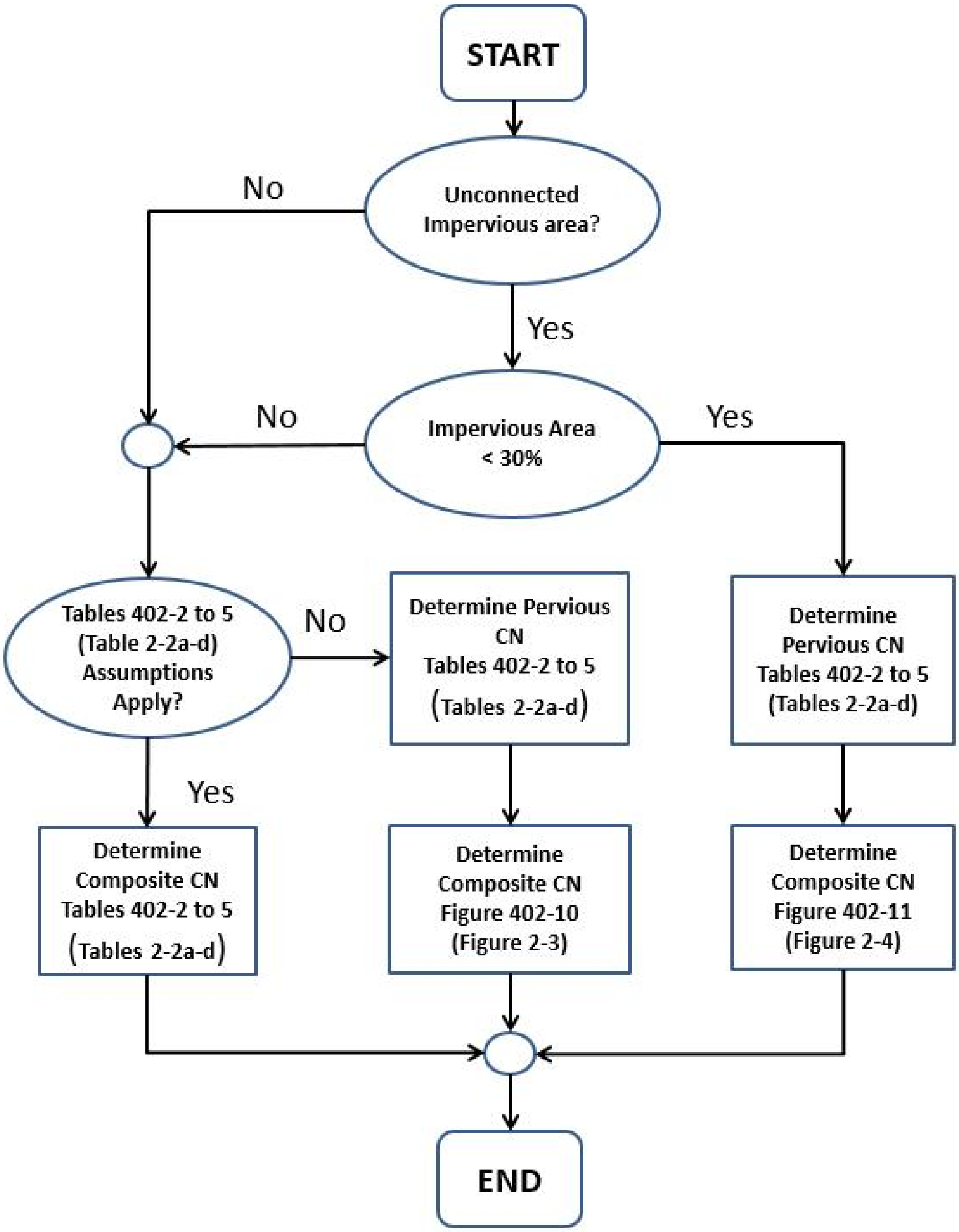
Storm Duration and Storm Recurrence Interval

TR-55 (NRCS, June 1986) states that "Normally a rainfall duration equal to or greater than the Time of Concentration (T_c) is used. Therefore, the rainfall distributions were designed to contain the intensity of any duration of rainfall for the frequency of the event chosen".

TR-55 (NRCS, June 1986) was developed based on the 24-hour rainfall depth (P_{24}) from various rainfall distributions. The Runoff (Q) Equation (**Equation 402-1**) presented in TR-55 was originally developed by the Soil Conservation Service (SCS, now the NRCS) prior to development of TR-55. The initial SCS runoff equation (**Equation 402-1**) was developed for various rainfall depths, without storm duration or recurrence interval limits.

Therefore, the TR-55 Direct Runoff Method (Q), may be applied to the 100-year recurrence interval storm and more frequent recurrence interval storms, and for storms of 24-hour duration and less. However, the 24-hour duration storm is required for NMDOT drainage analyses.

The decision process for determination of a Runoff Curve Number is presented in **Figure 402-9**.



Source: NRCS, June 1986, "TR-55, Urban Hydrology for Small Watersheds", Figure 2-2, p. 2-4.
https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044171.pdf

Figure 402-9 Flow Chart for Selecting the Appropriate Figure or Table for Determining Runoff Curve Numbers

Table 402-2 through **Table 402-5** (NRCS Tables 2-2 a-d) describe the effects of various cover and land use conditions for each of the four Hydrologic Soil Groups. Note that the CNs listed are for average runoff conditions. The index of runoff potential before a storm event is the Antecedent Runoff Condition (ARC), refer to **Section 404.5** for more information.

ARC is an attempt to account for the variation in CN at a site from storm to storm. CN for the average ARC at a site is the median value as taken from sample rainfall and runoff data. The amount of precipitation occurring in the five days preceding the storm in question is an indication of the ARC of the soil. Each ARC condition is defined here.

ARC I indicates dry watershed conditions that correlate with low runoff potential

ARC II indicates average watershed conditions that correlate with average runoff potential

ARC III indicates wet watershed conditions that correlate with high runoff potential

The CNs in **Table 402-2** to **Table 402-5** are for an average ARC II. New Mexico most often meets an ARC I or ARC II condition. Use ARC II for NMDOT Projects.

See “Part 630 Hydrology, National Engineering Handbook” (NRCS, 2004) for more detailed discussion of storm-to-storm variation and a demonstration of upper and lower enveloping curves.

Table 402-2 Runoff Curve Numbers for Urban Areas

Source: NRCS, June 1986, "TR-55, Urban Hydrology for Small Watersheds", Table 2-2a, p. 2-5.
https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044171.pdf

Table 2-2a Runoff curve numbers for urban areas [1]

Cover description: Cover type and hydrologic condition	Average percent impervious area [2]	Curve numbers for hydrologic soil group: A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.)[3]:					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only) [4]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation) [5]		77	86	91	94
Idle lands (CN's are determined using cover types similar to those in table 2-2c).					

1 Average runoff condition, and $I_a = 0.2S$.
2 The average percent impervious area shown was used to develop the composite CN's. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. CN's for other combinations of conditions may be computed using figure 2-3 or 2-4.
3 CN's shown are equivalent to those of pasture. Composite CN's may be computed for other combinations of open space cover type.
4 Composite CN's for natural desert landscaping should be computed using figures 2-3 or 2-4 based on the impervious area percentage (CN = 98) and the pervious area CN. The pervious area CN's are assumed equivalent to desert shrub in poor hydrologic condition.
5 Composite CN's to use for the design of temporary measures during grading and construction should be computed using figure 2-3 or 2-4 based on the degree of development (impervious area percentage) and the CN's for the newly graded pervious areas.

Table 402-3 Runoff Curve Numbers for Cultivated Agricultural Lands

Source: NRCS, June 1986, "TR-55, Urban Hydrology for Small Watersheds", Table 2-2b, p. 2-6.
https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044171.pdf

Table 2-2b Runoff curve numbers for cultivated agricultural lands [1]

Cover description			Curve numbers for hydrologic soil group			
Cover type	Treatment [2]	Hydrologic condition [3]	A	B	C	D
Fallow	Bare soil	—	77	86	91	94
	Crop residue cover (CR)	Poor	76	85	90	93
		Good	74	83	88	90
Row crops	Straight row (SR)	Poor	72	81	88	91
		Good	67	78	85	89
	SR + CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88
		Good	65	75	82	86
	C + CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & terraced (C&T)	Poor	66	74	80	82
		Good	62	71	78	81
	C&T+ CR	Poor	65	73	79	81
		Good	61	70	77	80
Small grain	SR	Poor	65	76	84	88
		Good	63	75	83	87
	SR + CR	Poor	64	75	83	86
		Good	60	72	80	84
	C	Poor	63	74	82	85
		Good	61	73	81	84
	C + CR	Poor	62	73	81	84
		Good	60	72	80	83
	C&T	Poor	61	72	79	82
		Good	59	70	78	81
	C&T+ CR	Poor	60	71	78	81
		Good	58	69	77	80
Close-seeded or broadcast legumes or rotation meadow	SR	Poor	66	77	85	89
		Good	58	72	81	85
	C	Poor	64	75	83	85
		Good	55	69	78	83
	C&T	Poor	63	73	80	83
		Good	51	67	76	80

1 Average runoff condition, and I_a=0.2S
2 Crop residue cover applies only if residue is on at least 5% of the surface throughout the year.
3 Hydraulic condition is based on combination factors that affect infiltration and runoff, including (a) density and canopy of vegetative areas, (b) amount of year-round cover, (c) amount of grass or close-seeded legumes, (d) percent of residue cover on the land surface (good ≥ 20%), and (e) degree of surface roughness.

Poor: Factors impair infiltration and tend to increase runoff.

Good: Factors encourage average and better than average infiltration and tend to decrease runoff.

Table 402-4 Runoff Curve Numbers for Other Agricultural Lands

Source: NRCS, June 1986, "TR-55, Urban Hydrology for Small Watersheds", Table 2-2c, p. 2-7.
https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044171.pdf

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Table 2-2c Runoff curve numbers for other agricultural lands [1/]

Cover description — Cover type	Hydrologic condition	Curve numbers for hydrologic soil group — A	B	C	D
Pasture, grassland, or range—continuous forage for grazing. [2/]	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow—continuous grass, protected from grazing and generally mowed for hay.	—	30	58	71	78
Brush—brush-weed-grass mixture with brush the major element. [3/]	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30 [4/]	48	65	73
Woods—grass combination (orchard or tree farm). [5/]	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods. [6/]	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30 [4/]	55	70	77
Farmsteads—buildings, lanes, driveways, and surrounding lots.	—	59	74	82	86

1 Average runoff condition, and $I_a = 0.2S$.
2 *Poor:* <50%) ground cover or heavily grazed with no mulch.
Fair: 50 to 75% ground cover and not heavily grazed.
Good: > 75% ground cover and lightly or only occasionally grazed.
3 *Poor:* <50% ground cover.
Fair: 50 to 75% ground cover.
Good: >75% ground cover.
4 Actual curve number is less than 30; use CN = 30 for runoff computations.
5 CN's shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CN's for woods and pasture.
6 *Poor:* Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.
Fair: Woods are grazed but not burned, and some forest litter covers the soil.
Good: Woods are protected from grazing, and litter and brush adequately cover the soil.

Table 402-5 Runoff Curve Numbers for Arid and Semiarid Rangelands

Source: NRCS, June 1986, "TR-55, Urban Hydrology for Small Watersheds TR-55", Table 2-2d, p. 2-8.
https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044171.pdf

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Table 2-2d Runoff curve numbers for arid and semiarid rangelands [1]

Cover description		Curve numbers for hydrologic soil group			
Cover type	Hydrologic condition [2]	A [3]	B	C	D
Herbaceous—mixture of grass, weeds, and low-growing brush, with brush the minor element.	Poor		80	87	93
	Fair		71	81	89
	Good		62	74	85
Oak-aspen—mountain brush mixture of oak brush, aspen, mountain mahogany, bitter brush, maple, and other brush.	Poor		66	74	79
	Fair		48	57	63
	Good		30	41	48
Pinyon-juniper—pinyon, juniper, or both; grass understory.	Poor		75	85	89
	Fair		58	73	80
	Good		41	61	71
Sagebrush with grass understory.	Poor		67	80	85
	Fair		51	63	70
	Good		35	47	55
Desert shrub—major plants include saltbush, greasewood, creosotebush, blackbrush, bursage, palo verde, mesquite, and cactus.	Poor	63	77	85	88
	Fair	55	72	81	86
	Good	49	68	79	84

1 Average runoff condition, and $I_a = 0.2S$. For range in humid regions, use table 2-2c.
2 Poor: <30% ground cover (litter, grass, and brush overstory).
Fair: 30 to 70% ground cover.
Good: > 70% ground cover.
3 Curve numbers for group A have been developed only for desert shrub.

The effects of urbanization, including the amount and connectedness of the impervious areas, has been studied by the NRCS, and a method for assessing the degree to which runoff is affected has been developed and is described below.

Connected Impervious Areas

An impervious area is considered connected if runoff from it flows directly into the drainage system. It is also considered connected if runoff occurs as shallow concentrated flow that runs over a pervious area and then flows into the drainage system, with the logic being that the losses within the pervious reach would be minimal in that circumstance.

Urban CNs related to **Table 402-2** (NRCS Table 2-2a) were developed for typical land use relationships based on specific assumed percentages of impervious area. These CN values were developed on the assumptions that (a) pervious urban areas are equivalent to pasture in good hydrologic condition and (b) impervious areas have a CN of 98 and are directly connected to the drainage system. Some assumed percentages of impervious area are shown in **Table 402-2.**

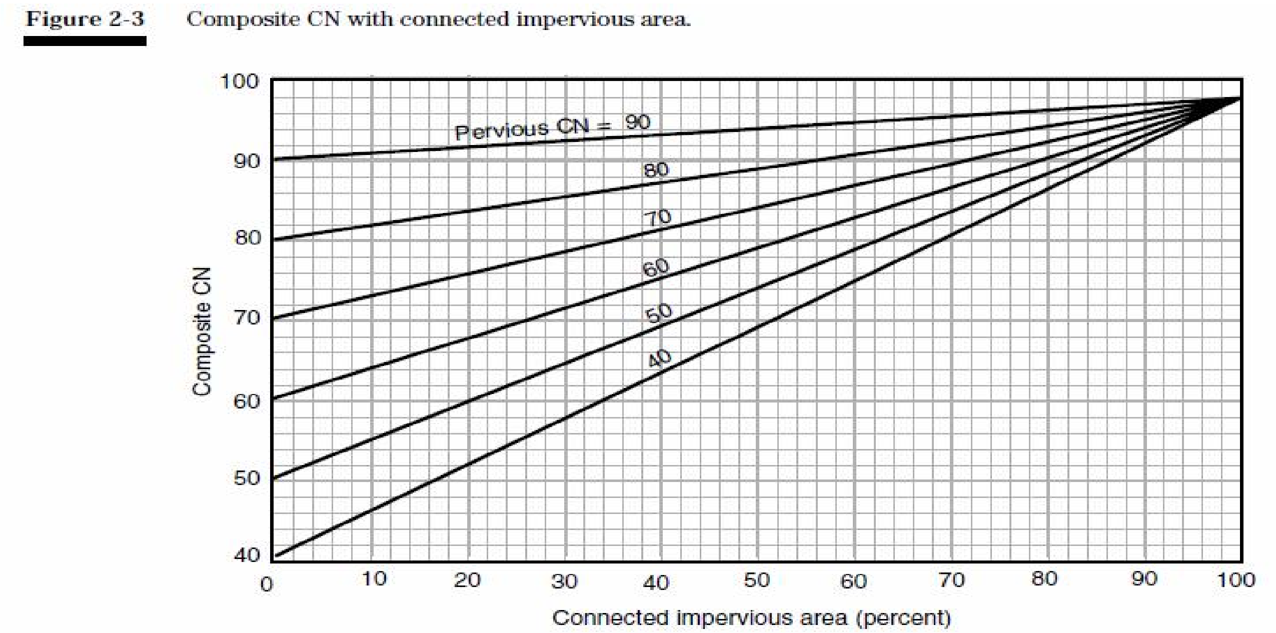
If not all of the impervious area is directly connected to the drainage system, and the impervious area percentages or the pervious land use assumptions in **Table 402-2** are not applicable, use **Figure 402-10** to compute a composite CN.

For example, a ½-acre lot in HSG B, with an assumed impervious area of 25 percent has a CN of 70. Assume that 20% of the impervious area is directly connected and assume the pervious area CN=61. Apply those values in **Figure 402-10** and a composite CN of 68 is determined. The difference between CN= 70 and 68 is because less runoff will be generated from the 80% impervious area that must pass through a pervious area (or not directly connected area), and therefore additional runoff will be infiltrated within the pervious area.

Unconnected Impervious Areas

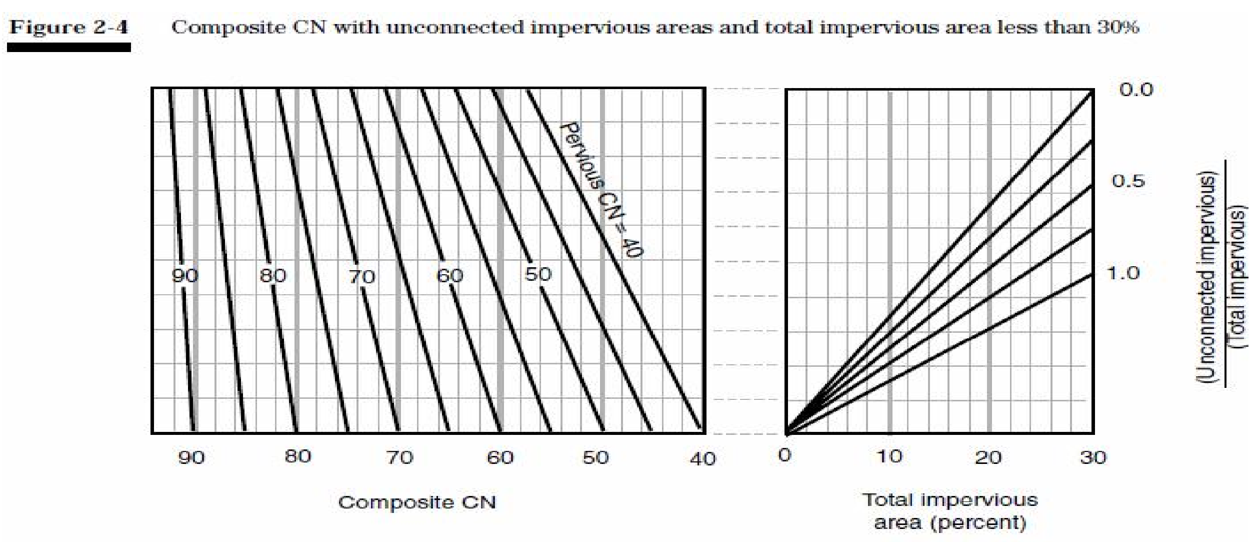
Runoff from unconnected (disconnected) impervious areas is that which spreads over a pervious area as sheet flow. To determine CN when all or part of the impervious area is not directly connected to the drainage system,

1. Use **Figure 402-10** if the total impervious area is greater than or equal to 30 percent, because the absorptive capacity of the remaining pervious areas will not significantly affect runoff.
2. Use **Figure 402-11** if the total impervious area is less than 30 percent.



Source: NRCS, June 1986, "TR-55, Urban Hydrology for Small Watersheds", Figure 2-3, p. 2-10.
https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044171.pdf

Figure 402-10 Composite CN with Connected Impervious Areas



Source: NRCS, June 1986, "TR-55, Urban Hydrology for Small Watersheds", Figure 2-4, p. 2-10.
https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044171.pdf

Figure 402-11 Composite CN with Unconnected Impervious Areas and Total Impervious Areas Less Than 30%

When impervious area is less than 30 percent, obtain the composite CN by entering the right side of **Figure 402-11** with the percentage of total impervious area and the ratio of total unconnected impervious area to total impervious area. Then move left to the appropriate pervious CN and read down to find the composite CN. For example, for a 1/2-acre lot with 20 percent total impervious area (75 percent of which is unconnected) and pervious CN of 61, the composite CN from **Figure 402-11** is 66. If all of the impervious area is connected, the resulting CN (from **Figure 402-10**) would be 68.

Limitations of the Runoff Curve Number Method

- Use the Runoff Curve Number Method with caution when re-creating specific features of an actual storm. The foundational rainfall/runoff equation does not contain an expression for time and, therefore, does not account for rainfall duration or intensity.
- Runoff from snowmelt or rain on frozen ground cannot be estimated using these procedures.
- The NRCS runoff procedures apply only to direct surface runoff; do not overlook large sources of subsurface flow or high ground water levels that contribute to streamflow. These conditions are often related to HSG A soils and forest areas that have been assigned relatively low CNs in **Table 402-4**. Good judgement and experience based on stream gage records are needed to adjust CNs as conditions warrant. *Note that this condition rarely impacts design decisions in New Mexico.*
- When the weighted CN is less than 40, use 40.

402.6.1 Curve Number Weighting

Examination of **Figure 402-8** reveals that the rainfall/runoff relationship described by the NRCS Curve Number (CN) Method is not linear for small rainfall amounts. This effect is most dramatic for lower CNs, therefore, when hydrologic conditions are reasonably consistent throughout the watershed, the use of a single CN is appropriate. For watersheds where CNs vary by 10 or less, an Area Weighted Curve Number is appropriate. When CNs vary by more than 10 within the basin or subasin, either subdivide the watershed into smaller drainage subbasins to obtain similar CNs, or use a Runoff Weighted Curve Number. Examples of each CN weighting procedure are shown below.

Area Weighted Curve Number

Assume a design rainfall event of 2.0 inches.

40% of the drainage basin is characterized by CN=65

60% of the drainage basin is characterized by CN=88

the area weighted CN = $\frac{(0.40) \times (65) + (0.60) \times (88)}{100}$ = 78.8 **use CN=79**

The runoff resulting from 2.0 inches of rainfall and a CN of 79 = 0.52 inches

Runoff Weighted Curve Number

40% of the drainage basin is characterized by CN=65

60% of the drainage basin is characterized by CN= 88

Use **Figure 402-8** or **Equation 402-1** to estimate 0.14 inches of direct runoff from the CN=65 land and 0.97 inches of direct runoff from the CN=88. **Equation 402-1** will provide more accurate results.

The weighted runoff is calculated by:

$$Q = (0.40) \times (0.14) + (0.60) \times (0.97) = 0.64 \text{ inches}$$

Use **Figure 402-8** to find a runoff weighted CN that will produce 0.64 inches of runoff from a 2.0 inch rainfall event, **CN=82**.

Comparison of Methods

Recall that by the Area Weighted Method, a CN = 79 was obtained. The Runoff Weighted Method determined that CN=82. The runoff difference between these CNs in this example is approximately 0.12 inches of direct runoff (a 23% increase in runoff volume).

Summary

Use the criteria described above to select the correct CN weighting method. Using the Runoff Weighted Curve Number Method requires more effort but will always produce the correct results. The Area Weighted Runoff Method is easier, gives reasonable results, and may be used when CN values vary by less than 10.

402.7 Other Land Use Effects

Recognize that both the Rational Formula Method Runoff Coefficient (C) and the Runoff Curve Number (CN) are lumped runoff parameters. This means that in most cases runoff volumes and sometimes peak rates incorporate all the losses to rainfall from the time it hits the ground until it reaches the analysis point, including canopy wetting, filling of minor depression storage, infiltration, evaporation, and transmission losses. In the case of the Rational Formula Method Coefficient (C), it includes any hydrologic routing effects as well.

Therefore, land use patterns, in addition to the relationship between rainfall and runoff volumes governed by the Soil-Cover Complex and the Rational Formula Method Runoff Coefficient (C) and the Runoff Curve Number (CN), affect the timing of runoff, how subbasins interact with the main stem of the stream system, and ultimately the shape and magnitude of the runoff hydrograph. Note that these effects are not linear. Doubling the rainfall may result in much higher than doubled peak runoff rates and volumes while doubling the drainage area may not have the same relative effect. The types of land use can also have a significant impact on water quality, even between two subbasins with identical soils and percentage imperviousness. Another often overlooked effect of land use is the relative location of the various land uses within a watershed. Further description of land use impacts is found in **Section 405**.

402.8 Travel Time, Lag, and Time of Concentration

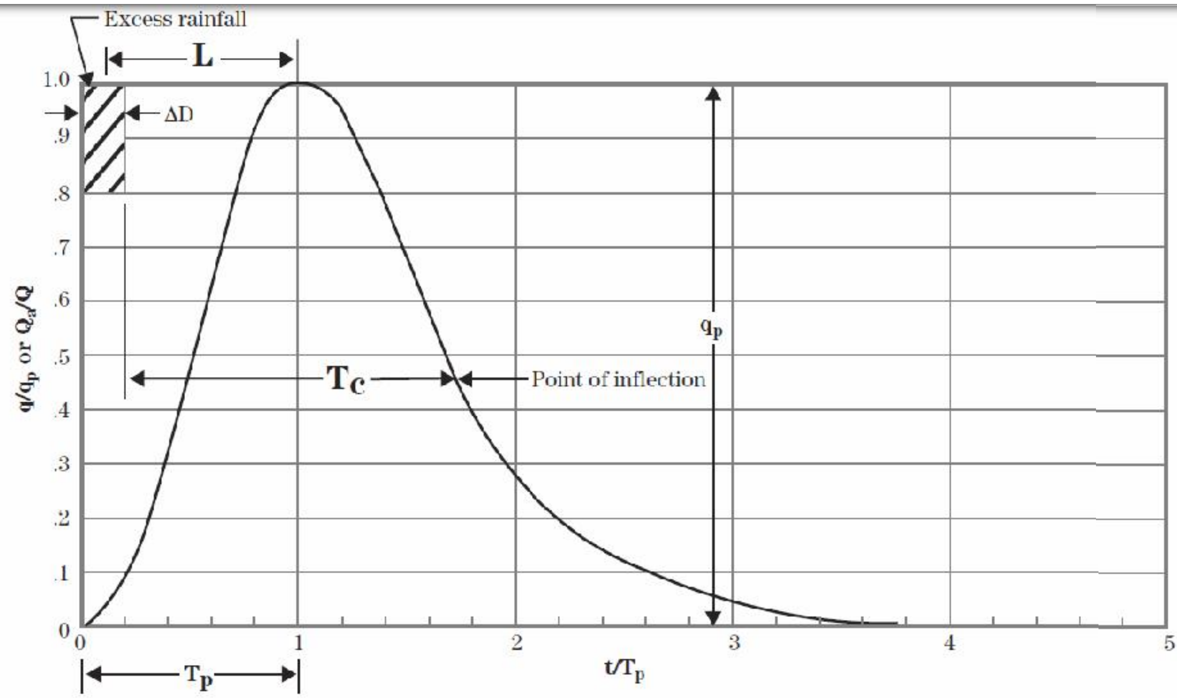
Travel Time (Tt) is the time it takes water to travel from one location to another.

Lag (L) is the delay between the *centroid of excess rainfall* from a rainfall event over a watershed until runoff reaches its maximum flow rate. Conceptually, lag may be thought of as a weighted Time of Concentration (Tc) where, if for a given storm, the watershed is divided into subbasins, the time required for each subbasin runoff to arrive at the outfall is related to the watershed peak by the relative contribution of each subbasin runoff in its individual lag time. In general, hydrologic modeling practice using the NRCS Unit Hydrograph Method, lag is a function of Tc.

Time of Concentration (Tc) is defined as the time required for excess precipitation (runoff) to travel from the hydraulically most remote part of the watershed to the point of interest. Peak rate calculations are very sensitive to Tc; therefore, it is one of the most important drainage basin characteristic needed to calculate the peak rate of runoff. Tc is a simplified proxy for the hydrologic response to precipitation by a watershed, capturing the effects of size, shape, length and slope of the basin or subbasin. The Tc for a watershed or subbasin has the most dramatic effect on the shape of the runoff hydrograph of any parameter. Therefore, accurate estimation of a watershed's Tc is crucial to every type of hydrologic modeling.

The method used to calculate Tc must be appropriate to the hydrologic analysis method selected for design. Engineers working on NMDOT projects must use the Time of Concentration methods specified in this section for each hydrologic method.

Figure 402-12 for a graphical explanation of L and Tc, and their relationship to one another.



where:
L = Lag, h
T_c = time of concentration, h
T_p = time to peak, h
ΔD = duration of excess rainfall, h
t/T_p = dimensionless ratio of any time to time to peak
q = discharge rate at time t, ft^3/s
q_p = peak discharge rate at time T_p, ft^3/s
Q_a = runoff volume up to t, in
Q = total runoff volume, in

Source: NRCS, 2010, “Part 630 Hydrology, National Engineering Handbook, Chapter 15 Time of Concentration”, Figure 15-3, p. 15-4.
http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=27002.wba

Figure 402-12 Graphical Representation of Relationships Between Lag, Tp and Tc

Table 402-6 defines the appropriate Time of Concentration method to be used for each hydrologic method.

Table 402-6 Selecting a Time of Concentration Calculation Method

Hydrologic Method	**Watershed Condition**	**Time of Concentration Method**
Rational Formula Method (**Section 403**)	Un-gullied Watershed*	Upland Method
	Gullied Watershed*	Kirpich Equation (Kerby-Kirpich Method for Valley Areas)
Simplified Peak Discharge Method (**Section 404**)	Un-gullied Watershed*	Upland Method
	Gullied Watershed*	Kirpich Formula (Kerby-Kirpich Method for Valley Areas)
	Watershed Partially Gullied	Upland Method for the Un-Gullied Portion, then Kirpich Equation for the Gullied Portion
USGS Regression Equations	varies	Not Required
Unit Hydrograph Method (**Section 405**)	No Defined Stream Channel	Upland Method
	Defined Stream Channel	Iterative Method within the Stream Hydraulic Method
Approved Urban Method	All Conditions	Use Tc Method Specified for the Approved Urban Method

*A watershed is considered un-gullied if 10% or less of the primary watercourse exhibits gullying.

Within each watershed, the engineer begins by locating the flow path to the most hydraulically remote point in the watershed. This is the flow path that extends from the bottom of the watershed, or drainage structure, to the most hydraulically distant (in time) point in the watershed. Generally, this process is begun at the bottom of the watershed and is continued upstream until the longest (in time) flow path has been found. At the top of the watershed, a defined watercourse may not exist. In these areas, overland flow will be the dominant flow type. As the runoff proceeds downstream, overland flows will naturally begin to coalesce, gradually concentrating together. Shallow concentrated flow often has enough force to shape small gullies in erosive soils. Gullies eventually combine until a well-defined stream channel is formed. The watercourse is, often at this point, large enough to be identified on a USGS quadrangle topographic map, or clearly visible in aerial photography depending on its quality.

Reaches along the primary watercourse should be divided into those which are hydraulically similar. In larger watersheds, the reaches may be sufficiently distinct to justify separate estimates of Tc for each reach of the watercourse. Tc in any given watershed is simply the sum of travel times within hydraulically similar reaches along the most remote (in time) flow path. Tc is determined from measured reach lengths and estimated average reach velocities.

The basic equation for Time of Concentration is:

$$Tc = \frac{\left[\frac{L_1}{V_1} + \frac{L_2}{V_2} + \frac{L_3}{V_3} + \frac{L_n}{V_n}\right]}{60} \qquad \textbf{402-3}$$

for minutes (or divide by 360 rather than 60 if Tc in hours is required)

where:

Tc	=	Time of Concentration, minutes (or hours depending on method)
V_1	=	average flow velocity in the uppermost reach of the watercourse, ft/s
L_1	=	length of the uppermost reach of the watercourse, ft
$V_2, V_3 \ldots V_n$	=	average flow velocities in subsequent reaches progressing downstream, ft/s
$L_2, L_3 \ldots L_n$	=	lengths of subsequent reaches progressing downstream, ft

Tc is the time required for runoff to travel from the hydraulically most distant point in the watershed to the outlet. The hydraulically most distant point is the point with the longest travel time to the watershed outlet, and not necessarily the point with the longest flow distance to the outlet, see **Figure 402-13**.

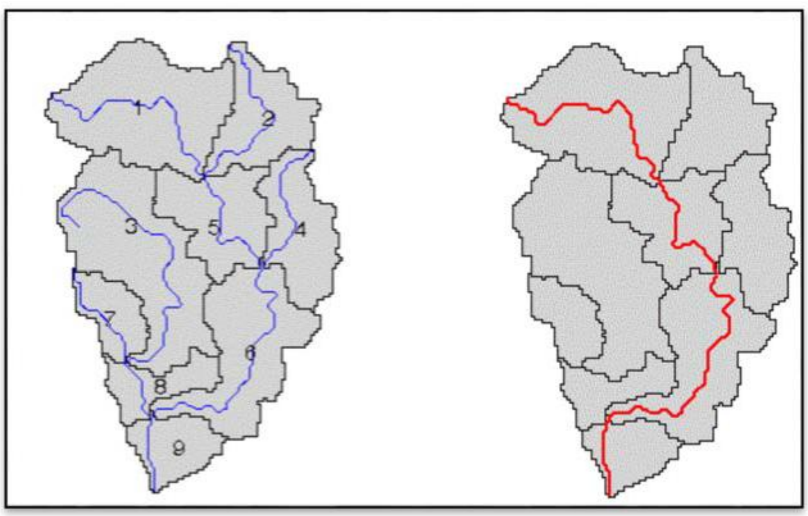


Figure 402-13 Longest Travel Time Illustration in Basin

Time of Concentration (Tc) is generally applied only to surface runoff and may be computed using many different methods. Tc will vary depending upon slope and character of the watershed and the flow path. In hydrograph analysis, Tc is the time from the end of excess rainfall to the point on the falling limb of the dimensionless unit hydrograph (point of inflection) where the recession curve begins, see **Figure 402-12**.

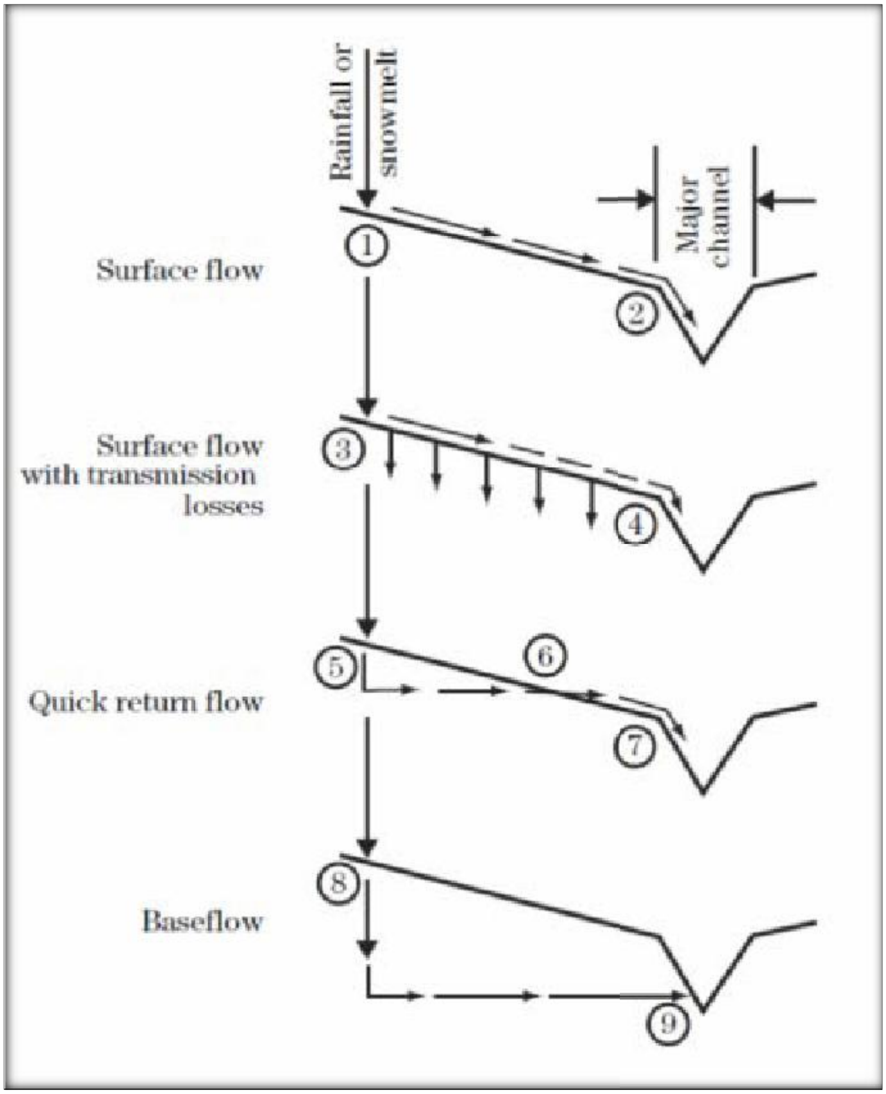
Tc can be estimated using one of the methods listed in **Table 402-6**, depending on the application and circumstances. In cases where only a peak discharge and/or hydrograph are desired at the watershed outlet and watershed characteristics are fairly homogenous, the watershed may be treated as a single basin. However, if land use, Hydrologic Soil Group, slope, or other watershed characteristics are not homogeneous throughout the watershed, or the basin is large enough that the assumption of one rainfall amount is not appropriate, then divide the watershed into smaller subbasins, which requires a Tc estimation for each subbasin. Hydrographs are then developed for each subbasin and routed appropriately to a point of reference using the methods described in **Section 405.11**.

Note: Peak rates of runoff are extremely sensitive to small changes in Tc. For this reason, it is very important that the physical processes and hydraulic principles involved are very well understood and that procedures used to estimate the Tc are valid and uniformly applied.

Rainfall over a watershed (that reaches the ground) will generally follow one of four potential paths:

- Some rain will be intercepted by vegetation and evaporate into the atmosphere
- Some rain will fall onto the ground surface and evaporate
- Some rain will infiltrate into the soil
- Some rain will run directly off from the ground surface

Depending on total storm rainfall and a variety of other factors, a portion of the stormwater runoff will drain to the stream system. There are four types of flow that may occur singly or in combination throughout the watershed as presented in **Figure 402-14**.



Source: NRCS, 2010, "Part 630 Hydrology, National Engineering Handbook, Chapter 15 Time of Concentration", Figure 15-1, p. 15-2.
http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=27002.wba

Figure 402-14 Types of Flow

Relation between Lag, Time to Peak, and Time of Concentration

Lag Time (L), Time to Peak (Tp), and Time of Concentration (Tc) are often misunderstood. When these terms are encountered in the documents referenced in this manual, it is important to understand each of them and their relationships to one another. The following is offered to assist in that understanding.

Researchers (Mockus 1961; Simas 1996) found that **Figure 402-12** graphically portrays the relationship between average natural watershed conditions and an approximately uniform distribution of runoff.

$$L = 0.6 \times Tc \qquad \textbf{402-4}$$

(NRCS, 2010, "Part 630 Hydrology, National Engineering Handbook, Chapter 15 Time of Concentration", Eq. 15-3, p. 15-3)
http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=27002.wba

where:

L	=	Lag, hr
Tc	=	Time of Concentration, hr

When runoff is not uniformly distributed due to significant differences in slope, drainage patterns, soils cover, and land use in a watershed, the watershed should be subdivided into subbasins with nearly uniform runoff characteristics so that **Equation 402-4** can be applied to each subbasin.

Four methods to calculate Tc presented in this manual are:

- The Upland Method
- The Kirpich Equation
- Kerby Equation
- The Kerby-Kirpich Method
- The Iterative Method within the Stream Hydraulic Method

402.9 Time of Concentration

402.9.1 The Upland Method

The Upland Method (also known as the Velocity Method) is used to estimate travel times for overland flow and shallow concentrated flow conditions. The Upland Method is used for the ungullied portion of the primary watercourse when the overland flow length is 300 feet or less.

The Upland Method was originally developed by the Soil Conservation Service (SCS), which is now the Natural Resource Conservation Service (NRCS). The Upland Method is described in Chapter 15 Time of Concentration of "Part 630 Hydrology, National Engineering Handbook" (NRCS, 2010). Note that in the current (2010) version of Chapter 15, the NRCS has renamed the "Upland Method" to the "Velocity Method." However, many documents still refer to it as the "Upland Method" and, therefore, the name "Upland Method" is used in this Drainage Design Manual.

The Upland Method is limited to use in watersheds that are less than 2,000 acres in size, or to the upper reaches of larger watersheds. For NMDOT projects the Upland Method may be used for computing the Time of Concentration when using the Rational Formula Method or the Simplified Peak Discharge Method on a largely un-gullied watershed. A watershed is considered un-gullied when 10% or less of the most hydraulically remote flow path exhibits gullying.

Water moves through a watershed as sheet flow, shallow concentrated flow, open channel flow, or some combination of these. The type of flow that occurs is a function of the conveyance system and is best determined by field inspection.

Travel time (Tt) is the ratio of flow length to flow velocity:

$$Tt = \frac{L}{3600 \times V} \qquad \textbf{402-5}$$

(NRCS, 2010, "Part 630 Hydrology, National Engineering Handbook, Chapter 15 Time of Concentration", Eq. 15-1, p. 15-2)
http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=27002.wba

where:

Tt	=	travel time, hr
L	=	flow length, ft
V	=	average velocity, ft/s
3600	=	conversion factor from seconds to hours

Time of Concentration (Tc), is the sum of Travel Time (Tt) values for the various consecutive flow segments:

$$Tc = T_t + T_2 + T_3 \ldots T_n \qquad \textbf{402-6}$$

(NRCS, 2010, "Part 630 Hydrology, National Engineering Handbook, Chapter 15 Time of Concentration", Eq. 15-7, p. 15-6)
http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=27002.wba

where:

Tc	=	Time of Concentration, hr
T_n	=	number of flow segments

Sheet Flow

At the top to the watershed, sheet flow is generally the predominant flow regime. Sheet flow is defined as flow over plane surfaces. Sheet flow usually occurs in the headwaters of a stream near the ridgeline that defines the watershed boundary. Typically, sheet flow occurs for no more than 100 to 300 feet before transitioning to shallow concentrated flow (Merkel, 2001).

A simplified version of the Manning's Kinematic Equation may be used to compute travel time for sheet flow. This simplified form of the Kinematic Equation presented here was developed by (Welle and Woodward,1986) after studying the impact of various parameters on the estimates.

$$Tt = \frac{0.007(\,n\,l\,)^{0.8}}{(\,P_2\,)^{0.5}\ S^{0.4}} \qquad \textbf{402-7}$$

(NRCS, 2010, "Part 630 Hydrology, National Engineering Handbook, Chapter 15 Time of Concentration", Eq. 15-8, p. 15-6)
http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=27002.wba

where:

Tt	=	travel time, hr
n	=	Manning's roughness coefficient (**Table 402-7**)
l	=	sheet flow length, ft
P_2	=	2-year, 24-hour rainfall, in.
S	=	slope of land surface, ft/ft

This simplification is based on the following assumptions:

- Shallow steady uniform flow
- Constant rainfall excess intensity (that part of a rain available for runoff) both temporally and spatially
- 2-year, 24-hour rainfall assuming standard NRCS rainfall intensity-duration relations apply (Types I, II, and III)
- Minor effect of infiltration on travel time

For sheet flow, the roughness coefficient includes the effects of roughness and the effects of raindrop impact including drag over the surface; obstacles such as litter, crop row ridges, and rocks; and erosion and sediment transport. These "n" values are only applicable for flow depths of approximately 0.1 foot or less, where sheet flow occurs. **Table 402-7** gives roughness coefficient values for sheet flow for various surface conditions.

Table 402-7 Roughness Coefficients (Manning's "n") for Sheet Flow

Source: NRCS, 2010, "Part 630 Hydrology, National Engineering Handbook, Chapter 15 Time of Concentration", Table 15-1, p. 15-6.
http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=27002.wba

Surface description	**"n" [1/]**
Smooth surfaces (concrete, asphalt, gravel, or bare soil)	0.011
Fallow (no residue)	0.05
Cultivated soils:0.	
Residue cover ≤20%	0.06
Residue cover >20%	0.17
Grass:	
Short grass prairie	0.15
Dense grasses [2/]	0.24
Bermuda grass	0.41
Range (natural)	0.13
Woods:[3/]	
Light underbrush	0.40
Dense underbrush	0.80

[1/] The "n" values are a composite of information compiled by Engman (1986).
[2/] Includes species such as weeping lovegrass, bluegrass, buffalo grass, blue grama grass, and native grass mixtures.
[3/] When selecting "n", consider cover to a height of about 0.1 ft. This is the only part of the plant cover that will obstruct sheet flow.

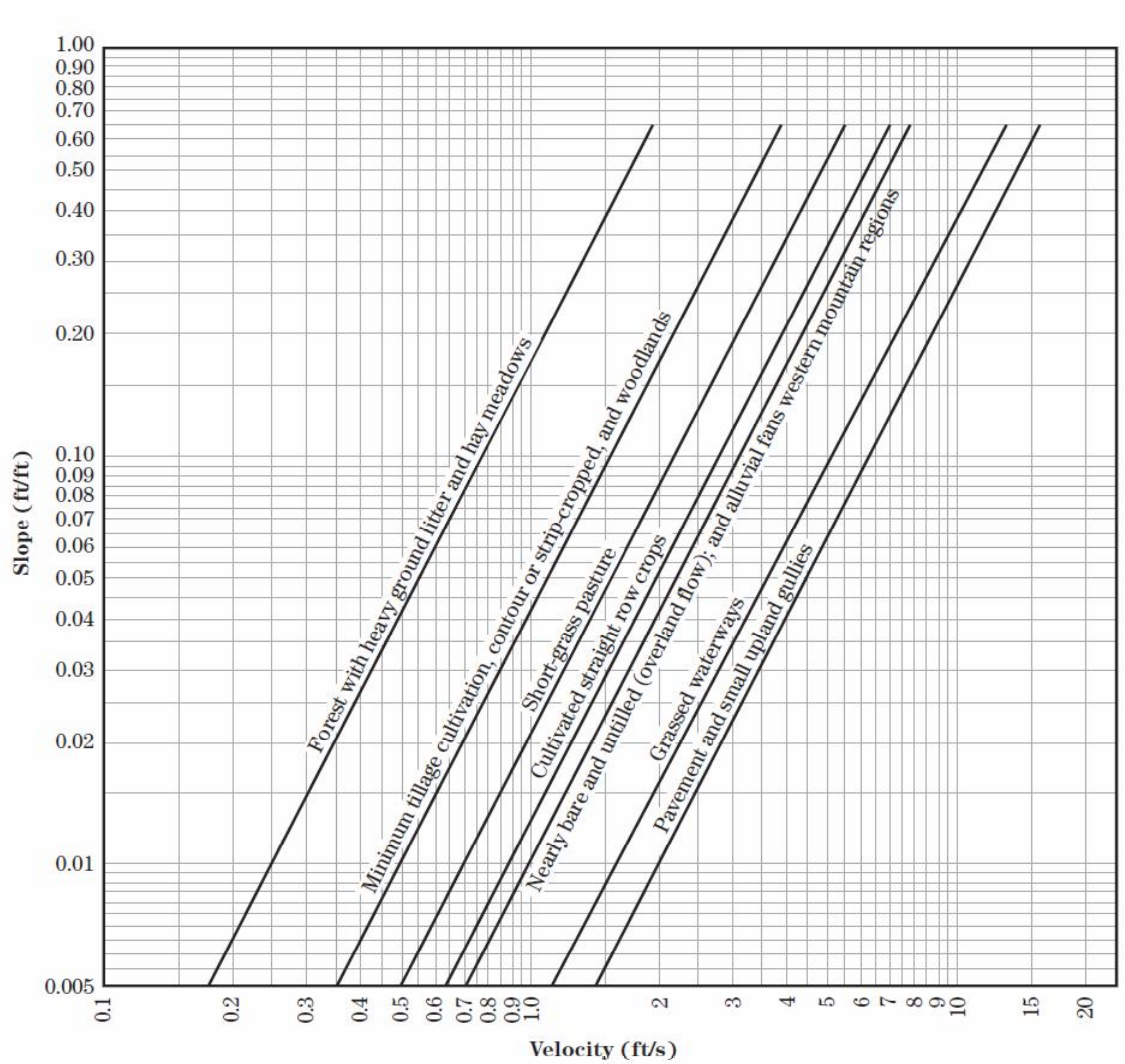
It is important to note that there are many locations in New Mexico where there is little or no runoff resulting from a 2-year storm and that due to the combination of high desert climate and soils in the upper portions of many watersheds, there is no evidence of gully formation for distances far exceeding 100 to 300 feet. However, the maximum sheet flow length used for NMDOT hydrologic analyses should not exceed 300 feet, except when a greater length can be justified by onsite inspection of the upper watershed or through inspection of high resolution aerial photography.

Overland flow continues until the volume of water is sufficient to create a shallow concentrated flow regime. In erosive soil formations with limited ground cover, the length of overland flow may be so short that it is negligible. Given the slope of the land and some knowledge of the ground cover conditions, once the most hydraulically remote flow path is determined, the overland flow length can be determined.

For NMDOT projects, shallow concentrated flow is assumed to occur from the end of overland flow to the bottom of a watershed where there is little or no gullying (10% or less). Where gullying is evident in the majority of the watershed (by field inspection, aerial photography or by a blue line shown on the USGS quadrangle topographic map), the Time of Concentration should be computed by the Kirpich Equation for the entire watershed. When the Simplified Peak Discharge Method is being used for NMDOT projects, the Upland Method may be used for the un-gullied portion of the watercourse, in combination with the Kirpich Equation for the gullied sections of the watercourse. For watersheds with more than 30% of the uplands or with little or no gullying (valley areas), the Kerby-Kirpich Method should be used. The NMDOT Drainage Design Bureau can be contacted to obtain a copy of a spreadsheet to determine Tc using these methods. Note that the Engineer/Consultant is responsible for understanding the use of, and the accuracy of the results from this spreadsheet.

Shallow Concentrated Flow

After approximately 100 to 300 feet, sheet flow usually becomes shallow concentrated flow collecting in swales, small rills, and gullies. Shallow concentrated flow is assumed not to have a well-defined channel and has flow depths of 0.1 to 0.5 feet. It is assumed that shallow concentrated flow can be represented by one of seven flow types. **Figure 402-15** presents curves as Velocity versus Slope for Shallow Concentrated Flow and these curves were used to develop the information in **Table 402-8**. To estimate shallow concentrated flow travel time, velocities are developed using **Figure 402-15**, in which average velocity is a function of watercourse slope and type of channel (Kent, 1973). For slopes less than 0.005 feet per foot, the equations in **Table 402-8** may be used. After estimating average velocity using **Figure 402-15**, use **Equation 402-5** to estimate travel time for the shallow concentrated flow segment.



Source: NRCS, 2010, "Part 630 Hydrology, National Engineering Handbook, Chapter 15 Time of Concentration", Figure 15-4, p. 15-8.
http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=27002.wba

Figure 402-15 Velocity Versus Slope for Shallow Concentrated Flow

Table 402-8 Equations and Assumptions Developed from Figure 402-15

Source: NRCS, 2010, "Part 630 Hydrology, National Engineering Handbook, Chapter 15 Time of Concentration", Table 15-3, p.15-8.
http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=27002.wba

Flow type	Depth (ft)	Manning's n	Velocity equation (ft/s)
Pavement and small upland gullies	0.2	0.025	$V=20.328(s)^{0.5}$
Grassed waterways	0.4	0.050	$V=16.135(s)^{0.5}$
Nearly bare and untilled (overland flow); and alluvial fans in western mountain regions	0.2	0.051	$V=9.965(s)^{0.5}$
Cultivated straight row crops	0.2	0.058	$V=8.762(s)^{0.5}$
Short-grass pasture	0.2	0.073	$V=6.962(s)^{0.5}$
Minimum tillage cultivation, contour or strip-cropped, and woodlands	0.2	0.101	$V=5.032(s)^{0.5}$
Forest with heavy ground litter and hay meadows	0.2	0.202	$V=2.516(s)^{0.5}$

For that portion of the flow path that is channel flow, use Manning's Equation (**Equation 402-10**) to calculate the velocity. The approach outlined in **Section 402.9.5** should be followed to determine the average velocity for the channel reaches.

Once the reach lengths and flow velocities for each defined reach along the flow path have been calculated as described above, the Tc for each of the segments are added together to find the total Tc.

402.9.2 Time of Concentration by the Kirpich Equation

The Kirpich Equation should be used in watersheds when gullying (including manmade conveyances in fully urbanized watersheds such as curb and gutter, storm drains and channels) is evident in more than 10% of the primary watercourse**.** Gullying can be assumed if a blue line appears on the watercourse shown on the USGS quadrangle topographic map or is apparent from field investigation or from inspection of aerial photography. The Kirpich Equation is given as:

$$Tc = 0.0078 \times L^{0.77} \times S^{-0.385} \qquad \textbf{402-8}$$

(TxDOT, July 2016, "Hydraulic Design Manual", Eq. 4-15, p. 4-39)
http://onlinemanuals.txdot.gov/txdotmanuals/hyd/index.htm

where:

Tc	=	Time of Concentration, minutes
L	=	maximum length of water travel, ft
S	=	surface slope, given by H/L, ft/ft
H	=	difference in elevation between the most hydraulically remote point in the drainage basin and the outlet, ft

In small watersheds where the slope is flat, and the flow path of the hydraulically longest flow path is dominated by overland flow greater than 300 feet, the Kerby Equation should be considered for the overland flow portion and Kirpich Equation for the channelized portion.

In gullied (and in fully urbanized) basins, the Kirpich Equation should generally be used for the entire drainage basin. The exception to this rule occurs when the Simplified Peak Discharge Method is being used on NMDOT projects or when the watercourse has a mixture of gullied and un-gullied sections. In these situations, mixing of Time of Concentration methods is allowed and is called the Kerby-Kirpich Method as described in **Section 402.9.4.**

402.9.3 Time of Concentration by the Kerby Equation

For small watersheds where overland flow and overland flow length are an important component of overall travel time, the Kerby Equation can be used. The Kerby Equation is:

$$T_{OV} = K\ (L \times N)^{0.467} \times S^{-0.235} \qquad \textbf{402-9}$$

(TxDOT, July 2016, "Hydraulic Design Manual", Eq. 4-14, p. 4-37)
http://onlinemanuals.txdot.gov/txdotmanuals/hyd/index.htm

where:

T_{OV}	=	overland flow Time of Concentration, minutes
K	=	a unit conversion coefficient, in which K = 0.828
L	=	the overland-flow length, feet
N	=	a dimensionless retardance coefficient
S	=	the dimensionless slope of terrain conveying the overland flow

In the development of the Kerby Equation, the length of overland flow was as much as 1,200 feet. This length is considered an upper limit, and in practice, shorter values generally are expected. The dimensionless retardance coefficient used is similar in concept to the well-known Manning's roughness coefficient; however, for a given type of surface, the retardance coefficient for overland flow will be considerably larger than for open-channel flow. Typical values for the retardance coefficient are listed in **Table 402-9**. Roussel et al., 2005, recommends that the user should not interpolate the retardance coefficients in **Table 402-9.** If it is determined that a low slope condition or a transitional slope condition exists, the user should consider using an adjusted slope in calculating the Time of Concentration.

Table 402-9 Kerby Equation Retardance Coefficient Values

Source: TxDOT, July 2016, "Hydraulic Design Manual", Table 4-5, p. 4-38.
http://onlinemanuals.txdot.gov/txdotmanuals/hyd/index.htm

Generalized Terrain Description	Dimensionless Retardance Coefficient (N)
Pavement	0.02
Smooth, bare, packed soil	0.10
Poor grass, cultivated row crops, or moderately rough packed surfaces	0.20
Pasture, average grass	0.40
Deciduous forest	0.60
Dense grass, coniferous forest, or deciduous forest with deep litter	0.80

402.9.4 The Kerby-Kirpich Method

The Upland Method is used for the ungullied portion of the primary watercourse when the overland flow length is 300 feet or less. The Kerby Equation should be used for the ungullied portions when the overland flow length is greater than 300 feet. The Kirpich Equation is used for the gullied portion of the watercourse, including those drained by manmade conveyances such as curb and gutter, storm drains and channels. The Tc result from each equation are added to obtain the watershed total Tc, thus the name "Kerby-Kirpich" Method.

402.9.5 The Iterative Method Within the Stream Hydraulic Method

The Iterative Method within the Stream Hydraulic Method is used when calculating peak discharges by the Unit Hydrograph Method in a watercourse where a defined stream channel is evident in the field or aerial photography (or a blue line, solid or broken, on a quadrangle topo map) and is the dominant runoff conveyance in the watershed. The Iterative Method within the Stream Hydraulic Method is applicable principally on larger basins where the longest flow path is dominated by channel flow, but that are small enough not to warrant subdividing the basin, or in basins where gullying is evident all the way to the top of the basin.

The engineer must measure or estimate the hydraulic properties of the stream channel. The total watercourse must be divided into channel reaches which are hydraulically similar within themselves. Often, hydraulically similar reaches will have similar slopes. Dramatic slope changes should be apparent from both topography and channel shape. Field reconnaissance measurements of the stream channel are suggested; however, sometimes direct measurements are not possible. The engineer must determine the slope, channel cross section, and an appropriate hydraulic roughness coefficient for each channel reach using the best information available within the limits of access, time, and budgets (topographic maps, aerial photography, etc.). Average slope is often determined from the topographic mapping. Channel cross sections should be measured in the field whenever possible, but scalable aerial photography may provide sufficient information to assess channel cross section characteristics.

Roughness coefficients of the waterway should be based on actual observations of the watercourse or of accessible nearby watercourses which are believed to be similar. If the reach is inaccessible, and if there is good quality aerial photography available it may provide adequate information for this purpose.

Time of Concentration (Tc) by Iterative Method within the Stream Hydraulic Method is simply the travel time (Tt) in the stream channel. Channel flow velocities can be estimated from normal depth calculations for the watercourse. In addition to the average flow velocity, engineers should compute the Froude number (Fr) of the flow. If the Fr number of the flow exceeds a value of 1.3, the engineer should verify that supercritical flow conditions can be sustained. For most earth lined channels, the velocity calculation should be recomputed using a larger effective Manning's roughness coefficient "n" until the Froude number has a value less than 1.3. Note that most upland arroyos flow very close to critical depth (Fr=1) and in most cases, normal depth and critical depth are very close to the same depth and velocity.

Velocity (V) is determined from Manning's Equation:

$$V = \frac{1.486}{n} R^{0.667} S^{0.5}$$ **402-10**

where:

V	=	velocity, ft/s
n	=	Manning's roughness coefficient
R	=	hydraulic radius (area/wetted perimeter), ft
S	=	slope of the energy grade line (assumed to be the same as the channel slope) ft/ft

Froude number (Fr) is calculated by the following equation:

$$Fr = \frac{V}{(g\ d)^{0.5}}$$ **402-11**

where:

Fr	=	Froude number
V	=	velocity, ft/s
g	=	gravitational acceleration, 32.2 ft/s^2
d	=	hydraulic depth (flow cross sectional area/top width of flow), ft

In order to solve Manning's Equation for velocity (V), calculate or estimate the hydraulic radius (R). If the flow depth or flow rate is known, then R may be found directly. However, the usual situation is that neither flow depth nor flow rate are known without first computing the Tc and an initial discharge. Three procedures are provided below for solving this problem.

Simplified Flow Estimating Procedure

Wide Shallow Channels

Use this method for channels where the flow depth is relatively shallow compared to the flow width. When this is true, the hydraulic radius (R) converges toward depth (d). The use of R=d is acceptable for NMDOT projects where the stream channel is relatively wide, and the flow is shallow. Larger arroyo systems in alluvial terrain often satisfy this criterion.

Moderate and Narrow Width Channels

Use this method for all other channels. Estimate the flow depth from high water mark evidence or other available data. For most ephemeral stream channels, the 25-year to 100-year storm flow depths may be in the range of 1 to 3 ft. Where a channel has obvious channel banks in the 1 to 3 ft height range, use the "bank full" depth. For most ephemeral streams use the bank full depth of the low flow channel. If the evidence suggests a flow depth greater than the height of an incised channel bank, use the physical evidence depth but compute the flow velocity based on water in the channel only (no overbank flow considered). Use the flow depth and channel cross section geometry to estimate R. For estimated flow depths deeper than 3 to 5 ft, the engineer should consider using the iterative procedure described below.

Iterative Procedure

For some channel flow conditions, the simplified procedures described above may not be adequate. In these cases, the iterative procedure described here must be followed. First, the peak rate of runoff from the watershed is estimated. A beginning estimate may be obtained using experience and judgment or by using the USGS regional regression equations for New Mexico (see **Section 407** of this Manual.) The flow rate for the velocity calculation is assumed to be two-thirds of the peak rate. Average channel velocity is calculated from **Equation 402-10** using the other hydraulic parameters of the channel. The average channel velocity for each reach is then used to determine the total Tc for the watershed. After the peak discharge from the watershed is computed, reassess the flow rate used to compute an average channel velocity. If the assumed peak discharge is within 10% of the calculated peak discharge, the computed average channel velocity and resulting Tc should be reasonably accurate. Often a second iteration is required using two-thirds of the computed peak flow to compute a new average channel velocity. This iterative procedure should be continued until the assumed peak discharge rate is within 10% of the computed peak discharge rate. Appendix 6 contains **Example Problem 6-5** that demonstrates this Method. Note: use of a computer program to calculate normal depth will greatly expedite this iterative procedure.

402.10 Channel and Floodplain Characteristics

Stream channels, floodplains, and reservoirs can have a significant impact on the delivery of water to any location along a stream network. Flood routing impacts the magnitude of the peak discharge, the time of the peak discharge, depth and extent of flooding, and environmental factors such as stream bank erosion, floodplain scour, sediment transport, and deposition.

The size, shape, and configuration of the channel and floodplain of a stream system are a reflection of the hydrologic processes within the watershed that created the stream system. A channel/floodplain system that is part of a high runoff producing watershed will look dramatically different than one that regularly produces little runoff. The process of both developing the hydrologic parameters needed to perform hydrologic analyses and the qualitative review of the results should include an assessment of the resulting channel/floodplain system.

The Time of Concentration (Tc) calculation is one of the most critical input parameters to any deterministic (as opposed to probabilistic) hydrologic analysis. Tc in a large watershed is determined largely on the hydraulics of the channel and floodplain system while in smaller watersheds, sheet flow and shallow concentrated flow may dominate.

Hydraulic parameters and qualities such as slope, cross section, bed form, Manning's roughness coefficient "n", rating curves, sediment size, sediment volumes, vegetation type and densities, are all related to the watershed's response to rainfall and the climate in which the watershed is located. Experience and judgment are required to assess the relative importance and impacts of each of these parameters. This experience is gained by always beginning with a qualitative assessment of the channel/floodplain system. Then developing hydrologic and hydraulic data, assumptions and calculations, and then checking the analysis results to verify that they are reasonable given the characteristics of the channel/floodplain system.

402.11 Sediment Bulking

Flood flows from high-intensity rainfall events on bare or mostly bare soils and flows within ephemeral sand bottom arroyos often contain significant amounts of sediment. When using one of the deterministic modeling approaches (but not Regional Regression Equations or streams with gage records) in this manual, it should be recognized that the resulting peak discharge and runoff volume are clean or clear water values, and therefore do not include the flow bulking that results from sediment.

Conveyance Structures

If the water conveyance structure (culvert, concrete box culvert, or bridge) has 120% or more of the required design capacity above the clear water discharge to meet NMDOT hydraulic criteria, then no further bulking factor analyses is required. However, if the conveyance structure does not meet the 120% criterion, see **Table 205-1**, then a more rigorous bulking factor analysis must be performed, or upsize the conveyance structure.

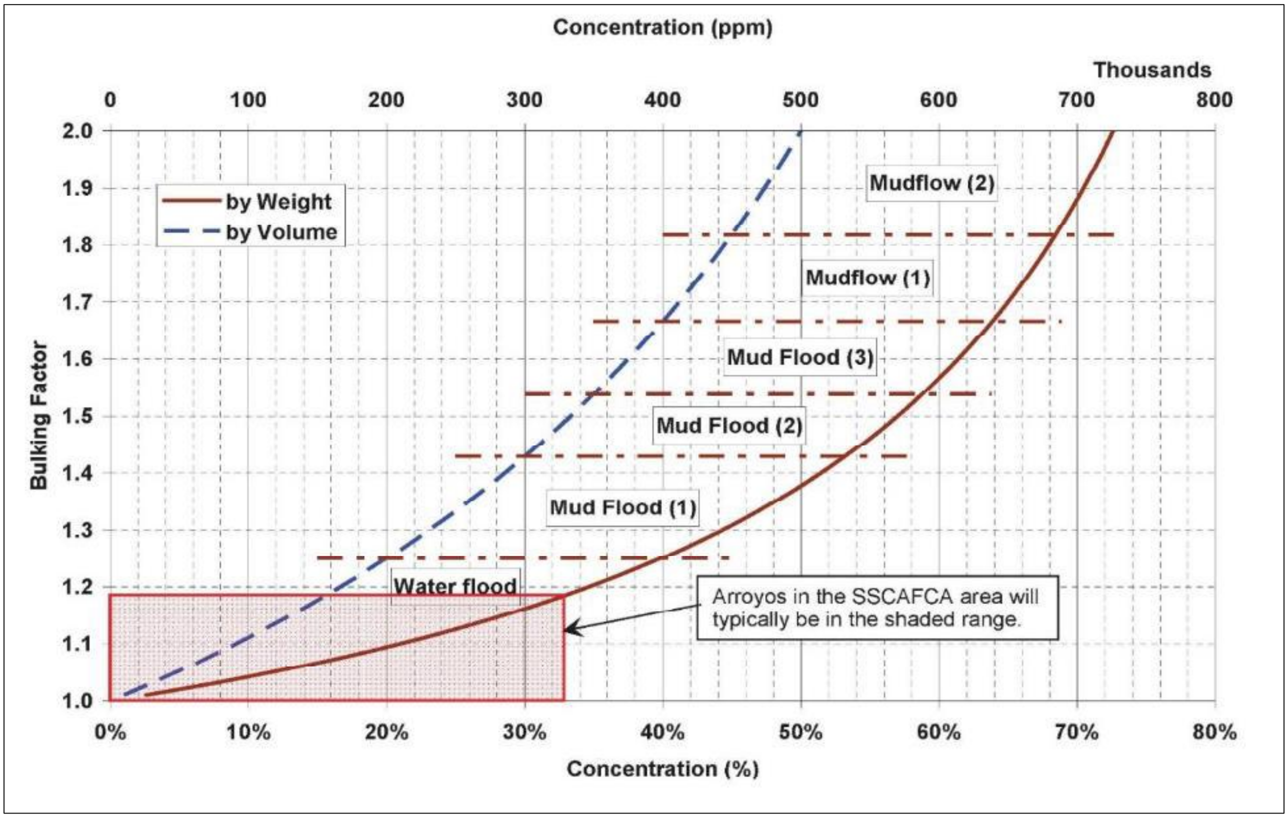
Detention and Retention Ponds

For the hydrologic analyses required for pond design, clear water storm runoff hydrographs must account for sediment by application of sediment bulking factors. The information presented in this Section combined with the pond design requirements presented in **Section 207** must be addressed during pond design.

402.11.1 SSCAFCA Sediment and Erosion Guide

The information in this Section was excerpted from a document titled "Sediment and Erosion Design Guide", November 2008, developed for the Southern Sandoval County Arroyo Flood Control Authority (SSCAFCA), prepared by Mussetter Engineering, Inc. http://sscafca.org/sediment-and-erosion-design-guide/

Figure 402-16 provides a guide to a range of possible sediment bulking factors in relation to sediment concentration for sand arroyos in the Sandoval County area. These figures and the supporting text of the Sediment and Erosion Guide will assist in estimating sediment bulking factors in arroyos outside the Sandoval County area (qualitatively at least).



Source: SSCAFCA, November 2008, "Sediment and Erosion Design Guide", Figure 3.8, p. 3.24. http://sscafca.org/development/documents/sediment_design_guide/Sediment%20Design%20Guide%2012-30-08.pdf

Figure 402-16 Relationship between Total Sediment Concentration and Bulking Factor

Bulking Factors for the SSCAFCA Area

Discharges estimated using standard rainfall-runoff procedures typically do not account for the presence of sediment in the flow. At high sediment loads, the total volume of the water/sediment mixture, and thus, the peak design discharges, can be substantially higher than the corresponding clear-water values. The following relation provides a means of computing a bulking factor (B_f) which is a factor applied to adjust (increase) the clear-water discharges for the presence of the transported sediment, if the sediment load is known:

$$B_f = \frac{Q + Q_{S_{total}}}{Q} = \frac{1}{1 - \dfrac{C_S / 10^6}{S_g - (C_S / 10^6)(S_g - 1)}} \qquad \textbf{402-12}$$

(SSCAFCA, November 2008, "Sediment and Erosion Guide", Eq. 3.25, p. 3.23)
http://sscafca.org/development/documents/sediment_design_guide/Sediment%20Design%20Guide%2012-30-08.pdf

where:

B_f	=	bulking factor
Q	=	clear-water discharge, cfs
$Q_{s\ total}$	=	total sediment load (i.e., combination of bed material and wash load), cfs
C_s	=	total sediment concentration by weight, ppm and
S_g	=	specific gravity of the sediment

This relationship indicates that the bulked discharge for a water/sediment mixture at the upper limit of concentrations for water floods (200,000 ppm by volume or 410,000 ppm by weight) would be about 25 percent greater than the clear water discharge (i.e., a bulking factor of 1.25) (**Figure 402-16**).

Because specific knowledge of the sediment load is often not available, conservative estimates of the bulking factor that can be applied to a range of potential design discharges were made by applying the MPM-Woo procedure for a typical rectangular cross section with width-depth ratio (F_D) at the dominant discharge (Q_D) of 40, assuming critical flow conditions and a range of median (D_{50}) particle sizes. Dominant discharge is defined in **Figure 402-17**, and a method for estimating its magnitude is provided in the text box that follows. Note that the figure enclosed within the text box is difficult to read as is the original document (SSCAFCA, 2008).

Chapter 3 of this guide provides guidance in relating bulking factors to median (D_{50}) bed material size for the following recurrence interval floods: 2-, 5-, 10-, 25-, 50- and 100-year, based on a range of dominant discharge values. D_{50} is defined as the sediment size for which 50% of the sample is finer by weight.

Annual Sediment Yield and Dominant Discharge

The **dominant** (or effective) discharge is defined as the increment of discharge that carries the most sediment over a long period of time (Wolman and Miller, 1960; Andrews, 1980; Biedenharn et al., 2000). In perennial, self-adjusted streams, the dominant discharge is often assumed to be same as the bankfull discharge because this represents the long-term condition to which the channel has adjusted, and it is also often assumed to be equivalent to about the mean annual flood peak. Care must be taken in making these assumptions, however, because the dominant, bankfull and mean annual flood peak discharges can be quite different, even in perennial, self-adjusted stream. For ephemeral streams, the dominant discharge tends to be associated with larger, less frequent flood peaks than in perennial streams, due to the absence of sustained flows and the flashy nature of the storm hydrographs. For design purposes, the dominant discharge for lightly developed watersheds in the SSCAFCA jurisdictional area will typically be in the range of the 5- to 10-year peak discharge. In more highly developed watersheds, the frequency of the dominant discharge is typically less because runoff (and sediment transport) associated with the more frequent storms tends to increase dramatically. As a result, the frequency of the dominant discharge is typically in the range of the 3- to 5-year flood peak.

A quantitative method for estimating Q_D in arroyos

If bed-material transport rating curves and storm hydrographs are available, the dominant discharge can be estimated as the peak of the storm event that will produce a bed-material sediment yield equal to the mean annual bed-material sediment yield. The mean annual sediment yield can be estimated by integrating the sediment yield frequency curve (Chang, 1988):

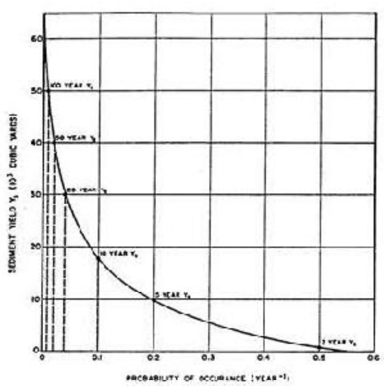
$$Y_{sm} = \int_{0}^{1} Y_s dP_F \qquad (3.26)$$

where Y_s is the individual storm sediment yield and P_F is the probability of occurrence of that flood in one year. The product $Y_s \cdot P_F$ represents the contribution of a particular flood to the long-term mean annual yield. For practical purposes, the integration can be accomplished for a series of discrete storm events using the trapezoidal rule. Using the 2-, 5-, 10-, 25-, 50-, and 100-year events, for example, the mean annual sediment yield is approximated by the following relationship:

$$Y_{s_m} = 0.015 Y_{s_{100}} + 0.015 Y_{s_{50}} + 0.04 Y_{s_{25}} + 0.08 Y_{s_{10}} + 0.2 Y_{s_5} + 0.4 Y_{s_2} \qquad (3.27)$$

If only the 2-, 10- and 100-year events are used, the following relationship is obtained:

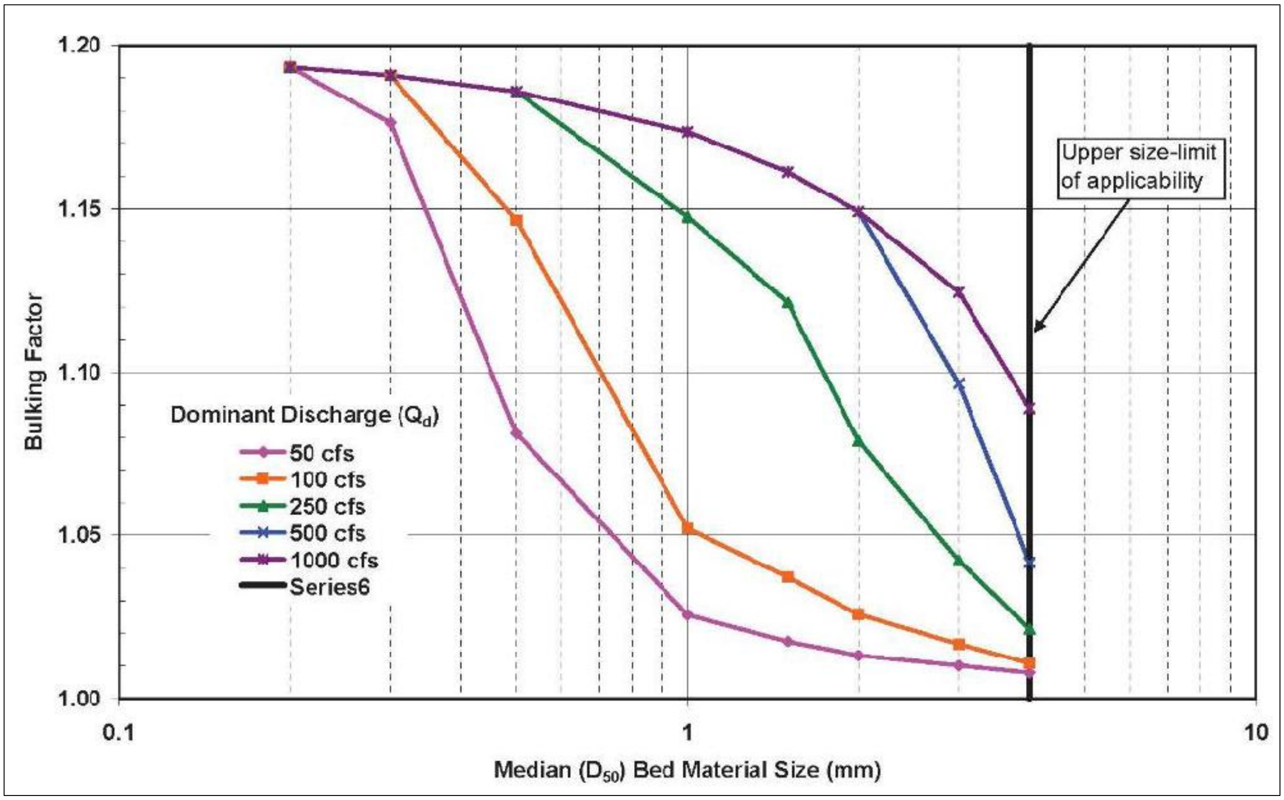
$$Y_{sm} = 0.055 Y_{s_{100}} + 0.245 Y_{s_{10}} + 0.45 Y_{s_2} \qquad (3.28)$$



Source: SSCAFCA, November 2008, “Sediment and Erosion Design Guide”, p. 3.28.
http://sscafca.org/development/documents/sediment_design_guide/Sediment%20Design%20Guide%2012-30-08.pdf

Figure 402-17 Annual Sediment Yield and Dominant Discharge

The assumed width-depth ratio (F_D) of 40 is based on data from a variety of existing, naturally adjusted arroyos (Leopold and Miller, 1956; Harvey et al., 1985). The assumption of critical flow is based on the observation that average Froude numbers (F_r) in stable sand-bed streams rarely exceed 0.7 to 1.0 (Richardson, personal communication) at high discharges. It should also be noted that current FEMA procedures for evaluating hydraulic conditions on alluvial fans is based on the assumption of critical flow (F_r = 1). Based on analysis of a wide range of arroyos in the greater Rio Rancho and Albuquerque area, the dominant discharge typically has a recurrence interval in the range of 5 to 10 years under relatively undeveloped conditions and decreases to 3 to 5 years under highly developed conditions due, primarily, to the increase in runoff during frequently occurring storms. The peak discharge associated with other recurrence interval flows was estimated using average ratios for conditions in the greater Rio Rancho and Albuquerque area. The 100-year peak discharge, for example, averages about five times the dominant discharge. Bulking factors estimated using the above assumptions for the 100-year peak are shown in **Figure 402-18** for channels with dominant discharge ranging from 50 to 1,000 cfs and median (D_{50}) bed-material sizes ranging from 0.5 to 4 mm. As shown in that figure, the bulking factors range from about 1.01 for small arroyos (W_d< = 50 cfs) with relatively coarse bed material (D_{50} = 4 mm) to a maximum of 1.19 for larger channels (Q_D> = 500 cfs) and relatively fine bed material (D_{50}<= 0.5 mm). Estimated bulking factors for other recurrence interval events for the median bed-material sizes are provided in **Figure 402-19**.



Source: SSCAFCA, November 2008, "Sediment and Erosion Design Guide", Figure 3.9, p. 3.25. http://sscafca.org/development/documents/sediment_design_guide/Sediment%20Design%20Guide%2012-30-08.pdf

Figure 402-18 Bulking Factors for the 100-year Peak Discharge for Natural Channels

Table 3.6. Estimated sediment bulking factors for arroyos in the SSCAFCA jurisdictional area.

Recurrence Interval (yrs)	Dominant Discharge (cfs)				
	50	100	250	500	1,000
D_{50} (mm) = 0.5 mm					
2	1.01	1.01	1.01	1.01	1.02
5	1.02	1.02	1.05	1.08	1.14
10	1.03	1.05	1.10	1.19	1.19
25	1.05	1.09	1.19	1.19	1.19
50	1.07	1.12	1.19	1.19	1.19
100	1.08	1.15	1.19	1.19	1.19
D_{50} (mm) = 1.0 mm					
2	1.01	1.01	1.01	1.01	1.01
5	1.01	1.01	1.01	1.03	1.05
10	1.01	1.01	1.03	1.07	1.16
25	1.02	1.03	1.08	1.17	1.17
50	1.02	1.04	1.12	1.17	1.17
100	1.03	1.05	1.15	1.17	1.17
D_{50} (mm) = 1.5 mm					
2	1.01	1.01	1.01	1.01	1.01
5	1.01	1.01	1.01	1.02	1.04
10	1.01	1.01	1.02	1.05	1.13
25	1.01	1.02	1.06	1.14	1.16
50	1.01	1.03	1.09	1.16	1.16
100	1.02	1.04	1.12	1.16	1.16
D_{50} (mm) = 2.0 mm					
2	1.01	1.01	1.01	1.01	1.01
5	1.01	1.01	1.01	1.01	1.03
10	1.01	1.01	1.02	1.04	1.08
25	1.01	1.01	1.04	1.09	1.15
50	1.01	1.02	1.06	1.15	1.15
100	1.01	1.03	1.08	1.15	1.15
D_{50} (mm) = 3.0 mm					
2	1.01	1.01	1.01	1.01	1.01
5	1.01	1.01	1.01	1.01	1.02
10	1.01	1.01	1.01	1.02	1.04
25	1.01	1.01	1.02	1.05	1.11
50	1.01	1.01	1.03	1.07	1.12
100	1.01	1.02	1.04	1.10	1.12
D_{50} (mm) = 4.0 mm					
2	1.01	1.01	1.01	1.01	1.01
5	1.01	1.01	1.01	1.01	1.01
10	1.01	1.01	1.01	1.02	1.03
25	1.01	1.01	1.02	1.03	1.06
50	1.01	1.01	1.02	1.04	1.10
100	1.01	1.01	1.03	1.06	1.10

Source: SSCAFCA, November 2008, "Sediment and Erosion Design Guide", Table 3.6, p. 3.26.
http://sscafca.org/development/documents/sediment_design_guide/Sediment%20Design%20Guide%2012-30-08.pdf

Figure 402-19 Estimated Bulking Factors

402.11.2 New Mexico Institute of Mining and Technology

The NMDOT previously contracted with New Mexico Institute of Mining and Technology (NMIMT) to study the sediment bulking issue in New Mexico streams and arroyos. The resulting study report "Development of Watercourse Aggradation/Degradation Risk Index for New Mexico," May 2013, may be acquired from the NMDOT website at: http://dot.state.nm.us/content/dam/nmdot/Research/NM10DSN-01_Final_Report_Aggredation_Risk_with_Impl.pdf

The NMIMT report provides estimates for sediment bulking factors and risk maps for selected New Mexico Watersheds and for each of the NMDOT Maintenance Districts. **Figure 402-20** and **Figure 402-21** are examples of the maps found in this report. The NMIMT figures illustrate bulking factors up to 1.50 for some areas. Note that a sediment bulking factor greater than about 1.25 would be considered mud flow based on the reference presented in the previous Section.

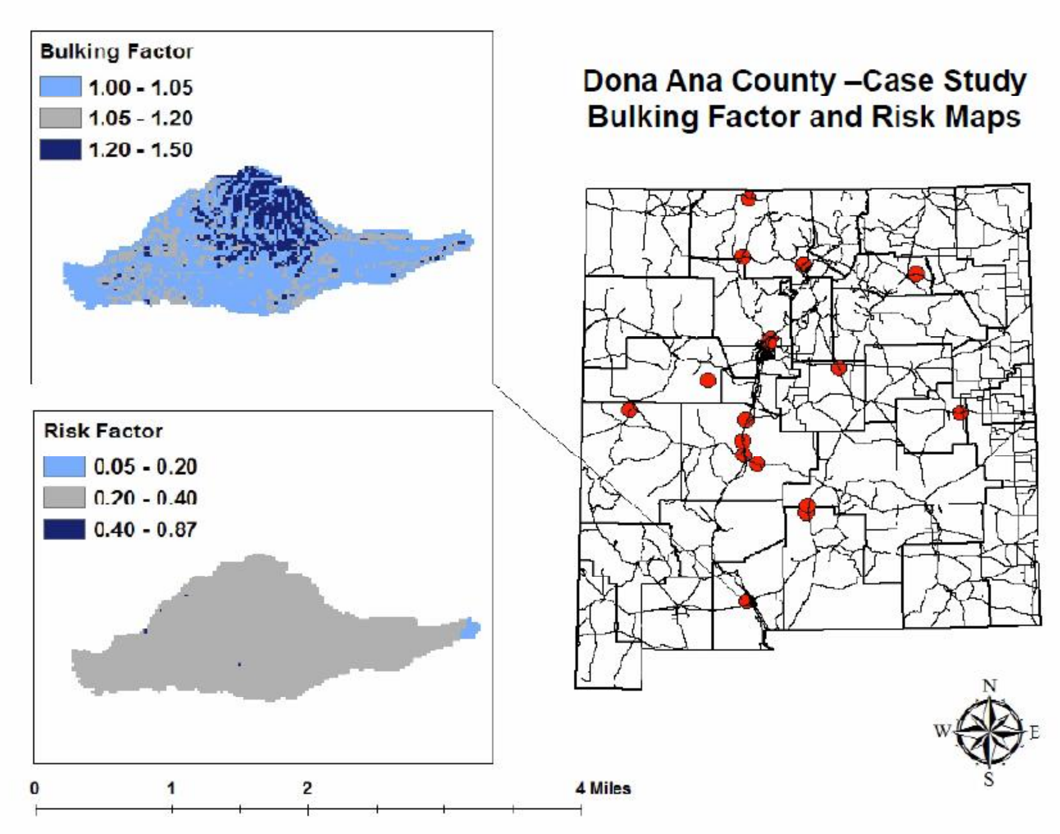


FIGURE 50: Bulking Factor and Risk Maps for Dona Ana County.

Source: New Mexico Institute of Mining and Technology, May 2013,
Development of Watercourse Aggradation/Degradation Risk Index for New Mexico

Figure 402-20 Bulking and Risk Map Example

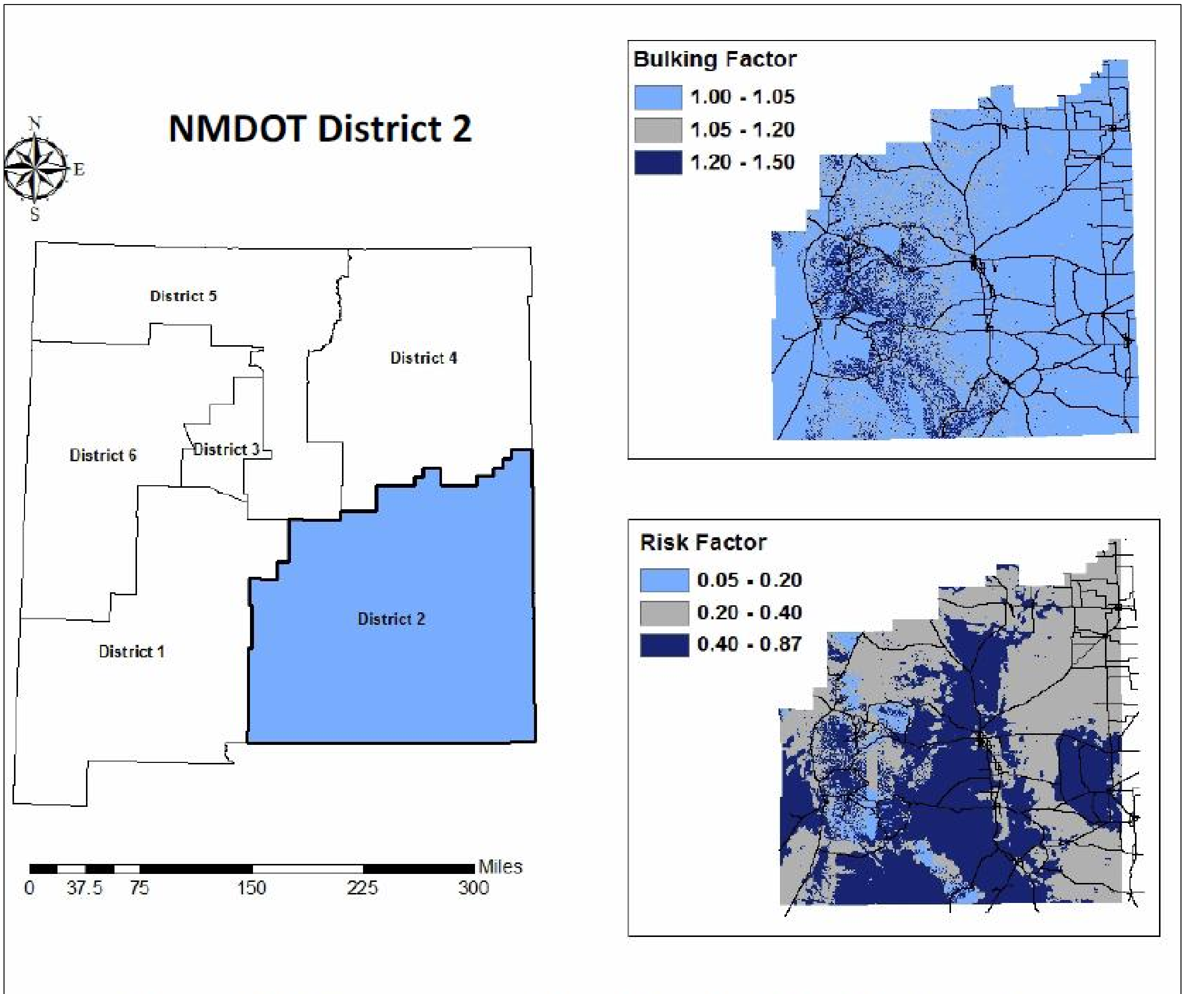


FIGURE 53: Bulking Factor and Risk Maps for NMDOT District 2.

Source: New Mexico Institute of Mining and Technology, May 2013,
Development of Watercourse Aggradation/Degradation Risk Index for New Mexico

Figure 402-21 District Bulking Factor and Risk Map Example

402.11.3 Guidance on Sediment Bulking Factor Selection

Sediment bulking factor selection is subjective and is driven by the basin land use type and condition, and also by the drainage conveyance system type and condition. General guidance, questions and items to consider that contribute or not, to bulking factor selection follow.

- Is the basin 100% urbanized without any exposed soil areas or landscape areas that will general sediment? If so, this would imply a bulking factor of 1.0 (no sediment load) from the basin surface. However, then the drainage conveyance system must also be evaluated.
- If the basin is 100% urbanized, does the drainage conveyance system consist of only storm drains and hard lined channels, or are there also unlined watercourses? A system that is totally lined would imply that no sediment bulking factor would be required (factor

of 1.0). However, if the urbanized basin contains unlined areas and unlined channels, a sediment bulking factor would be required.

- Mountain forest basins in good condition, with rock channels will generally contribute very minor sediment loads. However, if the land has been overgrazed, damaged by logging operations, damaged by recreational vehicular traffic and related activities, or burned by fire, the sediment yield to the watercourse must be considered and will obviously increase the sediment bulking factor compared to a healthy forest.
- Rangeland basins in good condition will contribute minor sediment loads, and rangelands generally outfall to natural unlined watercourses. The composition of the watercourse must be considered (clays, sands, gravels, cobbles, boulders). A bulking factor will be required for rangeland basins and the magnitude of the factor will depend on the basin and watercourse conditions. However, if the land has been overgrazed, damaged by logging operations, damaged by recreational vehicular traffic and related activities, or burned by fire, excess sediment yield to the watercourse must be considered and will obviously increase the sediment bulking factor compared to a healthy rangeland.

402.12 Rain on Snow

Snowmelt runoff is a major component of the hydrologic cycle in some parts of New Mexico and can be an important consideration for design flood analysis. Heavy rainfall on snow can result in runoff events that are significantly larger than would otherwise result from either the rainfall event or snowmelt event alone. Consult the Drainage Design Bureau when the drainage analysis is in a watershed with the potential for significant snow accumulations. The NRCS provides good guidance in “Part 630 Hydrology, National Engineering Handbook”, Chapter 11 Snowmelt” and in “Chapter 18, Selected Statistical Methods”.

402.13 Fire Related Impacts

Increased risk of severe wildfires has become increasingly frequent in New Mexico and the Western U.S. and are currently an area of intense study by a variety of Federal and State agencies. Much literature has been produced in recent years due to the number, size, and severity of wildfires in the west in general and in and around New Mexico specifically. While at this time no dependable analysis tools are available for estimating the runoff from a severely burned watershed, it is clear that severe wildfires in a watershed can result in flood flows that are orders of magnitude higher than would have been expected prior to the fire. While it may be unfeasible to design a highway crossing for a flood that is 10 to 100 times larger than would have resulted from the standard design storm, consideration should be given with respect to the potential flood risk after a severe wildfire. NRCS and the U.S. Forest Service are expected to produce planning, analysis, and design documents in the near future addressing this issue. The hope is that these tools will assist in planning for and defending against large post-fire flood events. Consult with the Drainage Design Bureau for guidance when simulating burned watersheds.

In the interim, Ventura County in California has conducted studies, and developed guidance for estimating the impacts of flood flows after a severe wildfire. The study is titled “Sediment/Debris Bulking Factors and Post-Fire Hydrology for Ventura County, Final Report – June 2011”. (A hotlink is not available.)

402.14 References

Easterling, Charles, M., May 2004, “Hatch Site 6 Runoff Methods Revisited”.

Kent, K.M., 1973, “A Method for Estimating Volume and Rate of Runoff in Small Watersheds”, U.S. Department of Agriculture, Soil Conservation Service, SCS-TP-149.

Interagency Technical Reference, 1996 (Rev. ed. 1997 and 1999), “Sampling Vegetation Attributes”.
http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044175.pdf

Mockus, V., 1961, “Watershed Lag”, U.S. Dept. of Agriculture, Soil Conservation Service, ES–1015, Washington, DC.

New Mexico Institute of Mining and Technology, May 2013, “Development of Watercourse Aggradation/Degradation Risk Index for New Mexico”.
http://dot.state.nm.us/content/dam/nmdot/Research/NM10DSN-01_Final_Report_Aggredation_Risk_with_Impl.pdf

NOAA, 1973, “Atlas 2, Vol. IV, New Mexico Precipitation-Frequency Atlas of the Western United States”, U.S. Dept. of Commerce National Oceanic and Atmospheric Administration National Weather Service, Silver Spring MD.

NOAA, Rev. ed. 2011, “Atlas 14, Precipitation-Frequency Atlas of the United States Volume 1 Version 5.0”.
http://www.nws.noaa.gov/oh/hdsc/PF_documents/Atlas14_Volume1.pdf

NOAA Hydrometeorological Design Studies Center Precipitation Frequency Data Server (PFDS).
http://hdsc.nws.noaa.gov/hdsc/pfds/

NRCS Web Soil Survey Website.
https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

NRCS, June 1986, “TR-55, Urban Hydrology for Small Watersheds”.
https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044171.pdf

NRCS, “Part 630 Hydrology, National Engineering Handbook”. Note that various Chapters have different dates.
https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/manage/hydrology/?cid=stelprdb1043063

NRCS, 1997, “Part 630 Hydrology, National Engineering Handbook, Chapter 1 Introduction”.
http://www.wcc.nrcs.usda.gov/ftpref/wntsc/H&H/NEHhydrology/ch1.pdf

NRCS, 2002, “Part 630 Hydrology, National Engineering Handbook, Chapter 8 Land Use and Treatment Classes”.
https://directives.sc.egov.usda.gov/viewerFS.aspx?hid=21422

NRCS, 2004, "Part 630 Hydrology, National Engineering Handbook, Chapter 9 Hydrologic Soil-Cover Complexes".
http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17758.wba

NRCS, 2004, "Part 630 Hydrology, National Engineering Handbook, Chapter 10 Estimation of Direct Runoff from Storm Rainfall".
https://directives.sc.egov.usda.gov/17752.wba

NRCS, 2004, "Part 630 Hydrology, National Engineering Handbook, Chapter 11 Snowmelt".
http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17753.wba

NRCS, 2007, "Part 630 Hydrology, National Engineering Handbook, Chapter 16 Hydrographs".
http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17755.wba

NRCS, 2009, "Part 630 Hydrology, National Engineering Handbook, Chapter 7 Hydrologic Soils Groups".
http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=22526.wba

NRCS, 2010, "Part 630 Hydrology, National Engineering Handbook, Chapter 15 Time of Concentration".
http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=27002.wba

NRCS, 2012, "Part 630 Hydrology, National Engineering Handbook, Chapter 18 Selected Statistical Methods".
http://www.wcc.nrcs.usda.gov/ftpref/wntsc/H&H/NEHhydrology/ch18.pdf

Roussel, M.C., Asquith, W. H., Thompson, D. B., Cleveland, T. G., and Fang, X., 2005, "Summary of Dimensionless Texas Hyetographs and Distribution of Storm Depth, Developed for Texas Department of Transportation Research Project 0-4194", US Geological Survey, Austin, TX. (TxDOT 0-4194-4).
http://library.ctr.utexas.edu/digitized/texasarchive/phase1/4194-4-TxDOT.pdf

Simas, M., 1996, "Lag Time Characteristics in Small Watersheds in the United States", A Dissertation Submitted to School of Renewable Natural Resources, University of Arizona, Tucson, AZ.
http://arizona.openrepository.com/arizona/bitstream/10150/282155/1/azu_td_9713386_sip1_m.pdf

Soil Conservation Service, 1973, revised by Luther McDougal, and Calvin Jackson, 1973, updated by Larry Goertz, February 1985, updated by Roger Ford, 2014, "Peak Rates of Discharge for Small Watersheds, Chapter 2, Engineering Field Manual for Conservation Practices". (Not available on-line, see **APPENDIX 5**).

Southern Sandoval County Arroyo Flood Control Authority (SSCAFCA), 2008, Mussetter Engineering Inc, "Sediment and Erosion Design Guide".
http://sscafca.org/development/documents/sediment_design_guide/Sediment%20Design%20Guide%2012-30-08.pdf

TxDOT, July 2016, “Hydraulic Design Manual,” Chapter 4, Section 11.
http://onlinemanuals.txdot.gov/txdotmanuals/hyd/index.htm

University of New Mexico, New Mexico Resource Geographic Information System (RGIS).
http://rgis.unm.edu/getdata/#.

Ventura County, June 2011, “Sediment/Debris Bulking Factors and Post-Fire Hydrology for Ventura County, Final Report”. A hotlink is not available.

403 Rational Formula Method

Hydrologic analyses performed on small (<160 acre) watersheds will normally be performed using the Rational Formula Method. The Rational Formula Method is a widely and long accepted procedure worldwide for estimating peak rates of runoff from small watersheds. The Rational Formula Method may be used on NMDOT projects for roadway drainage facilities and small drainage structures as described in **Section 401** (**Figure 401-1** and **Figure 401-2**) of this manual. The standard form of the Rational Formula Equation in English units is:

$$Q = C\,i\,A \qquad \textbf{403-1}$$

where:

Q	=	the peak rate of runoff, cfs
C	=	Runoff Coefficient
i	=	the rainfall intensity, in./hr
A	=	the watershed or drainage area, acres

The units in the Rational Formula do not yield peak discharge in cubic feet per second (cfs) directly, but rather are in acre-inches/hour. However, the conversion from acre-inches/hour to cfs is 1.008 which is commonly neglected because it does not introduce a significant error. The Rational Formula has several assumptions implicit to the method, including:

- The rainfall intensity is uniform for a duration equal to or greater than Tc
- Peak flow occurs when the entire watershed is contributing runoff
- The frequency of the resulting peak discharge is equal to the frequency of the rainfall event.
- Both the Runoff Coefficient (C) and the rainfall intensity (i) vary with the return period (both tend to increase as return period increases). Therefore, both must be determined separately for each design storm frequency.
- The Runoff Coefficient (C) is dependent on the Hydrologic Soil Group (HSG) and the vegetative cover or in the case of developed watersheds, the percentage of impervious cover. HSGs are divided into four soil groups and are described in **Section 402.4.**

Limitations for using the Rational Formula Method on NMDOT projects include the following:

- The total drainage area should not exceed 160 acres
- Land use, slope, and soils are fairly consistent throughout the watershed
- There are no diversions, detention basins, pump stations, or other structures in the watershed which would require the routing of a flood hydrograph
- The Time of Concentration (Tc) does not exceed one hour
- Runoff volumes may not be computed with the Rational Formula Method or Modified Rational Formula Method (not included in this Drainage Design Manual)

403.1 Time of Concentration (Tc) for Use in the Rational Formula Method

The assumptions within the Rational Formula Method are that the rainfall intensity is uniform for a duration equal to or greater than Tc and that the entire watershed is contributing runoff when the peak occurs. Therefore, in order to determine the appropriate rainfall intensity “i” for the watershed, the Tc must be determined. For NMDOT projects, Tc shall be calculated using the Kirpich Equation or Upland Method depending on specific circumstances.

The Upland Method was originally developed by the Soil Conservation Service (SCS), which is now the Natural Resources Conservation Service (NRCS). The Upland Method is described in Chapter 15 Time of Concentration of "Part 630 Hydrology, National Engineering Handbook" (NRCS, 2010). Note that in the current (2010) version of Chapter 15, the NRCS has renamed the "Upland Method" to the "Velocity Method." However, many documents still refer to it as the "Upland Method" and, therefore, the name "Upland Method" is used in this Drainage Design Manual.

The Upland Method is used to estimate travel times for overland flow and shallow concentrated flow conditions. The Upland Method is limited to use in watersheds less than 2000 acres in size, or to the upper reaches of larger watersheds. For NMDOT projects, the Upland Method may be used for computing the Tc when using the Rational Formula Method or the Simplified Peak Discharge Method on an ***un-gullied*** watershed. The use of Upland Method is described in **Section 402.9.1.**

When using the Rational Formula, the Kirpich Equation should be used in watersheds ***when gullying is evident in more than 10% of the primary watercourse***. Gullying can be assumed if a blue line appears on the watercourse shown on the USGS quadrangle topographic map or is apparent from field reconnaissance or from inspection of aerial photography. The Kirpich Equation is given as:

$$Tc = 0.0078\, L^{0.77}\, S^{-0.385} \qquad \textbf{403-2}$$

(TxDOT, July 2016, "Hydraulic Design Manual," Eq. 4-15, p. 4-39)
http://onlinemanuals.txdot.gov/txdotmanuals/hyd/index.htm

where:

Tc	=	Time of Concentration, minutes
L	=	maximum length of water travel, ft
S	=	surface slope, given by H/L, ft/ft
H	=	difference in elevation between the most hydraulically remote point in the drainage basin and the outlet, ft

In small watersheds where the slope is very flat, and the flow path of the hydraulically longest flow path is dominated by overland flow (> 300 ft), the Kerby Equation should be considered for the overland flow portion and Kirpich Equation for the channelized portion.

For small watersheds where overland flow is an important component of overall travel time, the Kerby Equation can be used. The Kerby Equation is:

$$T_{OV} = K\,(L\,N)^{0.467}\, S^{-0.235} \qquad \textbf{403-3}$$

(TxDOT, July 2016, "Hydraulic Design Manual", Eq. 4-14, p. 4-37)
http://onlinemanuals.txdot.gov/txdotmanuals/hyd/index.htm

where:

T_{ov}	=	overland flow Time of Concentration, minutes
K	=	K = 0.828, a unit conversion factor
L	=	the overland-flow length, ft
N	=	a dimensionless retardance coefficient
S	=	the dimensionless slope of terrain conveying the overland flow

In the development of the Kerby Equation, the length of overland flow was as much as 1,200 feet. Hence, this length is considered an upper limit, and in practice, shorter values generally are expected. The dimensionless retardance coefficient used is similar in concept to the well-known Manning's roughness coefficient; however, for a given type of surface, the retardance coefficient for overland flow will be considerably larger than for open-channel flow. Typical values for the retardance coefficient are listed in **Table 402-9**. Roussel et al. (2005), recommends that the user should not interpolate the retardance coefficients shown in **Table 402-9.** If it is determined that a low slope condition or a transitional slope condition exists, the user should consider using an adjusted slope in calculating the Tc.

Time of Concentration with the Kerby-Kirpich Method

When the Kirpich Equation result and the Kerby Equation result are combined, it is referred to as the Kerby-Kirpich Method. The watershed should be divided between the channelized reach and the overland flow reach and the travel time across each reach calculated and combined to compute the total Tc.

- If the calculations (with either Kirpich Equation or with the Kerby Equation) yield a Tc less than 10 minutes, use 10 minutes
- If the resulting Tc is greater than 1 hour, do not use the Rational Formula Method, select another hydrologic analysis method

403.2 Rainfall

When developing Intensity-Duration-Frequency (IDF) curves and Depth-Duration (DD) values for Rational Formula Method from NOAA Precipitation Frequency Data Server (PFDS), the following approach is provided to develop the IDF curves, from which the rainfall intensity "i" is derived for the design frequency storm required.

1. Go to NOAA Precipitation Frequency Data Server (PFDS) http://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=nm
    a. Click on New Mexico on the Map
    b. Data Description – use defaults
    c. Get Location Options
        i. Use navigation tools to either:
            1. Enter latitude and longitude or
            2. Select Station or
            3. Selection Location on map
    d. Data Description
        i. Data Type: Select "precipitation intensity"

   ii. Units: Select “*English*”
   iii. Time series type: Select “***partial duration***”
e. Scroll down to Depth-Duration-Frequency table below map
f. Scroll to bottom of table and in the “Estimates from the table in csv format” box select “***precipitation frequency estimates***”
g. Open in MS Excel and do a “save as” to your workspace as a .txt file
h. Open .txt file (it should open in Excel)
i. Insert Chart into the Excel spreadsheet (see **Table 403-1** example spreadsheet below)
   i. Insert a column adjacent to the durations and fill in with time values (*Excel doesn’t recognize “5-min” as a value*)
   ii. Select X Y Scatter Chart Type
   iii. Select Data with duration (in minutes) on the x axis, intensity (in./hr) on the y axis for each frequency (1-year, 2-year, 5-year, 10-year, 25-year, 50-year, 100-year) as needed for project analyses. (See **Table 403-1**)
j. Format x axis to allow reading duration in 1 minute increments and y axis to read intensity in 0.1 in./hour increments. (See **Figure 403-1**)
k. Read rainfall intensity that matches basin Tc for the storm frequency required.
l. **Minimum Tc = 10 minutes for this purpose!**

Table 403-1 NOAA Data Server Sample IDF Spreadsheet-Lemitar NM

Point precipitation frequency estimates (inches/hour)
NOAA Atlas 14 Volume 1 Version 5
Data type: Precipitation intensity
Time series type: Partial duration
Project area: Southwest
Location name: Lemitar, New Mexico, US*
Station Name: -
Latitude: 34.1580°
Longitude: -106.9181°
Elevation: 4712 ft*
* source: Google Maps

PRECIPITATION FREQUENCY ESTIMATES
by
duration

for ARI:		1	2	5	10	25	50	100	200	500	1000 years
5-min:	5	2.45	3.18	4.26	5.09	6.23	7.1	8.04	9	10.31	11.35
10-min:	10	1.87	2.42	3.24	3.88	4.74	5.41	6.11	6.85	7.84	8.64
15-min:	15	1.54	2	2.68	3.2	3.92	4.46	5.05	5.66	6.48	7.14
30-min:	30	1.04	1.34	1.8	2.16	2.64	3.01	3.4	3.81	4.36	4.81
60-min:	60	0.64	0.83	1.11	1.33	1.63	1.86	2.1	2.36	2.7	2.98
2-hr:		0.37	0.48	0.64	0.76	0.95	1.11	1.29	1.49	1.8	2.06
3-hr:		0.27	0.34	0.45	0.54	0.67	0.78	0.9	1.04	1.25	1.43
6-hr:		0.16	0.2	0.25	0.3	0.36	0.42	0.48	0.55	0.66	0.75
12-hr:		0.08	0.11	0.13	0.16	0.19	0.22	0.25	0.29	0.34	0.38
24-hr:		0.05	0.06	0.08	0.09	0.11	0.12	0.14	0.16	0.18	0.2
2-day:		0.03	0.03	0.04	0.05	0.06	0.07	0.07	0.08	0.1	0.11
3-day:		0.02	0.02	0.03	0.03	0.04	0.05	0.05	0.06	0.07	0.08
4-day:		0.02	0.02	0.02	0.03	0.03	0.04	0.04	0.05	0.05	0.06
7-day:		0.01	0.01	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.04
10-day:		0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.03	0.03
20-day:		0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02
30-day:		0	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
45-day:		0	0	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01
60-day:		0	0	0	0	0.01	0.01	0.01	0.01	0.01	0.01

Date/time (GMT): Fri Nov 13 22:14:03 2015
pyRunTime: 0.127875804901

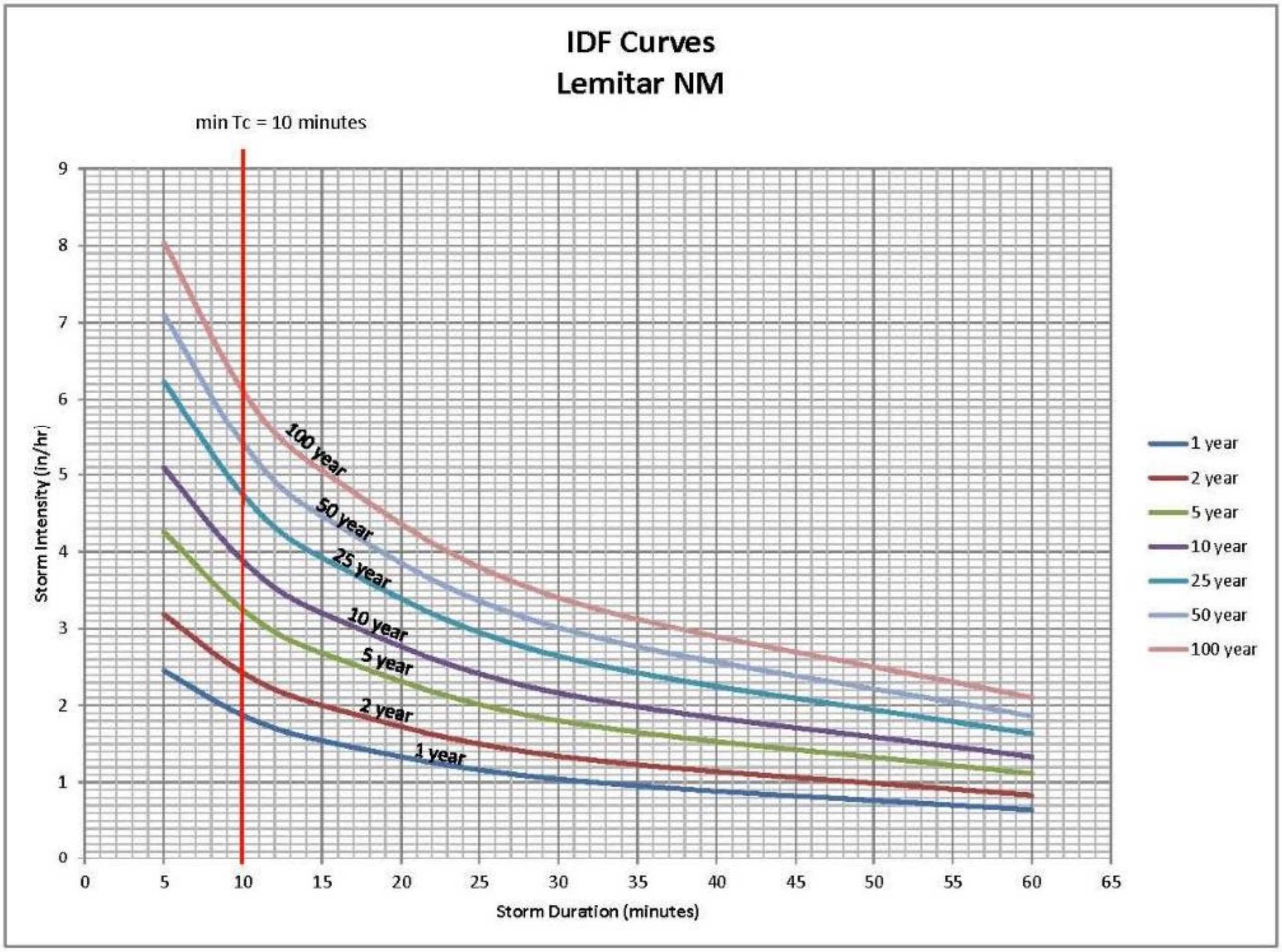


Figure 403-1 IDF Curves from NOAA Data Server-Lemitar, NM

To produce the Depth-Duration 1-hour precipitation values for use in determining the Rational Formula Runoff Coefficient "C", return to the NOAA Data Server for the same location as for the IDF Curve development (see **Table 403-2** from NOAA Data Server) http://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=nm

Table 403-2 Depth-Duration-Frequency Table from NOAA Data Server

http://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=nm

Point precipitation frequency estimates (inches)
NOAA Atlas 14 Volume 1 Version 5
Data type: Precipitation depth
Time series type: Partial duration
Project area: Southwest
Location name: Lemitar, New Mexico, US*
Station Name: -
Latitude: 34.1584°
Longitude: -106.9189°
Elevation: 4713 ft*
* source: Google Maps

PRECIPITATION FREQUENCY ESTIMATES

by duratior	1	2	5	10	25	50	100	200	500	1000 years
5-min:	0.2	0.27	0.35	0.42	0.52	0.59	0.67	0.75	0.86	0.95
10-min:	0.31	0.4	0.54	0.65	0.79	0.9	1.02	1.14	1.31	1.44
15-min:	0.39	0.5	0.67	0.8	0.98	1.12	1.26	1.41	1.62	1.78
30-min:	0.52	0.67	0.9	1.08	1.32	1.5	1.7	1.9	2.18	2.4
60-min:	0.64	0.83	1.11	1.33	1.63	1.86	2.1	2.36	2.7	2.98
2-hr:	0.75	0.96	1.27	1.52	1.9	2.22	2.58	2.98	3.59	4.13
3-hr:	0.81	1.03	1.35	1.61	2	2.33	2.7	3.12	3.75	4.3
6-hr:	0.93	1.18	1.51	1.78	2.18	2.52	2.9	3.31	3.93	4.48
12-hr:	1.01	1.28	1.63	1.91	2.31	2.65	3.03	3.44	4.06	4.59
24-hr:	1.16	1.45	1.82	2.12	2.55	2.9	3.29	3.72	4.35	4.88
2-day:	1.27	1.59	1.98	2.3	2.76	3.13	3.54	3.99	4.64	5.2
3-day:	1.36	1.7	2.12	2.46	2.94	3.34	3.78	4.25	4.95	5.55
4-day:	1.45	1.81	2.25	2.61	3.12	3.55	4.01	4.51	5.25	5.89
7-day:	1.67	2.08	2.57	2.96	3.52	3.97	4.46	4.99	5.77	6.41
10-day:	1.84	2.3	2.84	3.29	3.91	4.41	4.96	5.56	6.43	7.17
20-day:	2.33	2.9	3.54	4.03	4.71	5.25	5.81	6.39	7.2	7.89
30-day:	2.81	3.5	4.23	4.78	5.53	6.11	6.7	7.3	8.12	8.81
45-day:	3.41	4.23	5.08	5.7	6.51	7.12	7.71	8.29	9.11	9.78
60-day:	3.9	4.84	5.8	6.52	7.44	8.13	8.81	9.47	10.33	10.98

Date/time (GMT): Mon Nov 16 19:12:46 2015
pyRunTime: 0.126244068146

Procedure:

1. Data Description
   a. Data Type: Select "***precipitation depth***"
   b. Units: Select "***english***"
   c. Time series type: Select "***partial duration***"
2. Scroll down to Depth-Duration-Frequency table below map
3. Scroll to bottom of table and in the "Estimates from the table in csv format" box select "***precipitation frequency estimates***"
4. Open in MS Excel and do a "save as" to your workspace as a .txt file
5. Open .txt file (it should open in Excel) **Table 403-2**
6. Read point rainfall value for 1-hour design storm

403.3 Rational Formula Runoff Coefficient "C"

The Rational Formula Runoff Coefficient, "C" should be selected from **Figure 403-2** to **Figure 403-7** depending on the ground cover, Hydrologic Soil Group, type of development, and 1-hour rainfall depth for the design return period. The Runoff Coefficient "C" figures are adopted from the Arizona DOT Drainage Design Manual due to the similarities in climate, soils, vegetation and terrain between Arizona and New Mexico.

http://www.azdot.gov/docs/default-source/roadway-engineering-library/2014_adot_hydrology_manual.pdf?sfvrsn=16

Hydrologic Soil Groups are defined in **Section 402.4**. **Figure 403-2** to **Figure 403-7** show how "C" varies with 1-hour rainfall depth. This is because "C" is a function of infiltration and other hydrologic abstractions, relating the peak discharge to the theoretical peak discharge produced by 100% runoff.

Engineers are encouraged to review the supporting information provided in the Arizona manual before using these figures in order to familiarize themselves with their limitations and assumptions. When land use or other factors vary significantly throughout the watershed, an area weighted "C" value should be used. The weighted "C'" value is computed by the equation:

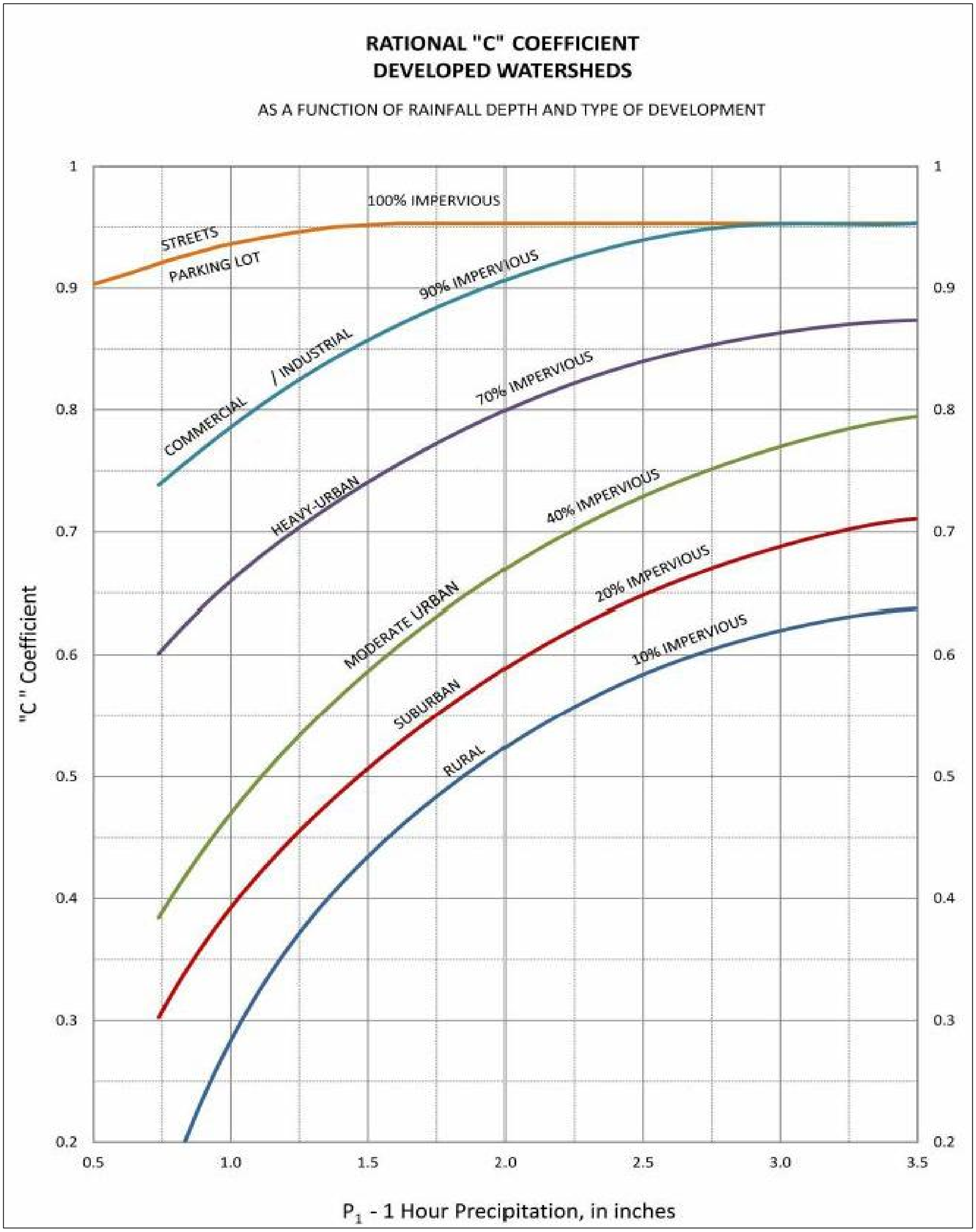
$$\text{Weighted C} = \frac{C1\ A1 + C2\ A2 + C3\ A3\ldots}{\sum A} \qquad \textbf{403-4}$$

(Arizona Department of Transportation, 2014, "Highway Drainage Design Manual, Volume 2, Hydrology, Second Edition", Eq. 2.5, p. 2-7)
http://www.azdot.gov/docs/default-source/roadway-engineering-library/2014_adot_hydrology_manual.pdf?sfvrsn=16

where:

C1	=	"C" Runoff Coefficient for subbasin(s) 1, etc.
A1	=	area of subbasin(s) 1, etc., acres
$\sum A$	=	total basin area, acres

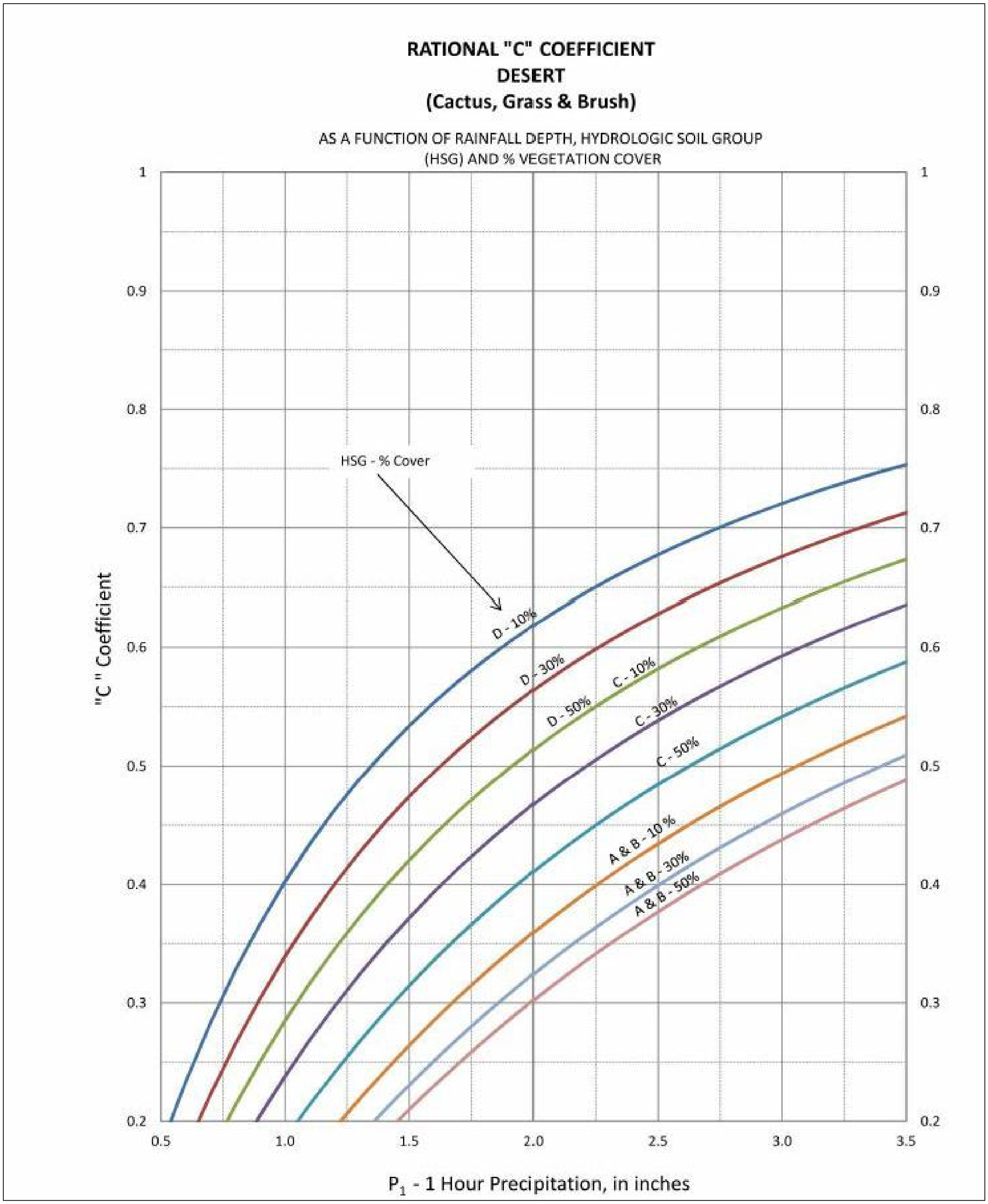
The designer should select the appropriate **Figure 403-2** to **Figure 403-7,** depending on the watershed location (desert, upland range, mountain or urban) and the predominant vegetation type (cactus, brush, grasses, juniper, pine). Enter the appropriate Figure with the design 1-hour rainfall depth. Move vertically up through the Figure until the appropriate curve is found, then move horizontally to find the design "C" value. The appropriate curve is selected based on the Hydrologic Soil Group (HSG) and the percent ground cover of the vegetation or percent imperviousness. When a value falls between two curves, interpolate linearly between the two nearest curves to the required percentage of cover or imperviousness.



Source: Arizona Department of Transportation, 2014, “Highway Drainage Design Manual, Volume 2, Hydrology, Second Edition”, Figure 2-1, p. 2-8.

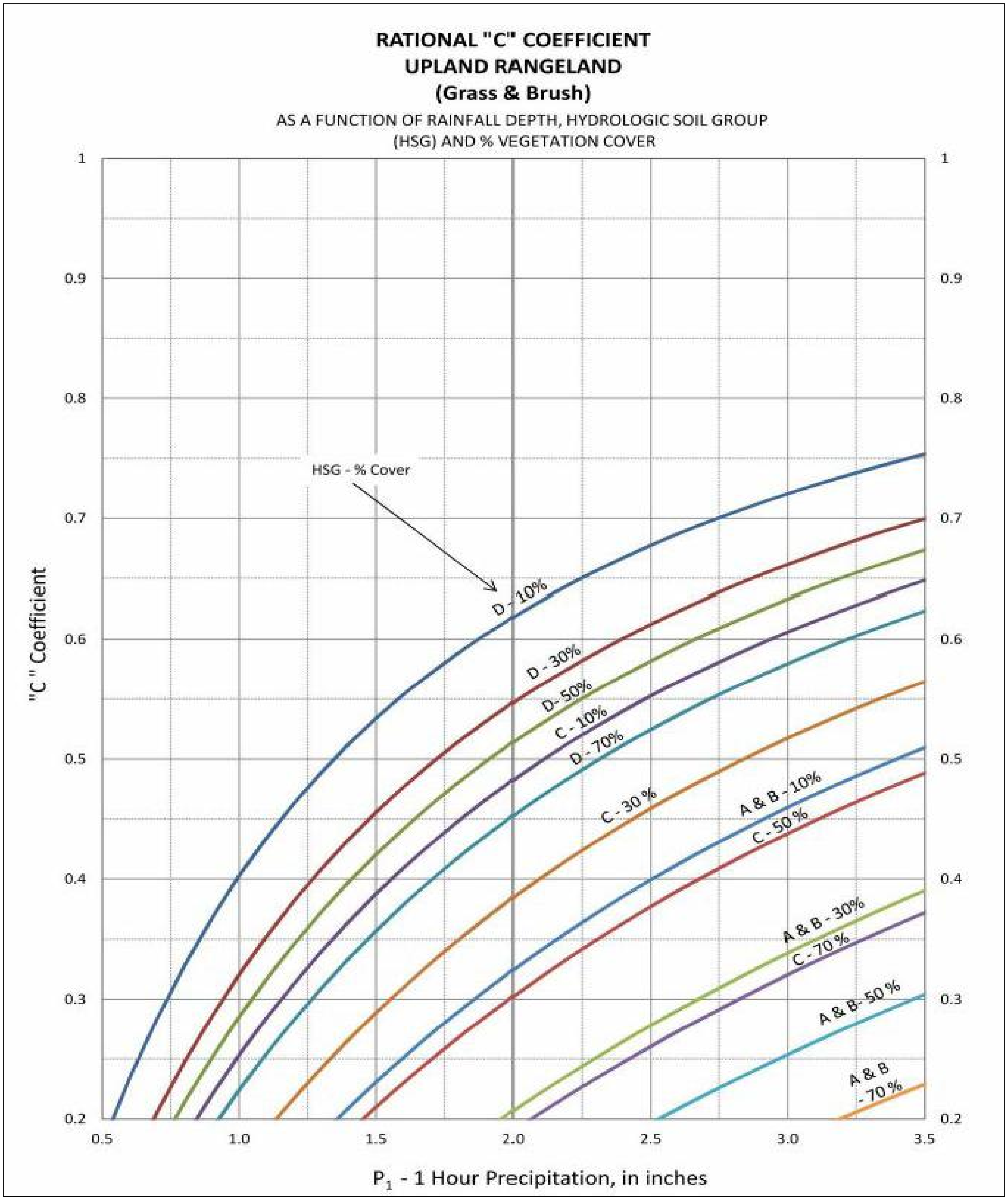
http://www.azdot.gov/docs/default-source/roadway-engineering-library/2014_adot_hydrology_manual.pdf?sfvrsn=16

Figure 403-2 Rational “C” Coefficient Developed Watersheds



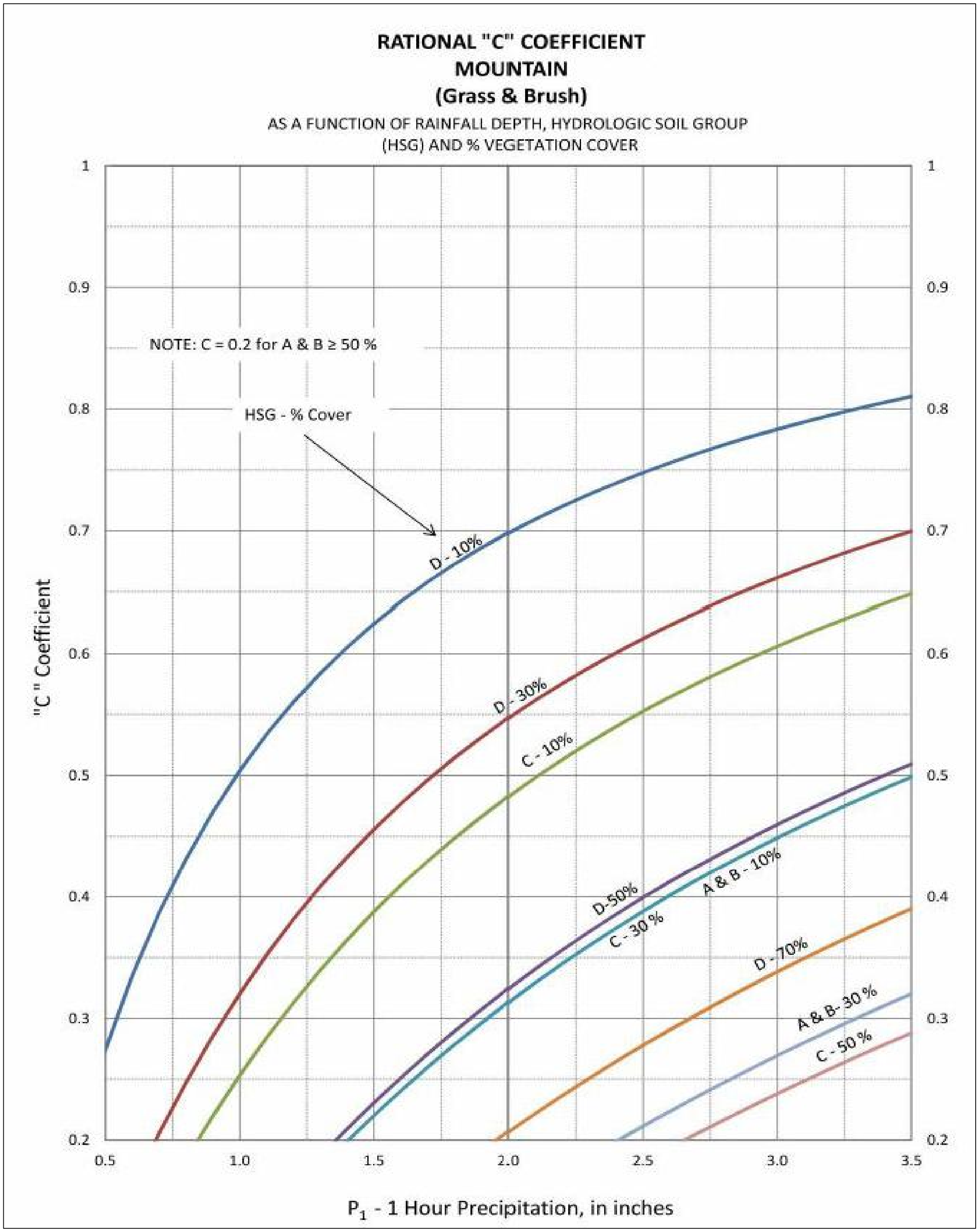
Source: Arizona Department of Transportation, 2014, “Highway Drainage Design Manual, Volume 2, Hydrology, Second Edition”, Figure 2-2, p. 2-9. http://www.azdot.gov/docs/default-source/roadway-engineering-library/2014_adot_hydrology_manual.pdf?sfvrsn=16

Figure 403-3 Rational “C” Coefficient Desert (Cactus, Grass & Brush)



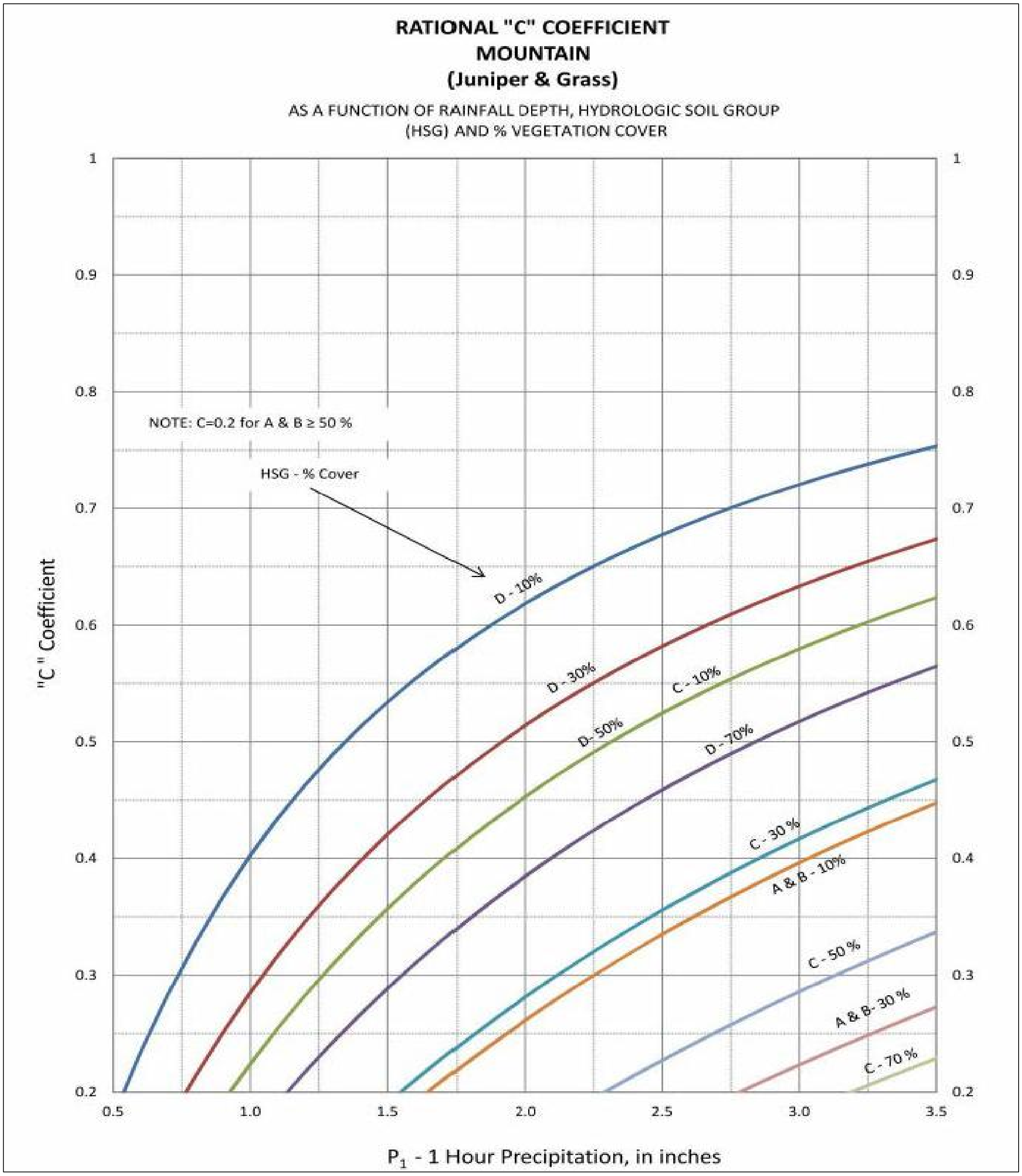
Source: Arizona Department of Transportation, 2014, "Highway Drainage Design Manual, Volume 2, Hydrology, Second Edition", Figure 2-3, p. 2-10. http://www.azdot.gov/docs/default-source/roadway-engineering-library/2014_adot_hydrology_manual.pdf?sfvrsn=16

Figure 403-4 Rational "C" Coefficient Upland Rangeland (Grass & Brush)



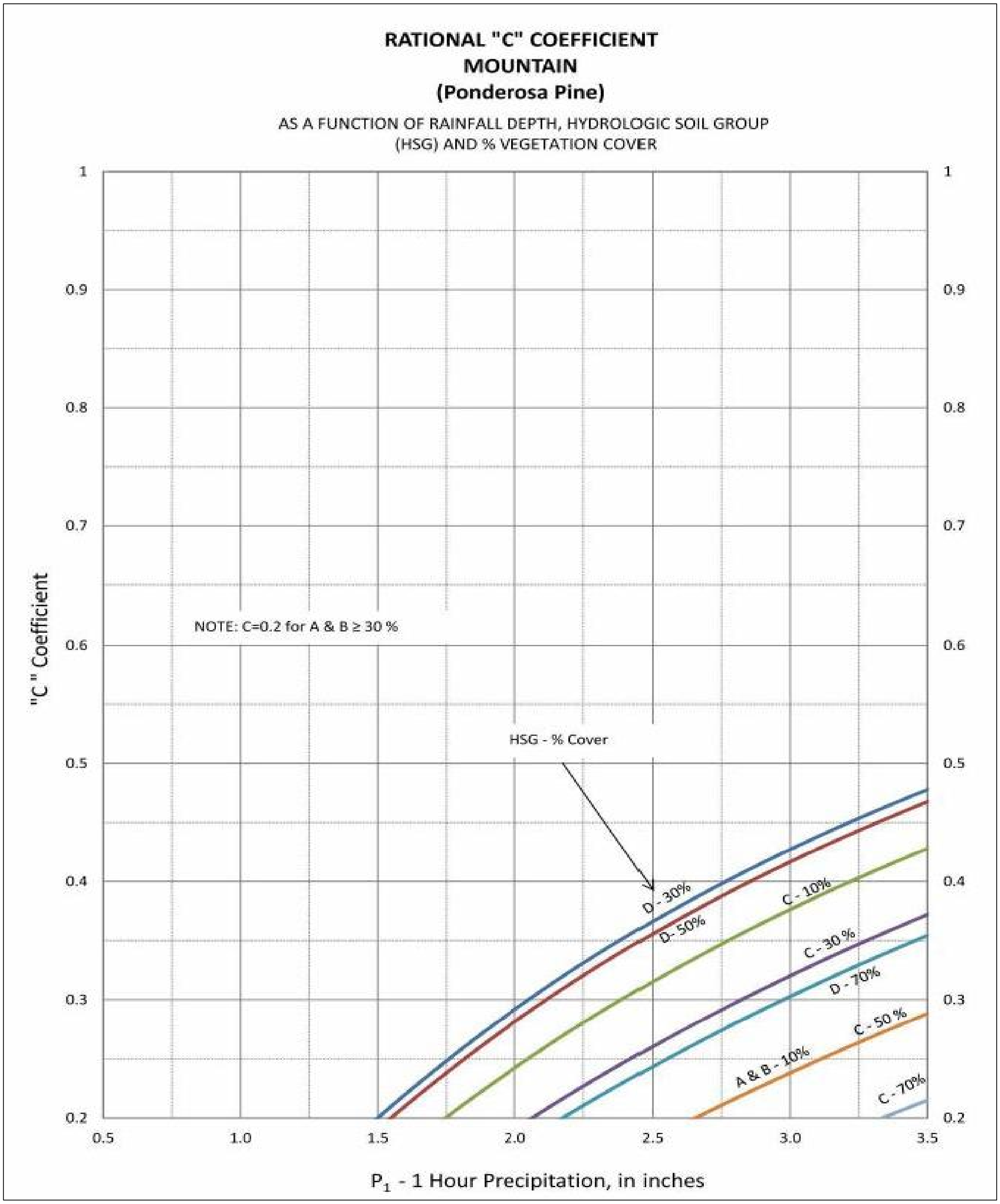
Source: Arizona Department of Transportation, 2014, "Highway Drainage Design Manual, Volume 2, Hydrology, Second Edition", Figure 2-4, p. 2-11. http://www.azdot.gov/docs/default-source/roadway-engineering-library/2014_adot_hydrology_manual.pdf?sfvrsn=16

Figure 403-5 Rational "C" Coefficient Mountain (Grass and Brush)



Source: Arizona Department of Transportation, 2014, "Highway Drainage Design Manual, Volume 2, Hydrology, Second Edition", Figure 2-5, p. 2-12. http://www.azdot.gov/docs/default-source/roadway-engineering-library/2014_adot_hydrology_manual.pdf?sfvrsn=16

Figure 403-6 Rational "C" Coefficient Mountain (Pinion, Juniper & Grass)



Source: Arizona Department of Transportation, 2014, “Highway Drainage Design Manual, Volume 2, Hydrology, Second Edition”, Figure 2-6, p. 2-13.
http://www.azdot.gov/docs/default-source/roadway-engineering-library/2014_adot_hydrology_manual.pdf?sfvrsn=16

Figure 403-7 Rational “C” Coefficient Mountain (Ponderosa)

Appendix 6 contains **Example Problem 6-1** and **Example Problem 6-2.**

Example Problem 6-1 and is a smaller site (34 acres) with 55% imperviousness located in central New Mexico. **Example Problem 6-2** is larger site (80 acres) with a more natural basin the demonstrates an area weighted Runoff Coefficient "C" calculation.

403.4 References

Arizona Department of Transportation, 2014, "Highway Drainage Design Manual, Volume 2, Hydrology, Second Edition".
http://www.azdot.gov/docs/default-source/roadway-engineering-library/2014_adot_hydrology_manual.pdf?sfvrsn=16

NOAA Hydrometeorological Design Studies Center Precipitation Frequency Data Server. (PFDS).
http://hdsc.nws.noaa.gov/hdsc/pfds/

NRCS, "Part 630 Hydrology, National Engineering Handbook". Note that various Chapters have different dates.
https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/manage/hydrology/?cid=stelprdb1043063

NRCS, 2010, "Part 630 Hydrology, National Engineering Handbook, Chapter 15 Time of Concentration".
http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=27002.wba

Roussel, M.C., Asquith, W. H., Thompson, D. B., Cleveland, T. G., and Fang, X., 2005, "Summary of Dimensionless Texas Hyetographs and Distribution of Storm Depth, Developed for Texas Department of Transportation Research Project 0-4194", U.S. Geological Survey, Austin, TX. (TxDOT 0-4194-4).
http://library.ctr.utexas.edu/digitized/texasarchive/phase1/4194-4-TxDOT.pdf

TxDOT, July 2016, "Hydraulic Design Manual," Chapter 4, Section 11.
http://onlinemanuals.txdot.gov/txdotmanuals/hyd/index.htm

404 NRCS Simplified Peak Discharge Method

404.1 General

The NRCS Simplified Peak Discharge Method estimates the peak rate of runoff and runoff volume from small to medium size watersheds (≤ 10 square miles). This method was developed by the Soil Conservation Service (now the NRCS) for use in New Mexico, and was originally developed in October 1973. This document was revised in 1985 titled "Peak Rates of Discharge for Small Watersheds, Chapter 2, Engineering Field Manual for Conservation Practices", SCS, February 1985. **APPENDIX 5** contains a copy that document. In April 2014, Supplemental Notice No. NM-36 was developed as a modification to the 1985 document. NM-36 only prescribed to replace the previous document (1985) rainfall data with NOAA Atlas 14 rainfall data.

The original Chapter 2 method (SCS, 1973) included unit peak discharge curves for different rainfall distributions, varying from 45% to 85% of the rainfall occurring in the peak hour.

After analysis of stream gage data, the 1985 update included only one peak discharge curve, representing a variable rainfall distribution depending on the Tc of the watershed. This curve is shown in **Figure 404-1**. Therefore, a separate estimate of rainfall distribution is not required to use this method. The analysis of gage data also showed that the method overestimated peak discharges at elevations above 7500 ft. Drainage structures above this elevation should be evaluated by the Unit Hydrograph Method (**Section 405**). The completion of the "Simplified Peak Discharge Method Worksheet" (**Figure 404-2**) is required when using this method. The NOAA Atlas 14 references and links are provided here.

NOAA, Rev. ed. 2011, "Atlas 14, Precipitation-Frequency Atlas of the United States Volume 1 Version 5.0".
http://www.nws.noaa.gov/oh/hdsc/PF_documents/Atlas14_Volume1.pdf

Precipitation Frequency Data Server (PFDS):
http://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=nm

The use of the PFDS is preferred due to the accuracy with which point rainfall amounts may be determined using the digital map based tools.

Infiltration and other losses are estimated using the NRCS Curve Number (CN) methodology. Input parameters are consistent with those used in the NRCS Unit Hydrograph Method. The Simplified Peak Discharge Method is limited for NMDOT use to single basins less than 10 square miles in area and should not be used when Tc exceeds 10.0 hours. When Tc is less than 10 minutes, use 10 minutes. This method may be used on NMDOT projects for those conditions identified in **Section 401** (**Figure 401-1** and **Figure 401-2**) of this manual. This method should not be used for watersheds with perennial streamflow. In the case of perennial streams, use the method described in **Section 406** if a stream gage exists, or the method described in **Section 405**, and include base flow.

The NMDOT Drainage Design Bureau can be contacted to obtain a copy of a spreadsheet used to calculate flows via the SCS/NRCS Simplified Peak Discharge Method. Note that the

Engineer/Consultant is responsible for understanding the use of, and the accuracy of the results from this spreadsheet.

404.2 Limitations

The NRCS Simplified Peak Discharge Method limitations are as follows:

- Do not use on watersheds larger than 10 square miles
- Do not use when more than 30% of the drainage area is urban
- Do not use when more than 30% of the watershed is above 7500 feet in elevation
- Do not use a Tc of less than 10 minutes (0.16 hours) or greater than 10 hours
- Do not use on watersheds with perennial streams
- Do not use on areas impacted by significant snowmelt or recently impacted by severe wildfire

404.3 Factors Affecting Runoff

Precipitation is the source of runoff from small watersheds. The soils and vegetation of the watershed affect the amount of precipitation that runs off. Mechanical treatment on a watershed, along with its topography and shape, also affect the rate at which water runs off. Runoff Curve Numbers (CNs) represent the combined effect of soil, vegetative cover, and conservation practices in runoff determinations. Transmission or channel losses in sand and gravel bed channels can also significantly affect the volume and peak discharge arriving at the point of interest in a watershed.

NRCS, 2007, Part 630 National Engineering Handbook, Chapter 19, Transmission Losses, provides guidance for calculating the impacts of these losses on the flood hydrograph. If the engineer believes that transmission losses have a significant impact on flows in the basin, the analysis should not be performed using the Simplified Peak Discharge Method, but rather the Unit Hydrograph Method in HEC-HMS (**Section 405**).

404.4 Precipitation

The highest rates of runoff from small watersheds are usually caused by intense rainfall. The intensity of rainfall affects the rate of runoff more than it does the volume of runoff. Intense rainstorms that produce high rates of runoff in small watersheds usually do not extend over a large area. The same intense rainstorm that causes flooding in a small tributary is not likely to be the one that will cause major flooding in a main watercourse that drains many square miles. Data from recording rain gages were studied to determine an appropriate rainfall distribution for New Mexico. Generally, New Mexico has more intense, shorter duration rainfalls than other parts of the U.S.

The melting of accumulated snow in the mountains may result in a greater volume of runoff, but usually at a lesser rate than runoff caused by rainfall. The melting of a winter’s snow accumulation over a large area may cause major flooding along rivers.

The Simplified Peak Discharge Method requires the 24-hour total precipitation depth, and the method is applicable to the 100-yr storm and all more frequent recurrence interval storms.

Obtain the 24-hour rainfall depth directly from the NOAA Precipitation Frequency Data Server (PFDS) as described in **Section 403.2**. For NMDOT projects, there is no reduction factor for partial series versus annual series applied to 2-year, 5-year, and 10-year rainfall depths. This represents a slight departure from the original NRCS Method (NRCS, 1985-2014) and adds a small percentage of safety factor for the more frequent return period events.

The time distribution of rainfall is built into the Simplified Peak Discharge Method. This statewide rainfall distribution varies from 45% to over 85% of the 24-hour rainfall occurring in the peak hour of the storm as the Time of Concentration (Tc) varies from 10 minutes to 10 hours.

For NMDOT drainage design, find the 24-hour rainfall depth from the NOAA Precipitation Frequency Data Server for the centroid of each watershed.

404.5 Antecedent Runoff Condition

The amount of precipitation occurring in the five days preceding the storm in question is an indication of the Antecedent Runoff Condition (ARC) of the soil. The CNs in **Table 402-2** to **Table 402-5** are for an average ARC II. Watersheds in New Mexico most often meet an ARC I or ARC II condition. NRCS has over 60 years of experience in the sizing of flood control dams around New Mexico using ARC II as the design condition. Experience has shown that the use of ARC II is conservative in that as it has been extremely rare for the emergency spillway on one of their dams to flow (a majority of these dams were designed for the 25-year or 50-year flood event). ARC III provides a very conservative assumption and generates significantly larger peak discharges and runoff volumes than ARC II for the same Curve Number and is typically not the case for most watersheds in New Mexico. Therefore, **use ARC II for NMDOT projects.**

404.6 Hydrologic Soil Groups

The texture, composition and density of soils have a direct impact on the amount and rate at which rainfall becomes runoff, and therefore, the soil type is a critical piece of information in the development of rainfall/runoff calculations. In general, soils are classified as sandy, silty, loamy or clayey. In nature, there can be an infinite number of combinations of these characteristics. The NRCS has divided the extremely wide range of soil textures by their hydrologic (runoff producing) characteristics into four Hydrologic Soils Groups: Type A, B, C and D. Type A soils are generally sandy soils and low runoff producers and Type D are clayey soils and high producers of runoff for a given rainfall volume. Types B and C soils runoff characteristics are subdivisions within the range of A to D.

Information regarding the soils in a watershed has been surveyed by NRCS and other agencies for almost the entire country including the State of New Mexico. This information is generally available from the NRCS by consulting the Natural Resources Conservation Service's (NRCS) Field Office Technical Guide; or the Web Soil Survey website.
http://websoilsurvey.nrcs.usda.gov/

Occasionally, when dealing with public lands (U.S. Forest Service, BLM, military bases) the soils information will not be shown in the NRCS database but may be available from the land management agency responsible for those lands.

For an expanded discussion and instructions on soils and their effects on runoff, see **Sections 402.4, 402.5,** and **402.6**. See also **Example Problem 6-7** located in Appendix 6 for a technical paper titled "Hatch Site 6 Runoff Methods Revisited" as an example of an approach for searching more deeply into predicted runoff results.

404.7 Vegetative Cover

Vegetation affects runoff in several ways including the following:

- The foliage and its litter maintain the soil's infiltration potential by preventing the sealing of the soil surface from raindrop impact
- Foliage retains some of the raindrops, increasing their chance of being evaporated
- Some of the moisture is intercepted on the plant and withheld from the initial period of runoff
- Vegetation transpires soil moisture leaving a greater void in the soil to be filled
- Vegetation, including its ground litter, forms numerous barriers along the path of the water flowing over the surface of the land (this lengthens the travel time and increases opportunity for infiltration)

The following information can be used as a guide in determining the vegetative cover conditions for range sites. Grass cover is evaluated on plant basal area while trees and shrubs are evaluated using canopy cover. Litter can be an effective cover and should be considered.

Cover Condition Class

Condition	**Vegetative Cover**
Poor	Less than 30% ground cover
Fair	About 30% to 70% ground cover
Good	More than 70% ground cover

Refer to NRCS NEH Part 630, (EFH) Amend. IA50, Nov. 2007 "Hydrologic Soil-Cover Complexes".
https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_022388.pdf

For a more complete guide to determining the percentage of vegetative cover, see "Sampling Vegetation Attributes" Interagency Technical Reference 1996 (Rev. ed. 1997 and 1999) at:
http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044175.pdf

For a more detailed discussion and instructions on determining the appropriate Cover Conditions see **Sections 402.5 and 402.6** and the example Soil Cover Complex photographs presented in **APPENDIX 4**.

404.8 Conservation Practices

Conservation practices, in general, reduce sheet erosion and thereby maintain an open structure of the soil surface. Soil and water conservation practices are control measures

consisting of managerial, vegetative, and structural practices to reduce the loss of soil and water. The application of conservation practices across a watershed reduces the volume of runoff, but the effect diminishes rapidly with increased storm magnitude. Some types of these practices are discussed below. Visit the NRCS website for more detailed information regarding conservation practices.
https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/technical/cp/ncps/?cid=nrcs143_026849

Crop residue tilled into the soil and the residual root system from grasses that have been in the crop rotations produce a condition favoring greater infiltration and water storage in the soil profile. The effect of conservation tillage on reducing runoff ranges from slight to substantial.

Contouring and terracing reduce sheet erosion and increase the amount of rainfall withheld from runoff by the small reservoirs they form. Land areas in which level terraces have been constructed may be excluded from the drainage area above downstream measures if they store the design depth of runoff. Gradient terraces increase the distance water must travel and thereby increase the Time of Concentration. This, in turn, reduces the peak rate of discharge.

Watershed slopes affect the rate of runoff and the peak discharge rate at downstream points. Slopes have a smaller effect on the volume of runoff than conservation practices such as contouring and terracing.

Small depressions may trap an initial amount of rain, thus reducing the amount of expected runoff. Where ponding or swampy areas occur in the watershed, a considerable amount of surface runoff may be retained in temporary storage. NRCS Small Watershed Hydrology WinTR-55 User Guide, 2009 contains a procedure to adjust the peak discharge for ponded areas.
http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1042897.pdf

404.9 Runoff Curve Number (CN)

The NRCS Runoff Curve Number (CN) is a lumped watershed parameter and most often serves as a proxy for all losses to precipitation from the time it hits the ground surface until it reaches the point of interest in a hydrologic analysis. As such, it should not be interpreted as a point infiltration value but rather as representing all losses (capture, infiltration, transmission, evaporation, etc.) unless separate calculations will be made for ponding and transmission losses.

Sections 402.5 and **402.6** contain important and useful excerpts from NRCS, June 1986, TR-55, Urban Hydrology for Small Watersheds, Chapter 2, which provides a complete and clear explanation of the CN, its determination, and its use in hydrologic analyses.
www.wcc.nrcs.usda.gov/ftpref/wntsc/H&H/other/TR55documentation.pdf

404.10 Time of Concentration

Calculate the Time of Concentration (Tc) for use in the Simplified Peak Discharge Method using the Upland Method for un-gullied watersheds and the upper, un-gullied portions of somewhat gullied watersheds. Use the Kirpich Equation for the gullied portions of the watershed and for watersheds that are almost entirely gullied. Follow the guidance in **Section 402.8**.

404.11 Peak Discharge Application Procedure

Step 1 – Gather input data.

Use the Simplified Peak Discharge Method worksheet **Figure 404-2**. Establish the appropriate Design Frequency Flood(s) for analysis (**Section 200**).

- Measure the drainage area, (A), in acres
- Compute the Time of Concentration, (Tc), in hours (**Sections 402.8** and **402.9**)
- Determine the appropriate Runoff Curve Number, CN, for the drainage basin (**Sections 402.5** and **402.6**)
- Obtain the 24-hour rainfall depth, P_{24}, in inches, for the appropriate design frequency, from NOAA Atlas 14 or online from the NOAA PFDS

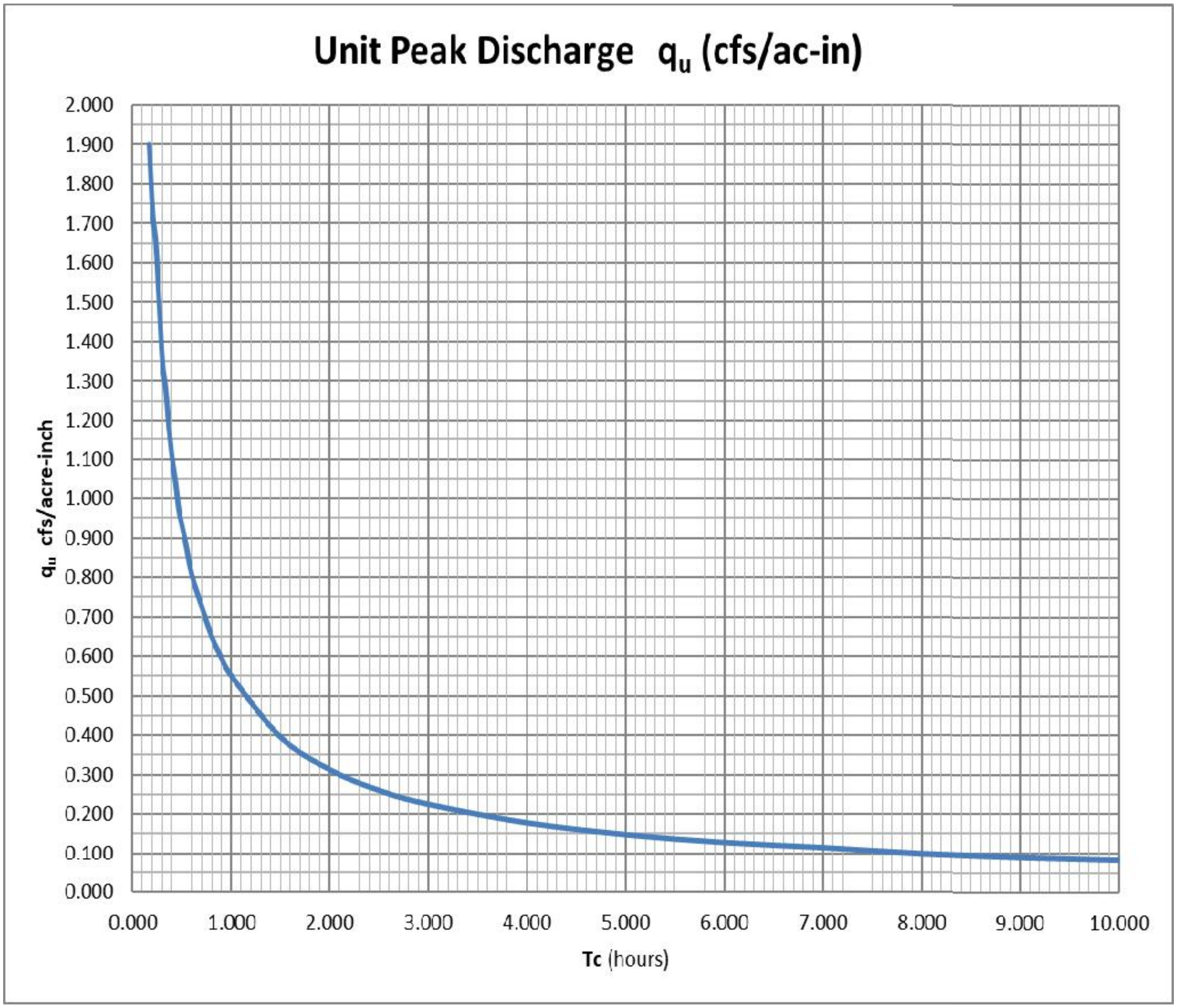
Step 2 – Determine the unit peak discharge, qu, for the watershed.

The unit peak discharge, $q_{u,}$ in cfs/ac-in. can be read from **Table 404-1** or **Figure 404-1**, given the Tc.

Table 404-1 Unit Peak Discharge Table for NRCS Simplified Peak Discharge Method

Source: Soil Conservation Service, 1973, revised by Luther McDougal, and Calvin Jackson, 1973, updated by Larry Goertz, February 1985, updated by Roger Ford, 2014, "Peak Rates of Discharge for Small Watersheds, Chapter 2, Engineering Field Manual for Conservation Practices".
(Not available on-line – see **APPENDIX 5**).

Tc		qu	Tc		qu
hours	min	cfs/ac-in	hours	min	cfs/ac-in
0.167	10.000	1.900	1.500	90	0.395
0.200	12.000	1.730	2.000	120	0.313
0.233	14.000	1.650	2.500	150	0.260
0.267	16.000	1.500	3.000	180	0.225
0.300	18.000	1.350	3.500	210	0.202
0.333	20.000	1.280	4.000	240	0.178
0.367	22.000	1.180	4.500	270	0.163
0.400	24.000	1.100	5.000	300	0.148
0.433	26.000	1.040	5.500	330	0.138
0.467	28.000	0.970	6.000	360	0.128
0.500	30.000	0.930	6.500	390	0.122
0.533	32.000	0.890	7.000	420	0.115
0.567	34.000	0.848	7.500	450	0.108
0.600	36.000	0.805	8.000	480	0.100
0.633	38.000	0.778	8.500	510	0.095
0.667	40.000	0.752	9.000	540	0.090
0.700	42.000	0.725	9.500	570	0.087
0.733	44.000	0.688	10.000	600	0.083
0.800	48.000	0.650			
0.867	52.000	0.623			
0.900	54.000	0.595			
1.000	60.000	0.550			



Source: Soil Conservation Service, 1973, revised by Luther McDougal, and Calvin Jackson, 1973, updated by Larry Goertz, February 1985, updated by Roger Ford, 2014, "Peak Rates of Discharge for Small Watersheds, Chapter 2, Engineering Field Manual for Conservation Practices".
(Not available on-line – see **APPENDIX 5**).

Figure 404-1 Unit Peak Discharge for NRCS Simplified Peak Discharge Method

If not using **Figure 404-1,** then read the unit peak discharge (q_u) value from **Table 404-1.**

Calculate the direct runoff depth (Q) from the watershed. The direct runoff is expressed as an average depth of runoff (Q) over the entire watershed, in inches. The direct runoff may be read from **Figure 402-8** using the 24-hour rainfall depth (P) in inches, and the Runoff Curve Number, CN.

The direct runoff depth (Q) may also be calculated from the following equation:

$$Q = \frac{\left[P - \left(200/_{CN}\right) + 2\right]^2}{P + \left(800/_{CN}\right) - 8} \qquad \textbf{404-1}$$

(Soil Conservation Service,1973, revised by Luther McDougal, and Calvin Jackson, 1973, updated by Larry Goertz, February 1985, updated by Roger Ford, 2014, “Peak Rates of Discharge for Small Watersheds, Chapter 2, Engineering Field Manual for Conservation Practices”)

where:

Q	=	direct runoff, inches
P	=	rainfall depth, inches
CN	=	Runoff Curve Number

Note that this method was developed based the 24-hour rainfall duration (P), with the maximum return period of 100-years, and is also applicable for more frequent return periods. The direct runoff depth (Q) may sometimes be shown as Q_d, to indicate depth, and to distinguish this term from the letter Q, which is also used often to designate discharge in cubic feet per second (cfs).

Step 3 – Compute the peak discharge

Compute the peak discharge (Q_p) from the watershed by the following equation:

$$Q_p = A\ Q\ q_u \qquad \textbf{404-2}$$

where:

Q_P	=	peak discharge, cfs
A	=	drainage area, acres
Q	=	direct runoff, inches
q_u	=	unit peak discharge, cfs/acre-inch

Step 4 – Compute the runoff volume, if required.

The runoff volume (Q) is obtained by the equation:

$$Q_v = (Q \ A) / 12 \quad \textbf{404-3}$$

where:

Q	=	direct runoff, inches
Q_v	=	runoff volume from the watershed, ac-ft
A	=	drainage area, acres

Step 5 – Estimate Transmission Losses

Transmission losses shall not be applied when using the Simplified Peak Discharge Method except for water quality and sediment transport related applications. For small frequent rainfall events and water quality analyses, transmission losses can be significant and should be considered. For sediment transport analyses, transmission losses should be considered to avoid over estimation of sediment transport rates.

Simplified Peak Discharge Method Worksheet

Structure Location: MP: ____________________ County: ________________

District: ____________________

Structure Description: ____

Drainage Area: **A** = ______________ acres, _____________ mi^2

Elevation at Centroid of Watershed: **Elev** = _________________ ft *

Location of Centroid: **Lat:** ________________ **Long:** ____________________

Time of Concentration: **T_c** = _______________ hours

Method: ☐ Upland ☐ Kirpich ☐ Mixed

Weighted Runoff Curve Number: **CN** = ____________________

Method: ☐ Area ☐ Runoff

Unit Peak Discharge (from Figure 404-1): **q_u** = ______________ cfs/ac-in

Design Frequency Flood	___________ - year	___________ - year
24-hour Rainfall Depth (NOAA PFDS):	P_{24} ___________ in.	P_{24} = ___________ in.
Direct Runoff (Figure 402-8):	**Qd** = _________ in.	**Qd** = ___________ in.
Peak Discharge, Qp = A • Qd • qu:	**Qp** = _________ cfs	**Qp** = ___________ cfs
Discharge per acre	___________ cfs/ac	___________ cfs/ac
Runoff Volume, Qv = A • Qd/12:	**Qv** = ________ ac-ft	**Qv** = ___________ ac-ft

Project Location: ______________________________

CN#: ______________________________

Date: ______________________________

Computed By: ______________________________

Checked By: ______________________________

* If elevation is greater than 7500 ft, use NRCS Unit Hydrograph method

Source: Soil Conservation Service,1973, revised by Luther McDougal, and Calvin Jackson, 1973, updated by Larry Goertz, February 1985, updated by Roger Ford, 2014, "Peak Rates of Discharge for Small Watersheds, Chapter 2, Engineering Field Manual for Conservation Practices".

Figure 404-2 Simplified Peak Discharge Method Worksheet

Appendix 6 contains two example Simplified Peak Discharge Method problems. **Example Problem 6-3** is for a mid-size basin (7.6 sq mi) and **Example Problem 6-4** is for a small basin (1.07 sq mi).

404.12 References

NOAA, Rev. ed. 2011, “Atlas 14, Precipitation-Frequency Atlas of the United States Volume 1 Version 5.0”.
http://www.nws.noaa.gov/oh/hdsc/PF_documents/Atlas14_Volume1.pdf

NOAA Hydrometeorological Design Studies Center Precipitation Frequency Data Server (PFDS).
http://hdsc.nws.noaa.gov/hdsc/pfds/

NRCS Website, “Conservation Practices”.
https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/technical/cp/ncps/?cid=nrcs143_026849

NRCS Web Soil Survey Website.
https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

NRCS, June 1986, “TR-55, Urban Hydrology for Small Watersheds”.
https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044171.pdf

NRCS, 1996 (Rev. ed. 1997 and 1999), Interagency Technical Reference, “Sampling Vegetation Attributes”.
http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044175.pdf

NRCS, 2007, “Part 630 Hydrology, National Engineering Handbook, Chapter 19, Transmission Losses”.
http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/16/stelprdb1043097.pdf

NRCS, November 2007, “Part 630 Hydrology, National Engineering Handbook, (EFH) Amend. IA50, Hydrologic Soil-Cover Complexes”.
https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_022388.pdf
http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_011485.pdf.

NRCS, 2009, “Small Watershed Hydrology WinTR-55 User Guide”.
http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1042897.pdf

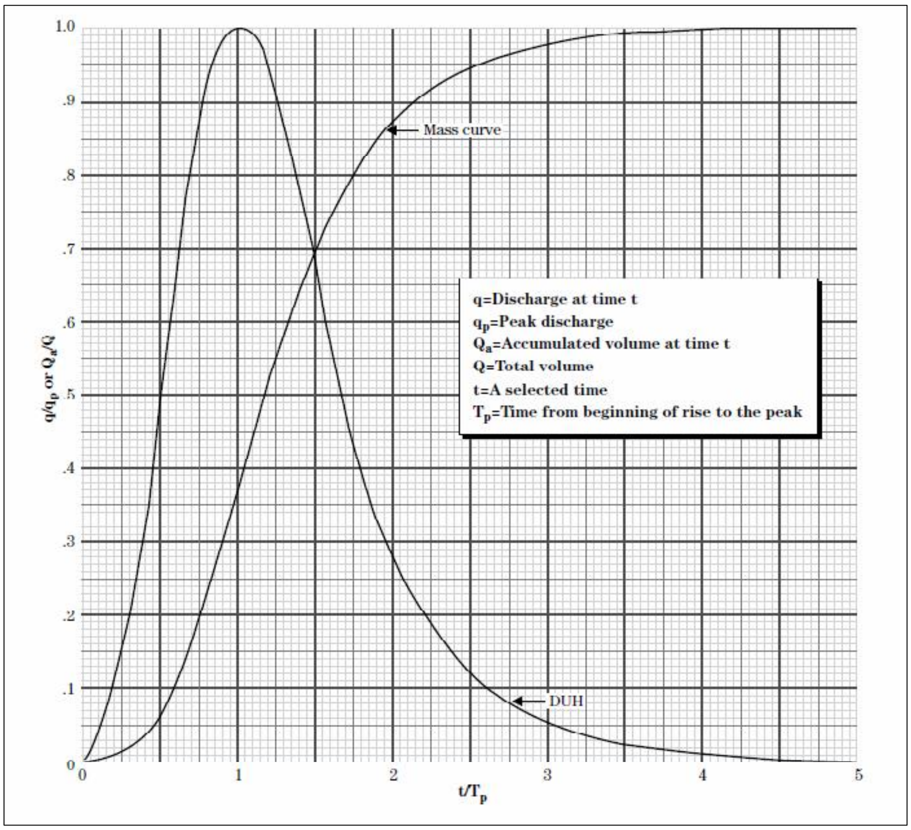
NRCS “Part 630 Hydrology, National Engineering Handbook, Chapters 8-12”.
http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/?cid=stelprdb1043063

Soil Conservation Service, 1973, revised by Luther McDougal, and Calvin Jackson, 1973, updated by Larry Goertz, February 1985, updated by Roger Ford, 2014, “Peak Rates of Discharge for Small Watersheds, Chapter 2, Engineering Field Manual for Conservation Practices”. (Not available on-line see **APPENDIX 5**).

405 NRCS (SCS) Unit Hydrograph Method within HEC-HMS

While there are multiple computer programs that can be used to develop a hydrograph, the NRCS Synthetic Unit Hydrograph Method has been selected for use on NMDOT projects in order to simplify reviews and to improve consistency. This method shall be used for watersheds over 10 square miles, or which have centroids above 7500 feet and whenever peak discharge calculations involve multiple subbasins and complex hydraulics within and among subbasins. The method should also be used whenever the analysis includes flood routing through detention facilities, pump stations, or long conveyance facilities. Synthetic unit hydrographs can be used to model drainage basins with or without base flow.

A hydrograph is a plot of discharge versus time. Synthetic unit hydrograph methods are used to adjust the shape of a generalized hydrograph to a particular drainage basin, usually at an ungaged site. A unit hydrograph is defined as the direct runoff hydrograph resulting from a rainfall event which has a specific temporal and spatial distribution, and which generates a unit depth of rainfall. The area beneath the unit hydrograph curve is equal to the volume of direct runoff from one inch of excess rainfall over the entire drainage basin or subbasin. **Figure 405-1** shows a dimensionless unit hydrograph and its associated cumulative mass curve.



Source: NRCS, 2007, "Part 630 Hydrology, National Engineering Handbook", Chapter 16, Hydrographs, Figure 16-1, p. 16-3. http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17755.wba

Figure 405-1 Dimensionless Unit Hydrograph and Mass Curve

The NRCS Unit Hydrograph was developed through the analysis of a large number of natural (measured) unit hydrographs from a broad cross section of geographic locations and hydrologic regions around the continental United States.

Computer models are the preferred approach for application of the SCS (now NRCS) Synthetic Unit Hydrograph Method. These computation methods make creation, addition, and routing of multiple hydrographs a relatively easy task.

There are commercially available software programs such as WMS and AutoDesk that perform hydrologic modeling. However, the NMDOT model of choice for large and/or complex watersheds and anytime a hydrograph is needed, is the U.S. Army Corps of Engineers (USACE) program HEC-HMS. Appendix 6 contains **Example Problem 6-6** that presents an example of a HEC-HMS problem.

The program, the User's Manual, the Technical Reference Manual, the Application Guide and sample models are available as free downloads from the USACE Hydrologic Engineering Center at:
http://www.hec.usace.army.mil/software/hec-hms/

HEC-HMS version 4.2.1 (latest version at the time of the publication of this manual) is capable of performing a wide variety of hydrologic analyses. With the GIS companion product (HEC-GeoHMS) data collection, basin delineation and rainfall input parameters have been simplified and made reproducible.

Basic data for HEC-HMS is standard to nearly all hydrologic analyses models as follows:

- Drainage basin area
- Time of Concentration
- Rainfall/Runoff algorithm (in this case Runoff Curve Number)
- Total rainfall depth
- Rainfall temporal distribution
- Conveyance system hydraulic data

Detailed instructions for the construction of a HEC-HMS model are not included in this manual since they are extensive and well presented in the HEC-HMS User's and Technical Reference Manuals. HEC-HMS has been updated several times since its introduction, and its capabilities are modified and expanded with each version. Also, since the use of the most current version is recommended, the inclusion of detailed usage instructions which are subject to change in this manual is not practical.

There are some basic requirements for use of a hydrologic computer model on a NMDOT project.

- Use of a computer model other than HEC-HMS must be approved by the NMDOT Drainage Design Bureau prior to its use.
- **The rainfall distribution used must be the 25% frequency** produced by HEC-HMS from rainfall data from NOAA Atlas 14 or the NOAA Precipitation Frequency Data Server for the specific flood frequency and watershed under investigation, unless otherwise authorized by the Drainage Design Bureau (see **Section 405.3** for further explanation).
- Tc must be computed using the Iterative Method within the Stream Hydraulic Method, and/or the Upland Method as appropriate. The use of the Kirpich Equation is appropriate for checking the results from **Section 402.9.5**. Refer to **Table 402-6** for guidance on

selection of a Time of Concentration method. Complete input files, routing diagrams, and summary output files must be included (in an appendix) in every drainage report, as well as the HEC-HMS Method worksheet (see **Figure 405-9**).

- When hydrograph routing is required, the Muskingum-Cunge Method is preferred for use with the NRCS Unit Hydrograph procedure. On occasion, special circumstances may warrant the use of one of the other routing methods available within HEC-HMS. Consult with the Drainage Design Bureau before using an alternative method.

405.1 Basin Delineation

Regardless of the hydrologic analysis method selected including HEC-HMS, the area of a drainage basin and its subbasins are always required. Basic to all hydrologic methods is the assumption that the basin or subbasin can be reasonably characterized by one set of hydrologic characteristics (soils, slope, rainfall, vegetative cover, and land use). The further the basin and subbasin characteristics diverge from this assumption, the less accurate and reproducible the results will be. Good “rules of thumb” regarding basin and subbasin sizing are that the length of a basin or subbasin delineation should not exceed 4 times its width and that no subbasin should be more than 10 times larger than the smallest subbasin.

Section 402.2 contains a more detailed description of the hydrologic factors that should be considered when delineating basins and subbasins. Also refer to the discussion in **Section 405.9** regarding minimum Tc and model computation interval as they relate to basin size and modeling.

405.2 Rainfall Volume

The rainfall depths for the design frequency storm are to be found at the NOAA Precipitation Frequency Data Server for the centroid of the watershed being studied (using the Partial Duration Series). In very large watersheds, the use of different rainfall volumes for portions of the watershed may be appropriate (e.g. mountain faces might differ from the alluvial plains below). Rainfall depths for specific durations (i.e. 5 minute, 15 minute, 60 minute, etc.) are also provided. These values are inputs to HEC-HMS for development of the 25% design rainfall temporal distribution used in the NRCS Unit Hydrograph Method.

405.3 Rainfall Temporal Distribution

Proper application of this method requires use of a 24-hour rainfall event with the peak precipitation rate occurring at 6 hours. Rainfall data for the NRCS Unit Hydrograph Method consists of point precipitation depths for various durations up to and including the 24-hour point depth, and also requires a rainfall distribution. Point precipitation depths for the design return period may be obtained directly from NOAA Atlas 14 or the NOAA Precipitation Frequency Data Server.

Previously, the rainfall distribution prescribed for use on NMDOT projects with the NRCS (SCS) Unit Hydrograph Method was called the Modified NOAA-SCS rainfall distribution. This Modified NOAA-SCS rainfall distribution was a combination of the peak rainfall intensity defined by NOAA, with an NRCS Type II-a storm rearrangement. HEC-HMS does not have a built in NRCS Type II-a storm distribution.

However, the 25% frequency storm distribution available within HEC-HMS is a very close approximation and is prescribed for NMDOT hydrologic analyses wherever a rainfall distribution is required. Given that NOAA Atlas 14 has a greatly expanded database compared to the data available to the U.S. Weather Bureau at the time the Type II-a distribution was developed, the 25% distribution available in the HEC-HMS program should produce more accurate results throughout New Mexico.

For NMDOT drainage design projects, apply the 25% frequency storm distribution. The HEC-HMS User's Manual describes the method for creating model rainfall distributions. **Figure 405-2** and **Figure 405-3** are provided for additional guidance.

NOAA Atlas 14, Volume 1, Version 5
Location name: Mountainair, New Mexico, US*
Latitude: 34.3000°, Longitude: -106.1000°
Elevation: 6500 ft*
* source: Google Maps

POINT PRECIPITATION FREQUENCY ESTIMATES

Sanja Perica, Sarah Dietz, Sarah Heim, Lillian Hiner, Kazungu Maitaria, Deborah Martin, Sandra Pavlovic, Ishani Roy, Carl Trypaluk, Dale Unruh, Fenglin Yan, Michael Yekta, Tan Zhao, Geoffrey Bonnin, Daniel Brewer, Li-Chuan Chen, Tye Parzybok, John Yarchoan

NOAA, National Weather Service, Silver Spring, Maryland

PF_tabular | PF_graphical | Maps_&_aerials

PF tabular

PDS-based point precipitation frequency estimates with 90% confidence intervals (in inches)[1]

Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	0.246 (0.216–0.280)	0.318 (0.280–0.362)	0.422 (0.371–0.482)	0.502 (0.440–0.574)	0.608 (0.534–0.696)	0.689 (0.606–0.793)	0.775 (0.681–0.897)	0.862 (0.759–1.00)	0.979 (0.863–1.15)	1.07 (0.947–1.28)
10-min	0.375 (0.329–0.427)	0.484 (0.425–0.551)	0.643 (0.564–0.734)	0.764 (0.669–0.874)	0.925 (0.812–1.06)	1.05 (0.922–1.21)	1.18 (1.04–1.37)	1.31 (1.16–1.53)	1.49 (1.31–1.76)	1.63 (1.44–1.94)
15-min	0.464 (0.408–0.529)	0.599 (0.527–0.683)	0.797 (0.700–0.910)	0.947 (0.829–1.08)	1.15 (1.01–1.31)	1.30 (1.14–1.50)	1.46 (1.28–1.69)	1.63 (1.43–1.89)	1.85 (1.63–2.18)	2.02 (1.79–2.41)
30-min	0.625 (0.549–0.713)	0.807 (0.710–0.920)	1.07 (0.942–1.23)	1.28 (1.12–1.46)	1.54 (1.36–1.77)	1.75 (1.54–2.02)	1.97 (1.73–2.28)	2.19 (1.93–2.55)	2.49 (2.19–2.93)	2.73 (2.41–3.24)
60-min	0.774 (0.680–0.882)	0.999 (0.878–1.14)	1.33 (1.17–1.52)	1.58 (1.38–1.81)	1.91 (1.68–2.19)	2.17 (1.90–2.49)	2.44 (2.14–2.82)	2.71 (2.39–3.16)	3.08 (2.72–3.63)	3.37 (2.98–4.01)
2-hr	0.907 (0.799–1.04)	1.16 (1.02–1.33)	1.53 (1.35–1.75)	1.82 (1.60–2.07)	2.23 (1.95–2.54)	2.57 (2.23–2.91)	2.93 (2.52–3.32)	3.31 (2.83–3.75)	3.86 (3.26–4.37)	4.32 (3.61–4.90)
3-hr	0.956 (0.848–1.09)	1.21 (1.08–1.39)	1.58 (1.39–1.81)	1.88 (1.65–2.14)	2.30 (2.00–2.61)	2.64 (2.28–2.99)	3.00 (2.58–3.41)	3.40 (2.90–3.85)	3.96 (3.34–4.50)	4.43 (3.70–5.04)
6-hr	1.08 (0.961–1.23)	1.37 (1.22–1.56)	1.75 (1.55–1.99)	2.06 (1.82–2.34)	2.49 (2.19–2.82)	2.84 (2.47–3.21)	3.21 (2.78–3.63)	3.61 (3.10–4.08)	4.16 (3.54–4.71)	4.62 (3.89–5.24)
12-hr	1.23 (1.09–1.39)	1.55 (1.37–1.75)	1.96 (1.74–2.22)	2.29 (2.02–2.59)	2.75 (2.42–3.11)	3.12 (2.73–3.52)	3.51 (3.05–3.96)	3.92 (3.39–4.43)	4.50 (3.84–5.09)	4.97 (4.21–5.63)
24-hr	1.42 (1.31–1.55)	1.78 (1.65–1.94)	2.23 (2.06–2.44)	2.59 (2.38–2.83)	3.08 (2.82–3.36)	3.47 (3.16–3.78)	3.87 (3.51–4.22)	4.28 (3.87–4.68)	4.85 (4.34–5.32)	5.29 (4.71–5.83)
2-day	1.58 (1.45–1.72)	1.98 (1.82–2.16)	2.47 (2.27–2.69)	2.86 (2.63–3.13)	3.40 (3.10–3.71)	3.83 (3.48–4.18)	4.27 (3.87–4.67)	4.73 (4.25–5.18)	5.35 (4.76–5.89)	5.85 (5.16–6.45)
3-day	1.72 (1.58–1.87)	2.15 (1.98–2.34)	2.68 (2.47–2.92)	3.11 (2.86–3.38)	3.69 (3.38–4.02)	4.15 (3.78–4.52)	4.63 (4.20–5.04)	5.12 (4.62–5.59)	5.79 (5.17–6.35)	6.33 (5.60–6.96)
4-day	1.85 (1.71–2.01)	2.32 (2.14–2.53)	2.89 (2.67–3.15)	3.35 (3.09–3.64)	3.98 (3.65–4.32)	4.48 (4.09–4.86)	4.98 (4.54–5.42)	5.51 (4.98–6.00)	6.23 (5.58–6.81)	6.80 (6.04–7.46)
7-day	2.25 (2.08–2.43)	2.81 (2.59–3.05)	3.48 (3.21–3.78)	4.02 (3.70–4.35)	4.74 (4.35–5.14)	5.30 (4.84–5.75)	5.87 (5.35–6.37)	6.45 (5.84–7.02)	7.24 (6.50–7.90)	7.86 (7.00–8.60)
10-day	2.53 (2.34–2.75)	3.16 (2.92–3.44)	3.94 (3.63–4.29)	4.54 (4.18–4.95)	5.38 (4.92–5.86)	6.03 (5.49–6.57)	6.69 (6.08–7.31)	7.37 (6.66–8.08)	8.30 (7.43–9.12)	9.02 (8.01–9.97)
20-day	3.36 (3.12–3.62)	4.19 (3.89–4.53)	5.15 (4.78–5.57)	5.88 (5.44–6.36)	6.83 (6.30–7.39)	7.55 (6.93–8.17)	8.26 (7.56–8.95)	8.96 (8.16–9.73)	9.88 (8.95–10.8)	10.6 (9.52–11.6)
30-day	4.06 (3.79–4.35)	5.06 (4.72–5.44)	6.17 (5.74–6.63)	6.99 (6.50–7.52)	8.04 (7.46–8.65)	8.82 (8.16–9.50)	9.58 (8.84–10.3)	10.3 (9.49–11.2)	11.3 (10.3–12.2)	12.0 (10.9–13.0)
45-day	5.11 (4.78–5.47)	6.36 (5.94–6.81)	7.67 (7.16–8.22)	8.63 (8.04–9.26)	9.83 (9.13–10.6)	10.7 (9.91–11.5)	11.5 (10.6–12.4)	12.3 (11.3–13.3)	13.3 (12.2–14.4)	14.1 (12.8–15.3)
60-day	6.00 (5.59–6.42)	7.47 (6.97–8.02)	9.00 (8.39–9.66)	10.1 (9.41–10.8)	11.5 (10.7–12.3)	12.4 (11.5–13.4)	13.4 (12.4–14.4)	14.2 (13.1–15.4)	15.3 (14.1–16.6)	16.1 (14.7–17.5)

[1] Precipitation frequency (PF) estimates in this table are based on frequency analysis of partial duration series (PDS).

Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and average recurrence interval) will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.

Please refer to NOAA Atlas 14 document for more information.

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Figure 405-2 Sample NOAA Precipitation Frequency Data Sever Output

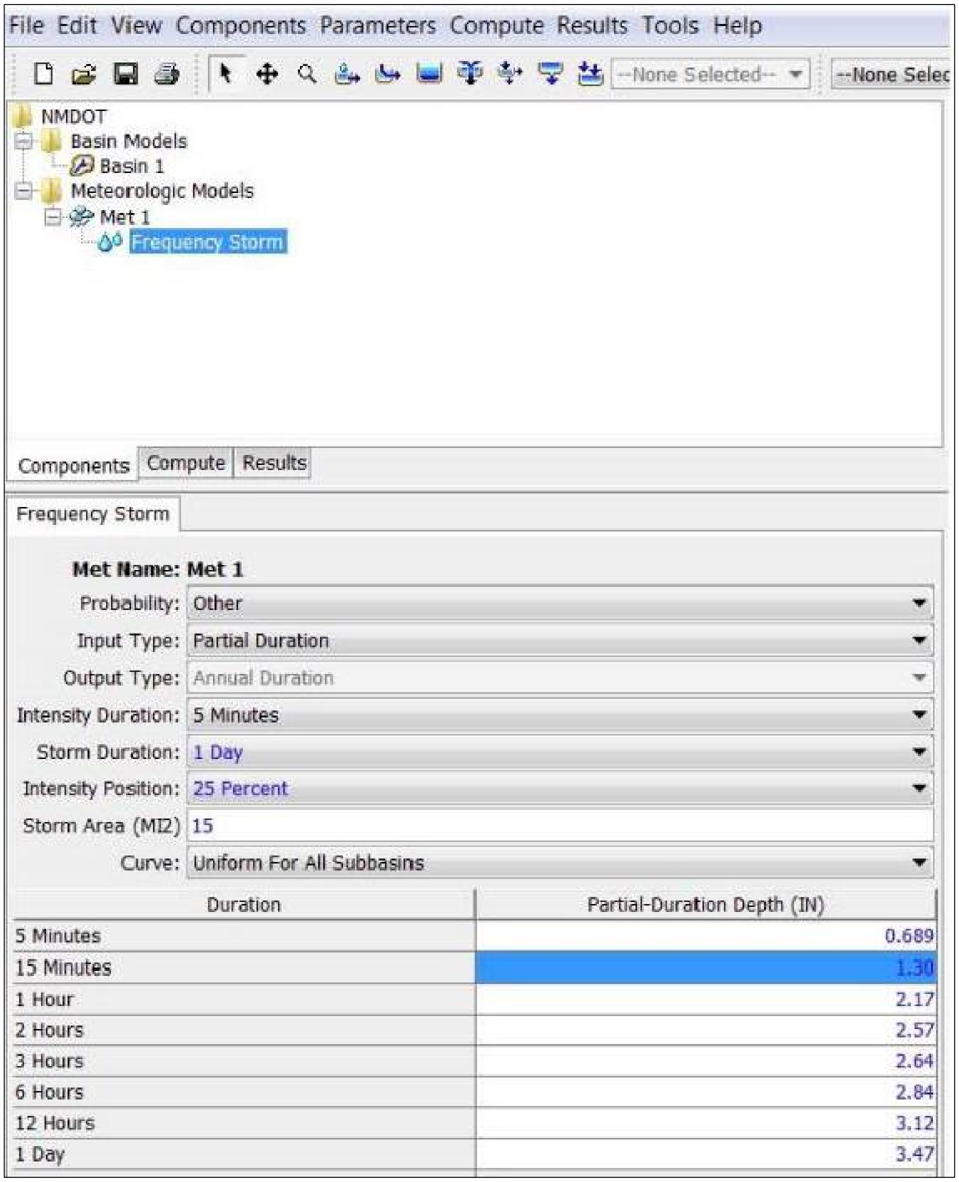


Figure 405-3 Sample HEC-HMS Precipitation Input Table

405.4 Soils Data

The NMDOT requires that hydrologic modeling within HEC-HMS utilize the NRCS Runoff Curve Number (CN) Method for determining a watershed's response to rainfall. Soils data (Hydrologic Soils Group) is integral to determining the CN.

The texture, composition and density of soils have a direct impact on the amount, and rate at which rainfall becomes runoff and, therefore, the soil type is a critical piece of information in the development of rainfall/runoff calculations. In general, soils are classified as sandy, silty, loamy or clayey. Of course, in nature, there can be an infinite number of combinations of these characteristics. The NRCS has divided the extremely wide range of soil textures by their hydrologic (runoff producing) characteristics into four Hydrologic Soils Groups: Type A, B, C, and D with: Type A being generally sandy soils and low runoff producers and Type D being clayey soils and high producers of runoff for a given rainfall volume. See **Section 402.4** for a more detailed description of soil classifications and their impact on the CN. Soils data are available for almost all of New Mexico from the NRCS Web Soil Survey at: http://websoilsurvey.nrcs.usda.gov/.

405.5 Hydrologic Soil Cover Complexes

A combination of a Hydrologic Soil Group (soil), land use and treatment class (cover) is a hydrologic soil-cover complex. A range of Runoff Curve Numbers (CNs) based on the combination of soil texture and cover has been developed by the NRCS from empirical data and is published by NRCS in their National Engineering Handbook, Chapter 9 as well in multiple other locations. **Section 402.5** contains a detailed description of the accepted process for determining appropriate soil cover complexes for use on NMDOT projects.

405.6 Runoff Curve Number

The NRCS Runoff Curve Number (CN) is a lumped watershed parameter and most often serves as a proxy for all losses from the beginning of precipitation until runoff reaches the point of interest in a hydrologic analysis. As such, it should not be interpreted as a point infiltration value but rather as representing all losses (initial abstraction, infiltration, transmission, evaporation, etc.) unless separate calculations will be made for ponding and transmission losses. **Section 402.6** contains a detailed description of the methods prescribed for determining the CN for NMDOT projects.

405.7 Other Land Use Effects

HEC-HMS has the ability to simulate the effects of directly connected impervious areas, ponds, dams, storm drains, and pump stations on the runoff hydrograph. The HEC-HMS User's Manual and the Technical Reference Manual should be consulted for the details regarding input data, limitations and capabilities of the software. Any NMDOT project that contains these elements and requires analyses of their impacts should utilize HEC-HMS unless approved by the Drainage Design Bureau.

Note that when modeling heavily urban basins, if the engineer inputs percentage impervious directly into the model, HEC-HMS assumes a CN=100 and produces 100% runoff from that area. Impervious areas should be classified as CN=98. Do not use the percentage impervious option in HEC-HMS.

405.8 Time of Concentration and Basin Lag

Time of Concentration (Tc), is defined as the time required for runoff to travel from the hydraulically most remote part of the watershed to the point of interest. The determination of Tc is one of the most important and sensitive drainage basin modeling needs when calculating the peak rate of runoff and hydrographs in HEC-HMS. Tc is a simplified proxy for the hydrologic response to precipitation by a watershed (capturing the interrelated effects of size, shape, and slope). The Tc for a watershed or subbasin has the most dramatic effect on the shape of the runoff hydrograph of any parameter. An accurate estimate of a watershed's Tc is therefore crucial to every type of hydrologic modeling. **Section 402.8** contains a detailed discussion and outlines the various methods approved to calculate and check Tc for a subbasin.

In the SCS (NRCS) Unit Hydrograph Method, basin lag (Lag or tlag) is defined as the time between the center of mass of excess rainfall and the peak of the unit hydrograph as:

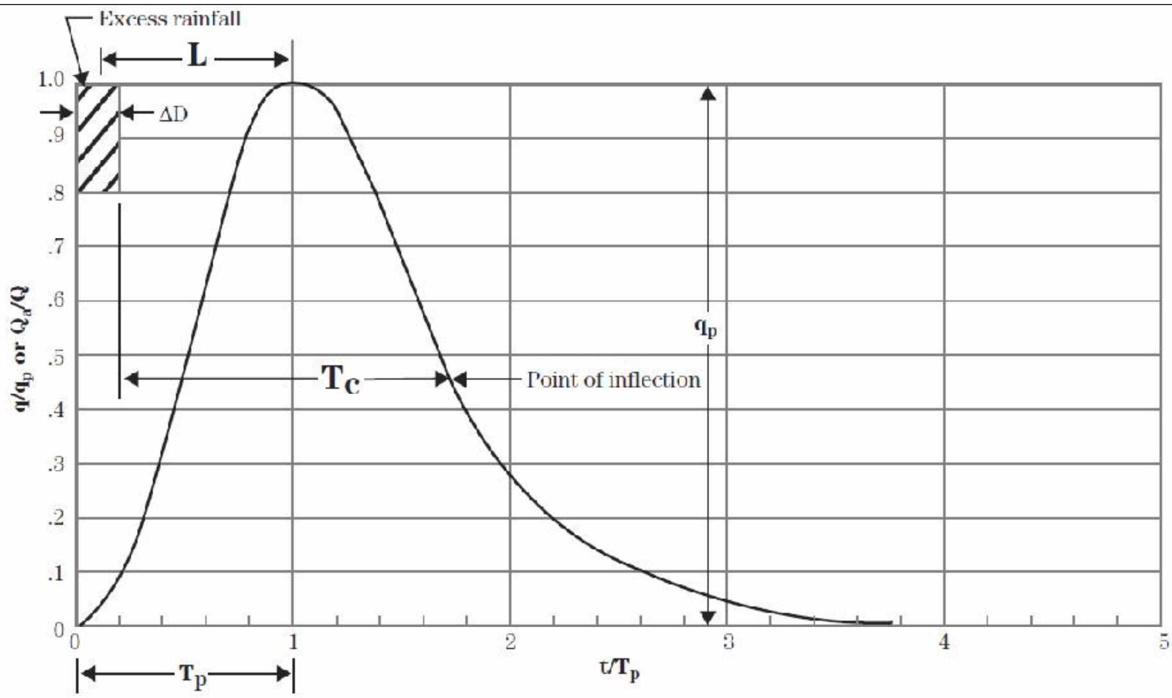
$$Lag = 0.6 \times Tc \quad \textbf{405-1}$$

(NRCS, 2010, “Part 630 Hydrology, National Engineering Handbook, Chapter 15 Time of Concentration”, Eq. 15-3, p. 15-3)
https://directives.sc.egov.usda.gov/27002.wbas

where:

Lag = the time between the center of mass of excess runoff and the hydrograph peak, hr
Tc = time of concentration, hr

Figure 405-4 illustrates the various time relationships important to the development of the dimensionless unit hydrograph and resulting basin specific hydrographs within the NRCS Unit Hydrograph Method.



where:

L = Lag, h

T_c = time of concentration, h

T_p = time to peak, h

ΔD = duration of excess rainfall, h

t/T_p = dimensionless ratio of any time to time to peak

q = discharge rate at time t, ft^3/s

q_p = peak discharge rate at time T_p, ft^3/s

Q_a = runoff volume up to t, in

Q = total runoff volume, in

Source: NRCS, 2007, Part 630 Hydrology, National Engineering Handbook, Chapter 16 Hydrographs, p. 16A-1
https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/?&cid=stelprdb1043063

Figure 405-4 Graphical Representation of Relationships Between Lag, Tp and Tc

405.9 HEC-HMS Computation Interval and Duration Guidance

405.9.1 Computation Interval

The computation interval or time step for modeling within HEC-HMS can be specified for a range of intervals as follows:

1, 2, 3, 4, 5, 6, 10, 15, 20, 30 (minutes)

1, 2, 3, 6, 8, 12, 24 (hours)

Selection of the appropriate computation interval can also affect the modeling results. The HEC-HMS Technical Reference Manual (USACE, March 2000) states: "*that for adequate definition of the ordinates on the rising limb of the NRCS Unit Hydrograph, a computational interval, Δt, that is less than 29% of t_{lag} must be used (USACE 1998).*"

Therefore, if basin Lag=0.6 Tc, (Lag is the same as t_{lag}) then the maximum computational interval for use within HEC-HMS to adequately define the rising limb of the hydrograph (and often to capture the peak) is given by:

$$\Delta t < 0.29 \times 0.60\ Tc < 0.17\ Tc \qquad \textbf{405-2}$$

Note that 0.29 x 0.60 = 0.17, therefore this equation reduces to

$\Delta t < 0.17\ Tc$

(USACE, March 2000, "Hydrologic Engineering Center, "HEC-HMS Technical Reference Manual, p. 55)
http://www.hec.usace.army.mil/software/hec-hms/documentation/HEC-HMS_Technical%20Reference%20Manual_(CPD-74B).pdf

The following items are offered as additional guidance for selecting the minimum model computation interval selection:

1. Generally, the computation interval "*Δt*" should be based on the Tc of the smallest subbasin in the model.
2. Note that the shortest rainfall interval available from NOAA is 5 minutes, selecting a shorter computation interval will require HEC-HMS to extrapolate to find a smaller than 5-minute rainfall increment.
3. For 24-hour storm distributions, use a computation interval "*Δt*" of 5 minutes or greater, unless there are other compelling reasons for deviating from 5 minutes.
4. For basins with Tc shorter than 30 minutes, be aware that the computed runoff volume will be accurate but that the model may misstate the peak. Peak rates developed with HEC-HMS for basins with Tc shorter than 30 minutes should always be checked against other methods and experience.
5. Note that shorter and more numerous computation intervals do not always result in better answers (accuracy versus precision).

405.9.2 Duration of Simulation

The model simulation duration (the beginning and ending date and time) should be long enough to capture the entire storm runoff hydrograph. After an initial model run duration of 24 hours, the engineer should review the terminal basin outfall hydrograph to determine if the discharge has returned to zero. If zero discharge is not achieved, extend the model duration and simulate again to obtain zero discharge. Durations greater than 24 hours will generally be required for larger basins (greater than 10 square miles) and for models which contain reservoir routings with long detention times.

405.10 Transmission Losses (Channel Losses)

HEC-HMS has the ability to include the effects of channel losses to the hydrograph. This function is available only in the Modified Puls and Muskingum-Cunge hydrograph routing Methods. Channel losses are included in the "Reach" description within the Basin Model Manager within HEC-HMS. Generally, channel losses do not significantly affect the peak rate of discharge for larger, infrequent flood events, but may have a significant and measurable effect on floods up to the 5-year flood. Therefore, transmission losses should not be considered in the modeling of floods events equal to or greater than the 10-year event. Models constructed for the purpose of evaluating water quality and for determining channel stability and sediment transport will benefit from consideration of transmission losses. If the need to determine the values for use in calculating channel losses on NMDOT projects should arise, use the Percolation Loss/Gain method as outlined in the HEC-HMS User's Manual (p. 234) and the NRCS, 2007, Part 630 Hydrology National Engineering Handbook, Chapter 19, Appendix 19C "Estimating Transmission Losses When No Observed Data are Available".
http://www.hec.usace.army.mil/software/hec-hms/

http://www.wcc.nrcs.usda.gov/ftpref/wntsc/H&H/NEHhydrology/ch19.pdf

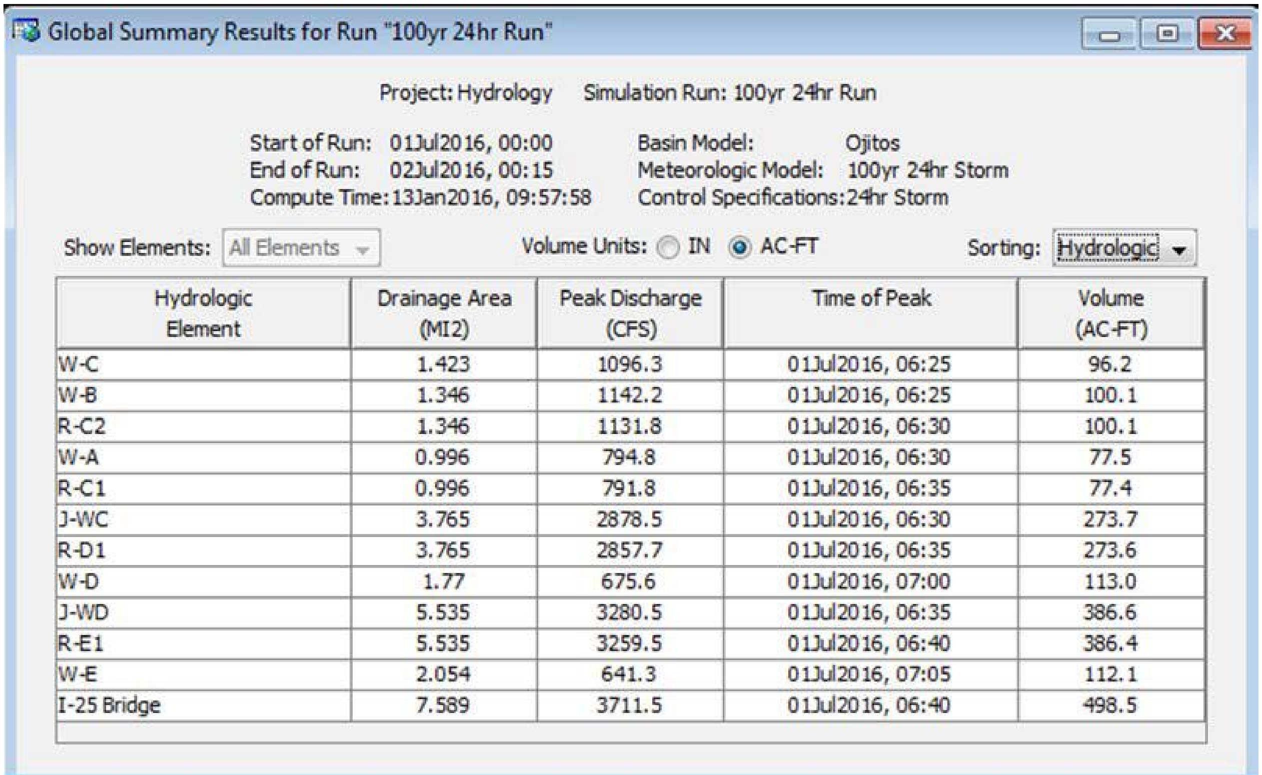
405.11 Flood Routing

HEC-HMS offers a total of six hydrologic routing methods for simulating flow in open channels. For most NMDOT project applications, the Muskingum-Cunge Method is the preferred method. HEC-HMS can also include flood hydrograph routings through diversions, reservoirs, and pump stations.

The Muskingum-Cunge Routing Method is based on the combination of the conservation of momentum and the conservation of mass. This Method relates storage to both inflow and outflow discharges from both the channel and floodplain within each analysis reach. This Method is sometimes referred to as a Variable Coefficient Method because routing parameters are recalculated every time step based on channel properties and the flow depth. The computations attempt to simulate the attenuation of flood waves and can be used in reaches with a mild slope.

405.12 Model Results Reporting

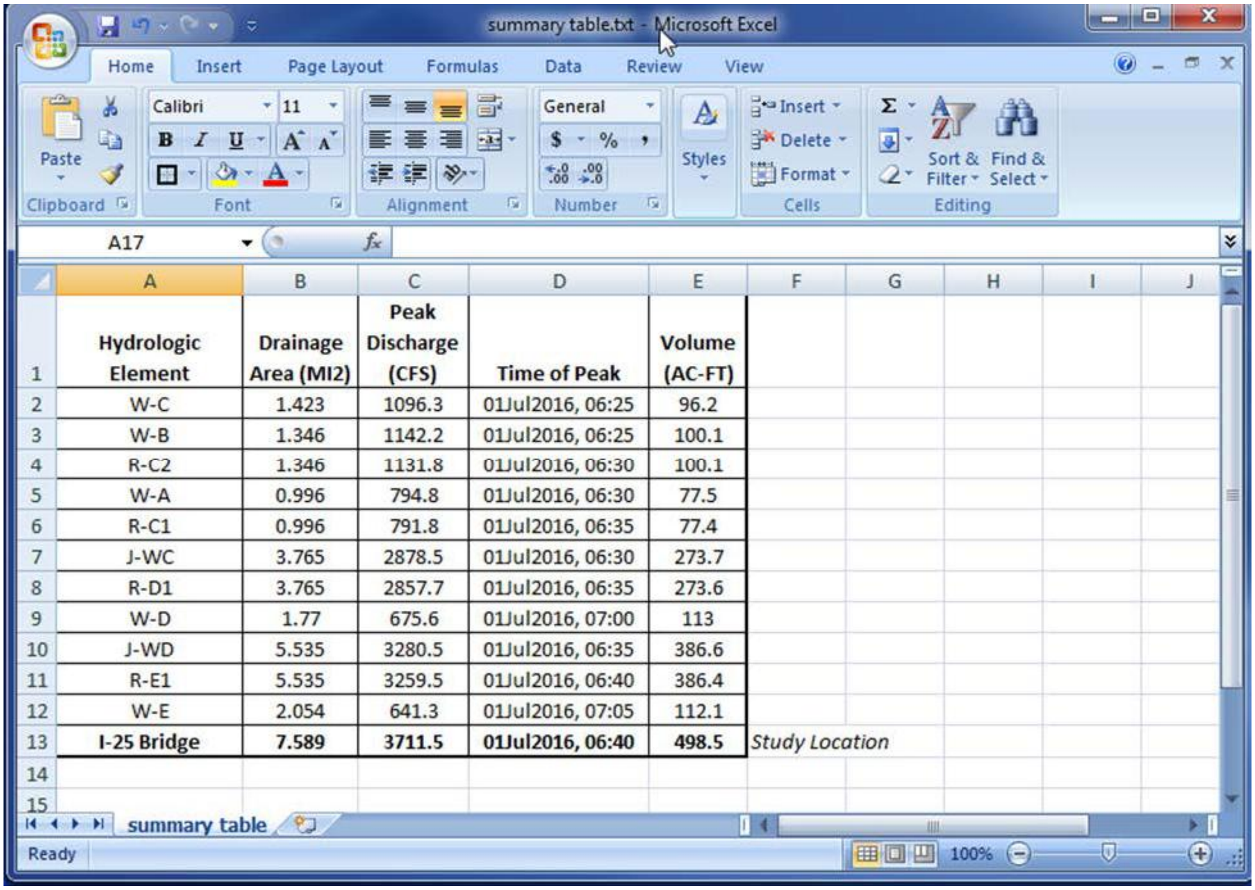
Once the model has been run and the results have been checked for reasonableness, the engineer must include the summary results for each storm frequency simulated in the report. See **Figure 405-5** for the HEC-HMS "Global Summary Table".



Hydrologic Element	Drainage Area (MI2)	Peak Discharge (CFS)	Time of Peak	Volume (AC-FT)
W-C	1.423	1096.3	01Jul2016, 06:25	96.2
W-B	1.346	1142.2	01Jul2016, 06:25	100.1
R-C2	1.346	1131.8	01Jul2016, 06:30	100.1
W-A	0.996	794.8	01Jul2016, 06:30	77.5
R-C1	0.996	791.8	01Jul2016, 06:35	77.4
J-WC	3.765	2878.5	01Jul2016, 06:30	273.7
R-D1	3.765	2857.7	01Jul2016, 06:35	273.6
W-D	1.77	675.6	01Jul2016, 07:00	113.0
J-WD	5.535	3280.5	01Jul2016, 06:35	386.6
R-E1	5.535	3259.5	01Jul2016, 06:40	386.4
W-E	2.054	641.3	01Jul2016, 07:05	112.1
I-25 Bridge	7.589	3711.5	01Jul2016, 06:40	498.5

Figure 405-5 HEC-HMS Global Summary Results Example

Sort the results in the Global Summary Table using "Hydrologic" order, and also select the "Volume Units" to be in ac-ft. Then the HEC-HMS "Global Summary Table" can be exported as a text file to any number of spreadsheet programs for formatting needs as shown in **Figure 405-6**.



Hydrologic Element	Drainage Area (MI2)	Peak Discharge (CFS)	Time of Peak	Volume (AC-FT)	
W-C	1.423	1096.3	01Jul2016, 06:25	96.2	
W-B	1.346	1142.2	01Jul2016, 06:25	100.1	
R-C2	1.346	1131.8	01Jul2016, 06:30	100.1	
W-A	0.996	794.8	01Jul2016, 06:30	77.5	
R-C1	0.996	791.8	01Jul2016, 06:35	77.4	
J-WC	3.765	2878.5	01Jul2016, 06:30	273.7	
R-D1	3.765	2857.7	01Jul2016, 06:35	273.6	
W-D	1.77	675.6	01Jul2016, 07:00	113	
J-WD	5.535	3280.5	01Jul2016, 06:35	386.6	
R-E1	5.535	3259.5	01Jul2016, 06:40	386.4	
W-E	2.054	641.3	01Jul2016, 07:05	112.1	
I-25 Bridge	**7.589**	**3711.5**	**01Jul2016, 06:40**	**498.5**	*Study Location*

Figure 405-6 HEC-HMS Discharge Summary Table Example

In addition, a Basin Model map generated in HEC-HMS (**Figure 405-7**) should be included in the report. This can be created simply by utilizing a screen capture program to copy the screen from HEC-HMS. This Basin Model Map is a schematic that is valuable to assist in understanding the model organization, and the order that basin elements were applied to simulate the basin storm runoff.

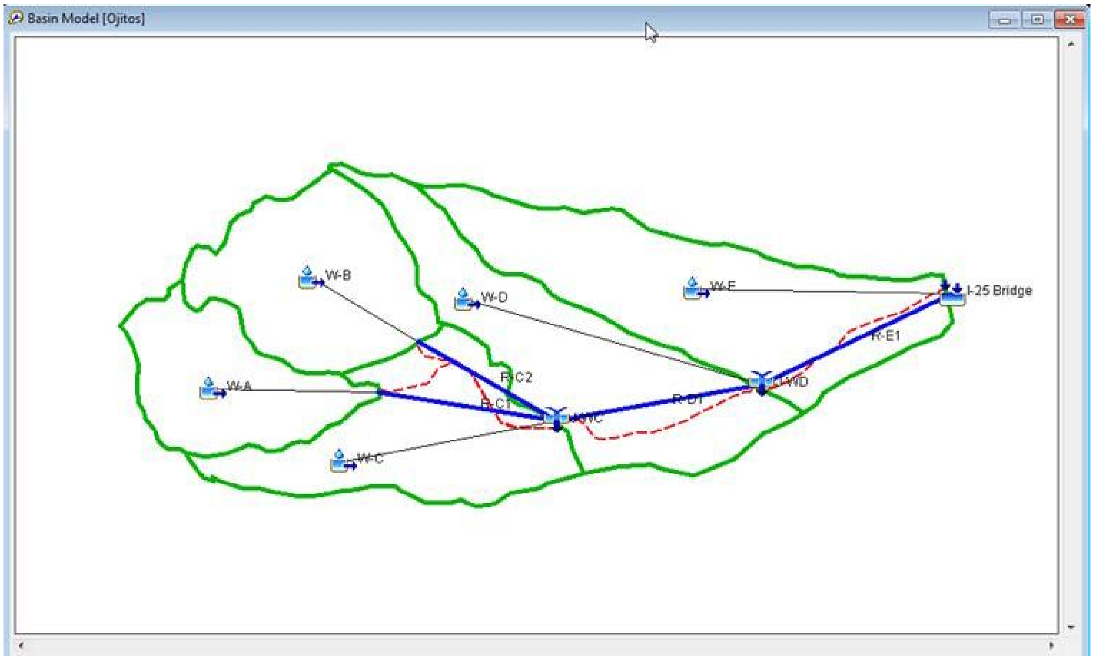


Figure 405-7 HEC-HMS Basin Model Example

The hydrograph shape can be found under the element results **(Figure 405-8).**

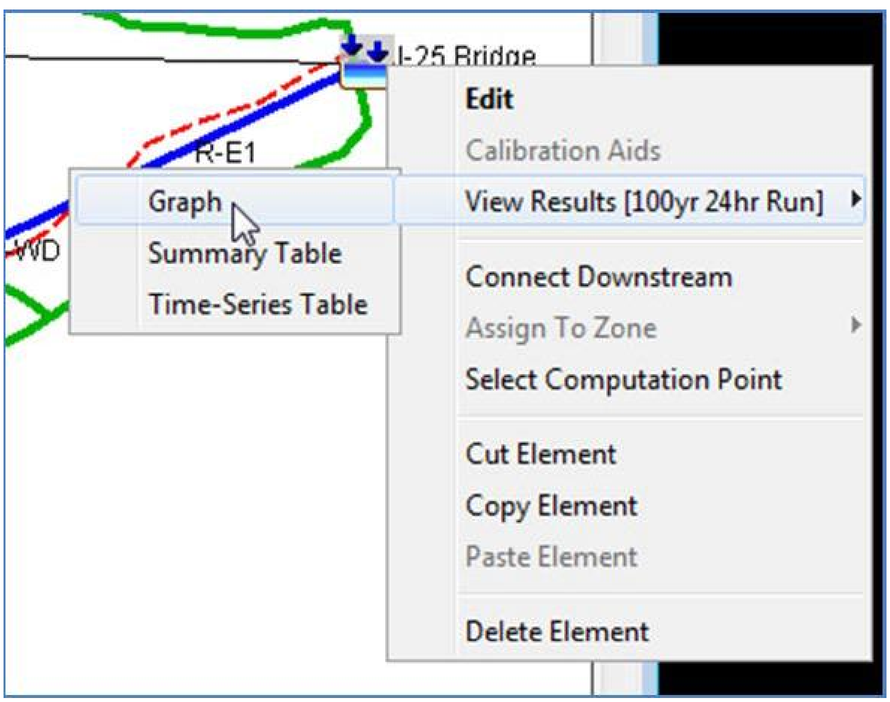


Figure 405-8 HEC-HMS Display Hydrograph Menu Example

The HEC-HMS Method Worksheet (**Figure 405-9**) should be filled out as well.

HEC-HMS Method Worksheet

Structure Location: MP: ____________________ County: ________________
District: ____________________
Structure Description: ____________________________
Drainage Area: **A** = ______________ acres ______________ mi²

Meteorological Model Summary
Elevation at Centroid of Watershed: **Elev** = __________________ ft *
Location of Centroid: **Lat:** ________________ **Long**: ____________________

Design Frequency Flood	__________ - year	__________ - year
24-hour Rainfall Depth (NOAA PFDS):	**P_{24}** __________ in.	**P_{24} =** __________ in.

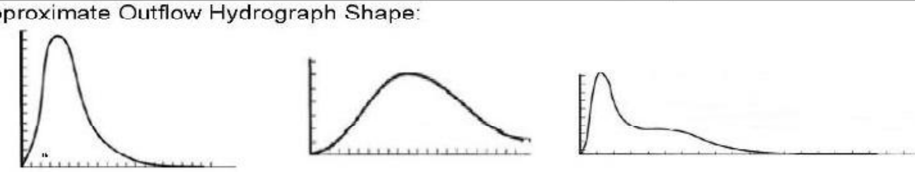
Basin Model Summary
Number of Sub-Basins ________________
Curve Number Range Used for modeling Low: __________ High: ______________
Basin Lag Range Used for modeling Low: __________ min High: ______________ min

Control Specifications Summary
Total Model Duration __________ Hrs:Min Time Interval ________ (min\hrs)

Summary Output (at Structure Location

Design Frequency Flood	__________ - year	__________ - year
Peak Discharge (cfs)	**Q** = __________ cfs	**Q** = __________ cfs
Discharge per acre	__________ cfs/ac	__________ cfs/ac
Total Volume (ac-ft)	**V** = __________ ac-ft	**V** = __________ ac-ft
Total Runoff (in)	**V** = __________ in	V = __________ in

Approximate Outflow Hydrograph Shape:



Peaky" "Broad" "Mixed"

Project Location: ______________________________
CN#: ______________________________
Date: ______________________________
Computed By: ______________________________
Checked By: ______________________________
* If elevation is greater than 7500 ft, use NRCS Unit Hydrograph method

Figure 405-9 HEC-HMS Method Worksheet

405.13 References

Easterling, Charles, M. 1979, "Urban Watershed Modeling with HYMO", ASCE Irrigation and Drainage Division Specialty Conference".

NOAA Hydrometeorological Design Studies Center Precipitation Frequency Data Server (PFDS).
http://hdsc.nws.noaa.gov/hdsc/pfds/

NRCS Web Soil Survey Website.
https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

NRCS, 2004, "Part 630 Hydrology, National Engineering Handbook, Chapter 9 Hydrologic Soil-Cover Complexes".
http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17758.wba

NRCS, 2007, "Part 630 Hydrology, National Engineering Handbook, Chapter 16 Hydrographs".
http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17755.wba

NRCS, 2007, "Part 630 Hydrology, National Engineering Handbook, Chapter 19 Transmission Losses".
http://www.wcc.nrcs.usda.gov/ftpref/wntsc/H&H/NEHhydrology/ch19.pdf

NRCS, 2007, "Part 630 Hydrology, National Engineering Handbook, Chapter 19, Appendix 19C, Estimating Transmission Losses When No Observed Data are Available".
http://www.wcc.nrcs.usda.gov/ftpref/wntsc/H&H/NEHhydrology/ch19.pdf

NRCS, 2010, "Part 630 Hydrology, National Engineering Handbook, Chapter 15 Time of Concentration".
https://directives.sc.egov.usda.gov/27002.wbas

USACE Hydrologic Engineering Center - HEC-HMS, "HEC-HMS User's Manual", "HEC-HMS Technical Reference Manual", "HEC-HMS Application Guide".
http://www.hec.usace.army.mil/software/hec-hms/

USACE, March 2000, "Hydrologic Engineering Center, "HEC-HMS Technical Reference Manual".
http://www.hec.usace.army.mil/software/hec-hms/documentation/HEC-HMS_Technical%20Reference%20Manual_(CPD-74B).pdf

406 Watersheds with Stream Gage Data

When considering the use of statistical analysis of gage data for design purposes, it is important to determine if the present watershed conditions are represented by the stream gage record or if there has been a significant change in land use. If there has been a significant increase in urbanization or change in agricultural practices, the historical record may not represent current conditions. While many hydrologic techniques are available for the prediction of frequency of flow events, this section presents concepts and techniques for analyzing peak flows using stream gage data and, to a lesser extent, low flows, following the recommendations of

USGS, England, J.F., Jr., Cohn, T.A., Faber, B.A., Stedinger, J.R., Thomas, W.O., Jr., Veilleux, A.G., Kiang, J.E., Mason, R.R., Jr., 2018, “Guidelines for Determining Flood Flow Frequency, Bulletin #17C, Chapter 5 of Section B, Surface Water, Book 4, Hydrologic Analysis and Interpretation, Techniques and Methods 4-B5”.
https://pubs.er.usgs.gov/publication/tm4B5

Elements of risk and uncertainty are inherent in any flood frequency analysis. It is possible to standardize many elements of flood frequency analysis, but reliable results are only possible where available records are adequate to warrant statistical analysis of the data.

Flow frequency analysis relates the magnitude of a given flow event with the frequency or probability of that event’s exceedance. If a stream gage is available and the conditions applicable, a gage analysis is generally considered preferable to deterministic methods (Rational Formula Method, Simplified Peak Discharge Method or NRCS Unit Hydrograph Method within HEC-HMS). Since a gage represents the actual rainfall-runoff behavior of the watershed in relation to the stream. A variety of Federal, state, and local agencies operate and maintain stream gages. Currently, the USGS operates about 7,000 active stream gaging stations across the country. Data are also available for about 13,000 discontinued gaging stations. Data is available for 155 currently active sites in New Mexico and for a total of 495 sites when the discontinued sites are included.

The USGS has determined station specific flood frequency data for 293 gage locations for recurrence intervals of 2-, 5-, 10-, 25-, 50-, 100- and 500-years that generally have 10 or more years of record (through 2004). Historical peak flow data for both active and discontinued gages can be found at the following USGS website at:
http://nwis.waterdata.usgs.gov/usa/nwis/peak.

This information is also found in Appendix 1 of the USGS report prepared for New Mexico in cooperation with the NMDOT: “Analysis of the Magnitude and Frequency of Peak Discharge and Maximum Observed Peak Discharge in New Mexico and Surrounding Areas”, Scientific Investigations Report 2008-5119, USGS, Waltemeyer, Scott, D., 2008.
http://pubs.usgs.gov/sir/2008/5119/

The USGS has also developed a web-based flood-frequency analysis tool called "PeakFQ-Flood-Frequency Analysis", for determining the stream flood statistics at gaging stations with sufficiently long records. This program is available at:
https://water.usgs.gov/software/PeakFQ/

Streamflow data from gages other than USGS gages should not be used for design of NMDOT projects (unless approved by the NMDOT), but may be useful for checking against peak discharge estimates derived from other methods and sources. There are several general scenarios in which data from a non-USGS streamflow gage may be utilized:

1. The gage has been in place for a sufficient number of years (Bulletin 17C recommends at least 10 years)
2. The gage data is reasonably representative of the average watershed conditions during the period of record
3. The gage is located at the highway drainage structure
4. The gage is located upstream or downstream at some distance from the highway

The majority of the gage data in New Mexico has been collected by the USGS. For most of their active streamflow gage sites and many of their inactive sites, the USGS has computed flood frequency estimates. These estimates can be used directly for design if the gage is located at or near (as defined below) the highway crossing. The current USGS study of peak stream flows in New Mexico (USGS, Waltemeyer, Scott, D., 2008) includes tabulated flood frequency estimates for most USGS gage sites in New Mexico.

If the gage data set represents a relatively short period of record, a correction weighting procedure is recommended. The gage frequency distribution peak flood estimate is weighted according to the length of record and equivalent years from the USGS regression analysis. Waltemeyer (USGS, 1996) describes a procedure for improving flood frequency estimates at gaged sites, using USGS regression equations. In the event that the USGS gage at the highway drainage structure was not included in Waltemeyer's study, then a frequency distribution analysis is necessary. A comprehensive discussion of frequency analysis is beyond the scope of this manual. There are several publications which describe the process in great detail. References for two such publications are provided below:

USGS, England et al., 2018, "Guidelines for Determining Flood Flow Frequency, Bulletin #17C, Chapter 5 of Section B, Surface Water, Book 4, Hydrologic Analysis and Interpretation, Techniques and Methods 4-B5".
https://pubs.er.usgs.gov/publication/tm4B5

U.S. Army Corps of Engineers, 1993, "Engineering and Design, Hydrologic Frequency Analysis".
http://www.publications.usace.army.mil/Portals/76/Publications/EngineerManuals/EM_1110-2-1415.pdf

Typically, a Log-Pearson Type III probability distribution is fit to the set of streamflow data. The use of a partial duration series may be appropriate rather than an annual series depending on data availability and quality.

When the USGS streamflow gage is located on the same stream but some distance upstream or downstream of the highway, the gage site can still be used to provide a weighted flood frequency estimate. The area weighted correction procedure (USGS, Waltemeyer, Scott, D., 1996) includes a drainage area ratio adjustment which can be used when the ratio of ungaged watershed area to gaged watershed area is within the limits 0.5 to 1.5. The following excerpt from Waltemeyer explains that process.

406.1 Ungaged Site on a Stream Having a Nearby Gaging Station

This information in this section was obtained from "Analysis of the Magnitude and Frequency of Peak Discharge and Maximum Observed Peak Discharge in New Mexico and Surrounding Areas", Scientific Investigations Report 2008-5119, USGS, Waltemeyer, Scott, D., 2008.
http://pubs.usgs.gov/sir/2008/5119/

Flood-frequency estimates can be made for ungaged sites upstream or downstream from gaging stations by using a method developed by Sauer (1974). Using this method, flood-frequency data at the gaging station is transferred to the ungaged site by using the following drainage-area ratio adjustment equation:

$$Q_{T(u)} = Q_{T(g)} (A_u / A_g)^{x} \qquad \textbf{406-1}$$

(USGS, Waltemeyer, Scott, D., 2008, “Analysis of the Magnitude and Frequency of Peak Discharge and Maximum Observed Peak Discharge in New Mexico and Surrounding Areas”, Scientific Investigations Report 2008-5119, Eq. 3, p.11)

where:

$Q_{T(u)}$	=	weighted flood-frequency estimate at the ungaged site, ft^3/s
$Q_{T(g)}$	=	flood-frequency estimate at the gaging station, ft^3/s
A_u	=	drainage area at the ungaged site, square miles
A_g	=	drainage area at the gaging station, square miles
x	=	exponent of the drainage area of the applicable regional regression equation is listed in Table 2 found on pages 9 and 10 of the USGS document “Analysis of the Magnitude and Frequency of Peak Discharge and Maximum Observed Peak Discharge in New Mexico and Surrounding Areas”, by Scott D. Waltemeyer 2008

According to Sauer (1974), the equation is applicable when the drainage-area ratio (A_u/A_g), is between 0.5 and 1.5. For example, to estimate a 50-year peak discharge at an ungaged site in Region 2 upstream from gaging station Cisco Wash near Cisco, Utah (09163700), the station value listed in Appendix 1 is 4,670 ft^3/s. Note that the weighted value of 5,500 ft^3/s was not used because when using this technique, a regional adjustment is made by using the exponent from the regional equation. The weighted value is considered the best flood-frequency value, but when using this technique, a double weight would be made based on the regional flood information. The drainage area at the gaging station is 90.7 square miles (Appendix 1, USGS, 2008). The 50-year recurrence interval regression equation exponent for the drainage area is 0.308 for Region 2 (Table 2, USGS, 2008). The drainage area at the ungaged site is 75.5 square miles, and when equation 4 (USGS, 2008) is used (equation below), the peak discharge at the ungaged site is:

$$Q_{50u} = Q_{50g} \left(A_u / A_g\right)^{x}$$

$$Q_{50u} = (4{,}670)(75.5 / 90.7)^{0.308} = 4{,}410 \ ft^3/s \qquad \textbf{406-2}$$

(USGS, Waltemeyer, Scott, D., 2008, “Analysis of the Magnitude and Frequency of Peak Discharge and Maximum Observed Peak Discharge in New Mexico and Surrounding Areas”, Scientific Investigations Report 2008-5119, Eq. 3, p.12)
http://pubs.usgs.gov/sir/2008/5119/

Note: The USGS has developed a web application called “StreamStats”. StreamStats incorporates a Geographic Information System (GIS) to provide users with access to an assortment of analytical tools that are useful for a variety of water resources planning and management purposes, and for engineering and design purposes.
https://water.usgs.gov/osw/streamstats/

406.2 References

Sauer, V.B., 1974, “Flood Characteristics of Oklahoma Streams: U.S. Geological Survey Water-Resources Investigations Report 52-73”.

U.S. Army Corps of Engineers, March 1993, “EM 1110-2- 1415 Hydrologic Frequency Analysis”. http://www.publications.usace.army.mil/Portals/76/Publications/EngineerManuals/EM_1110-2-1415.pdf

USGS, Website, "PeakFQ-Flood-Frequency Analysis". https://water.usgs.gov/software/PeakFQ/

USGS, Website, “StreamStats”. https://water.usgs.gov/osw/streamstats/

USGS, Website, “Stream Flow Gage Data, Active and Discontinued Gages” http://nwis.waterdata.usgs.gov/usa/nwis/peak.

USGS, Waltemeyer, Scott, D., 1996, “Analysis of the Magnitude and Frequency of Peak Discharge and Maximum Observed Peak Discharge in New Mexico”, Water-Resources Investigations Report 96-4112. http://pubs.er.usgs.gov/publication/wri964112

USGS, England, J.F., Jr., Cohn, T.A., Faber, B.A., Stedinger, J.R., Thomas, W.O., Jr., Veilleux, A.G., Kiang, J.E., Mason, R.R., Jr., 2018, “Guidelines for Determining Flood Flow Frequency, Bulletin #17C, Chapter 5 of Section B, Surface Water, Book 4, Hydrologic Analysis and Interpretation, Techniques and Methods 4-B5”. https://pubs.er.usgs.gov/publication/tm4B5

USGS, Waltemeyer, Scott, D., 2008, “Analysis of the Magnitude and Frequency of Peak Discharge and Maximum Observed Peak Discharge in New Mexico and Surrounding Areas”, Scientific Investigations Report 2008-5119. http://pubs.usgs.gov/sir/2008/5119/

407 Statistical Methods in Watersheds without Stream Gage Data

The USGS’s (Waltemeyer, 2008) report titled “Analysis of the Magnitude and Frequency of Peak Discharge and Maximum Observed Peak Discharge in New Mexico and Surrounding Areas”, Scientific Investigations Report 2008-5119, was prepared in cooperation with the NMDOT. The report summarized the analyses and equations developed for estimating peak discharges for recurrence intervals of 2-, 5-,10-, 25-, 50-, 100- and 500-years at ungaged sites by use of data collected through 2004 for 293 gaging stations on unregulated streams that have 10 or more years of record.

The regional flood frequency equation values shown in Table 2 of the above-referenced report list the “Average Standard Error of Estimates” for each of the nine hydrologic regions and for recurrence intervals of 2-, 5-, 10-, 25-, 50-, 100- and 500-years. Flood magnitude estimates from the USGS are based on information collected from stream gage data as well as from estimates of flood magnitude using high water marks and eyewitness accounts when gages were damaged or destroyed by the flood. Many records are relatively short compared to the exceedance frequency projected by the statistics. There are also inherent accuracy problems with some of the data collected by means other than from a properly functioning gage. Hence the estimates produced may differ from those that would have been produced if the records were long and accurate.

It is important to consider the Standard Error when using USGS regression estimates as it affects the accuracy of the estimates and, therefore, the reliance that can be placed on the interpretations drawn from the data.

The USGS states in the above-referenced report: The average Standard Error of prediction, which includes average sampling error and average Standard Error of regression, ranged from 38 to 93 percent (mean value is 62, and median value is 59) for the 100-year flood. The 1996 investigation Standard Error of prediction for the flood regions ranged from 41 to 96 percent (mean value is 67, and median value is 68) for the 100-year flood that was analyzed by using generalized least-squares regression analysis. Overall, the equations based on generalized least-squares regression techniques are more reliable than those in the 1996 report because of the increased length of record and improved geographic information system (GIS) method to determine basin and climatic characteristics.

The Standard Error measure indicates the extent to which a regression estimate is likely to deviate from the true population and is expressed as a number. The Relative Standard Error (RSE) is the Standard Error expressed as a fraction of the estimate and is usually displayed as a percentage. Estimates with a RSE of 25% or greater are subject to high sampling and regression error and should be used with caution.

The average Standard Error of estimates listed in Table 2 of the above referenced USGS report all exceed 25% (with some exceeding 100%). Therefore, the use of the USGS regional regression equations for New Mexico should be limited to:

1. Determination that the peak discharges calculated using one of the three approved hydrologic peak discharge analyses methods are within reason and supported by the exercise of judgment, and
2. For very preliminary peak discharge estimation when scoping a project
3. USGS regional regression equations may be used for design when checked against one of the hydrologic peak discharge analysis methods and approved by the NMDOT Drainage Engineer

The tabulation of maximum observed peak discharges for sites within each of the nine hydrologic regions around New Mexico are listed in Appendix 3 of the Waltemeyer 2008 report. The engineer is encouraged to review that Appendix when performing drainage analyses to gain further understanding of the hydrologic response of the various regions around the state. An excerpt from Appendix 3 is shown below (**Figure 407-1**) for reference.

Appendix 3. Miscellaneous sites, maximum peak discharge, drainage area, and site elevations.

[DMS, degrees minutes seconds; NGVD 29, National Geodetic Vertical Datum of 1929]

Map identi-fier (fig. 2)	Latitude (DMS)	Longi-tude (DMS)	Miscellaneous site name	Date	Maximum peak discharge (cubic feet per second)	Drainage area (square miles)	Site elevation (feet above NGVD 29)	Region
1	362958	1030731	Apache Creek at State Highway 18 near Clayton, New Mexico	1952	2,500	50.8	4,780	1
2	354906	1034621	Arroyo del Alamo near Mosquero, New Mexico	05/16/54	3,440	27.4	4,380	1
3	350110	1040426	Arroyo Laguana tributary near Montoya, New Mexico	07/05/60	2,660	3.40	4,460	1
4	350216	1033407	Barranca Creek near Norton, New Mexico	08/23/59	3,870	147	4,040	1
5	350714	1035416	Blanco Creek tributary at Palomas, New Mexico	07/05/60	1,540	2.90	4,330	1
6	365451	1030515	Bontz Arroyo near Guy, New Mexico	07/06/58	2,410	4.90	4,450	1
7	364546	1042933	Canadian River tributary near Hebron, New Mexico	06/17/65	2,130	2.01	6,300	1
8	364818	1030100	Carrizozo Creek tributary near Moses, New Mexico	07/06/58	307	0.15	4,730	1
9	352646	1034249	Carros Creek near Gallegos, New Mexico	07/08/60	2,590	9.40	4,050	1
10	361550	1031235	Carrizo Creek near Clayton, New Mexico	05/28/57	29,500	305	4,780	1
11	365210	1042246	Chicorica Creek near Raton, New Mexico	06/17/65	12,800	78.8	6,460	1
12	365100	1042125	Chicorica Creek tributary near Raton, New Mexico	06/17/65	1,810	1.33	6,470	1
13	362122	1032812	Carrizo Creek above State Road 56 near Clayton, New Mexico	06/17/65	9,270	305	5,245	1
14	353616	1045352	Conchas River tributary near Trujillo, New Mexico	07/05/67	4,530	3.43	6,480	1
15	353622	1045208	Conchas River near Trujillo, New Mexico	07/05/67	9,810	18.6	6,430	1
16	364216	1043536	Crow Creek below Waldron Canyon near Koehler, New Mexico	06/17/65	30,400	59.8	6,260	1
17	363755	1043225	Crow Creek near Maxwell, New Mexico	06/17/65	13,100	78.4	6,030	1
18	351813	1041843	Cuervo Creek near Conchas Dam, New Mexico	06/18/69	12,800	135	4,280	1
19	360020	1033331	Del Muerto Creek near Bueyeros, New Mexico	07/16/72	34,600	29.0	4,690	1
20	365540	1042130	East Fork Chicorica Creek at Yankee, New Mexico	06/17/65	13,500	22.7	6,780	1
21	351256	1031216	Frost Creek near Porter, New Mexico	07/16/58	2,910	10.0	3,900	1
22	354430	1040722	La Cinta Creek near Roy, New Mexico	08/17/77	13,300	116.5	4,700	1
23	361249	1043900	Ocate Creek at Colmar, New Mexico	07/04/51	25,000	434	5,900	1
24	354113	1030746	Minneosa Creek near Nara Visa, New Mexico	07/23/54	20,400	118	4,300	1
25	345838	1034502	Paris Creek near Quay, New Mexico	07/17/56	3,410	9.20	4,220	1

Source: USGS, Waltemeyer, Scott, D., 2008, "Analysis of the Magnitude and Frequency of Peak Discharge and Maximum Observed Peak Discharge in New Mexico and Surrounding Areas", Appendix 3, p. 91.
http://pubs.usgs.gov/sir/2008/5119/

Figure 407-1 USGS Appendix 3 Excerpt

407.1 References

USGS, Waltemeyer, Scott, D., 2008, "Analysis of the Magnitude and Frequency of Peak Discharge and Maximum Observed Peak Discharge in New Mexico and Surrounding Areas", Scientific Investigations Report 2008-5119.
http://pubs.usgs.gov/sir/2008/5119/

408 Risk and Uncertainty in Hydrologic Analysis

Highway drainage structures are designed to safely pass a certain magnitude flood. On most New Mexico highways, the Design Flood will be the "50-year" frequency flood. This flood is theoretically equivalent to the largest flood which will occur at that location on average at least once every fifty years. By designing drainage structures to safely pass relatively rare events, the risk to users of the highway is reduced to an acceptable level. There is always some chance, or risk, that a flood will occur which exceeds the design flood used to size a particular drainage structure. While it might be desirable to design all drainage structures to pass the largest possible flood, economic realities prevent this option. Instead, a level of protection must be provided which is both responsible and reasonable.

Design exceptions or variances may be required as a result of budget impacts, right-of-way limitations, environmental and property impacts, or other constraints. Such variances are only allowed when all other options have been considered and found to be inadequate. If deviation from the criteria and design standards for major drainage structures or systems is necessary, a risk assessment may be required. If a jurisdiction or organization has more stringent criteria than the NMDOT criteria, those criteria shall govern the drainage design. Even though the 50-year flood occurs on average at least once every 50 years, there is some small, but very real possibility (2% chance) that this flood could occur in any given year. Stated another way, just because a 50-year flood occurred last year, does not mean that it could not occur again this year. The probability of a 50-year flood occurring or being exceeded this year and every year is remains at 2%.

In order to better quantify the risk associated with a certain design frequency the following example is provided:

Consider a drainage structure capable of passing the 100-year frequency event with a structural design life of 50-years. What is the probability or risk, that the structure will see a 100-year flood (or greater) during its design life? The logical answer might be 1 chance in 2, or 50%. However statistical analyses show that the risk is lower, actually at 39.5%. Statistically, the concept of risk is described by a binomial distribution

USGS, England et al., 2018, "Guidelines for Determining Flood Flow Frequency, Bulletin #17C, Chapter 5 of Section B, Surface Water, Book 4, Hydrologic Analysis and Interpretation, Techniques and Methods 4-B5".
https://pubs.er.usgs.gov/publication/tm4B5

Equation 408-1 describes this statistical relationship.

$$R = 1 - \left(1 - \frac{1}{T_r}\right)^m \times 100 \qquad \textbf{408-1}$$

where:

R	=	the risk of design discharge being exceeded at least once during the design life, percent
T_r	=	the recurrence interval or frequency of the design flood, years
m	=	the design life of the structure, years

$R = 1 - \left(1 - \frac{1}{100}\right)^{50} \times 100 = 39.5\%$ for the example above.

Assuming that the structure is designed for the 50-year flood and has a design life of 50 years, then **Equation 408-1** predicts that the structure's capacity has a 63.6% chance of being equaled or exceeded during the structure's design life.

$$R = 1 - \left(1 - \frac{1}{50}\right)^{50} \text{ x } 100 = 63.6\%$$

Table 408-1 lists computed values of risk for a range of structure design lives.

Table 408-1 Tabulation of Risk of at Least One Exceedance during the Design Life

	Design Life - Years					
Recurrence Interval	**2**	**5**	**10**	**25**	**50**	**100**
2	75.0%	97.0%	100.0%	100.0%	100.0%	100.0%
5	36.0%	67.0%	89.0%	100.0%	100.0%	100.0%
10	19.0%	41.0%	65.0%	93.0%	99.0%	100.0%
25	8.0%	18.0%	34.0%	64.0%	87.0%	98.0%
50	4.0%	10.0%	18.0%	40.0%	64.0%	87.0%
100	2.0%	5.0%	10.0%	22.0%	39.0%	63.0%
500	0.4%	1.0%	2.0%	5.0%	10.0%	18.0%
1000	0.2%	0.5%	1.0%	2.0%	5.0%	10.0%

Another way of looking at the concept of risk is to define an acceptable level of risk and then compute the design flood which would have to be accommodated by the drainage structure to satisfy that level of risk. **Equation 408-1** can be rearranged to solve for the required return period, yielding **Equation 408-2**.

$$Tr = \frac{1}{1 - \left(1 - \frac{R}{100}\right)^{1/m}}$$ **408-2**

Assume that a 10% level of risk is desirable, or stated another way, there is a 90% confidence level that the structure is adequate. Then **Equation 408-2** predicts that the structure with the design life of 50 years must be capable of passing the 475-year flood.

$$Tr = \frac{1}{1 - \left(1 - \frac{10}{100}\right)^{\frac{1}{50}}} = 475 \text{ years}$$

It becomes apparent that risk cannot be completely eliminated, but may be reduced to a level acceptable to society. Even if there were unlimited funds to build drainage structures, the ability to accurately calculate the magnitude of flood events decreases as the design flood magnitude increases. All of the current flood prediction methods, whether analytical or parametric, are based on observed flood flows from watersheds with measured response characteristics, and occasionally rain gage data. The effective period of recorded data in New Mexico reaches 100 years in only a few locations. Thus, the prediction of a 475-year flood is done by extrapolating the data, since the desired flood has only a small chance of being included in the data set. The uncertainty in predicted flood flows increases as the return period lengthens.

The accuracy of predicted flood magnitudes up to the 100-year event is, while not perfect, certainly much better. For the analytic methods presented in this manual, risk takes the form of uncertainty in the input parameters. A drainage area can be measured by multiple engineers and the answers from each, should all be within two or three percent. Use of a consistent method to compute Tc reduces variability in the estimation of Tc. However, the selection of a Rational Formula Method Runoff Coefficient "C", or a NRCS Runoff Curve Number “CN” involves considerable judgement. Even meticulous measurement of watershed areas, land uses, and Hydrologic Soil Groups may not accurately describe the response of the watershed for every storm. There is some inherent variability of the data, and of its interpretation, leading to uncertainty in the selection of the correct “C” or “CN”. This uncertainty cannot be universally quantified, and thus becomes part of the overall risk and uncertainty in predicting peak flood magnitudes.

With the analytic methods in this manual, one approach to qualitatively assess the risk is to perform a sensitivity analysis. This is done by varying a particular input parameter across its range of reasonable values and comparing the resulting range of predicted peak flows. The most sensitive analytic parameter in larger watersheds will probably be the “C” or “CN”. Use the “C” or “CN” value obtained by normal design methods to compute a peak flow, as well as the lowest and highest “C” or “CN” values which could occur in the watershed. (Note: In small watersheds, Tc can be the most sensitive input value, but the process is the same.)

The resulting three computed peak flow values provide an estimate of the range of most probable peak flood flows. This is not a precise computed range of risk, but it does help to bracket the most likely peak flow value. The middle peak flood flow value will often be used to size the structure, while the upper limit peak flood flow can be used to assess the "worst case" headwater or overtopping condition. If the risk and consequences of an overtopping or significant backwater are unacceptably adverse to the roadway or nearby property, consider an alternate design.

408.1 Reference

USGS, England, J.F., Jr., Cohn, T.A., Faber, B.A., Stedinger, J.R., Thomas, W.O. Jr., Veilleux, A.G., Kiang, J.E., Mason, R.R., Jr., 2018, “Guidelines for Determining Flood Flow Frequency, Bulletin #17C, Chapter 5 of Section B, Surface Water, Book 4, Hydrologic Analysis and Interpretation, Techniques and Methods 4-B5”.
https://pubs.er.usgs.gov/publication/tm4B5
https://water.usgs.gov/osw/bulletin17b/dl_flow.pdf

ATTACHMENT III.4.B

NOAA POINT PRECIPITATION FREQUENCY ESTIMATES

NOAA Atlas 14, Volume 1, Version 5
Location name: Bloomfield, New Mexico, USA*
Latitude: 36.7555°, Longitude: -107.983°
Elevation: 5723.55 ft**
* source: ESRI Maps
** source: USGS

POINT PRECIPITATION FREQUENCY ESTIMATES

Sanja Perica, Sarah Dietz, Sarah Heim, Lillian Hiner, Kazungu Maitaria, Deborah Martin, Sandra Pavlovic, Ishani Roy, Carl Trypaluk, Dale Unruh, Fenglin Yan, Michael Yekta, Tan Zhao, Geoffrey Bonnin, Daniel Brewer, Li-Chuan Chen, Tye Parzybok, John Yarchoan

NOAA, National Weather Service, Silver Spring, Maryland

PF_tabular | PF_graphical | Maps_&_aerials

PF tabular

PDS-based point precipitation frequency estimates with 90% confidence intervals (in inches)[1]

Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	0.149 (0.128-0.175)	0.192 (0.165-0.224)	0.258 (0.223-0.301)	0.313 (0.269-0.365)	0.392 (0.333-0.457)	0.457 (0.385-0.532)	0.527 (0.439-0.614)	0.602 (0.495-0.703)	0.710 (0.571-0.832)	0.799 (0.633-0.941)
10-min	0.227 (0.196-0.265)	0.292 (0.251-0.341)	0.393 (0.338-0.458)	0.476 (0.409-0.556)	0.596 (0.507-0.695)	0.696 (0.586-0.809)	0.801 (0.668-0.934)	0.917 (0.754-1.07)	1.08 (0.869-1.27)	1.22 (0.964-1.43)
15-min	0.281 (0.242-0.329)	0.362 (0.311-0.423)	0.487 (0.420-0.568)	0.590 (0.507-0.689)	0.739 (0.629-0.861)	0.862 (0.726-1.00)	0.993 (0.828-1.16)	1.14 (0.934-1.33)	1.34 (1.08-1.57)	1.51 (1.20-1.78)
30-min	0.379 (0.326-0.443)	0.488 (0.419-0.569)	0.656 (0.565-0.765)	0.795 (0.683-0.928)	0.995 (0.846-1.16)	1.16 (0.977-1.35)	1.34 (1.11-1.56)	1.53 (1.26-1.79)	1.80 (1.45-2.11)	2.03 (1.61-2.39)
60-min	0.469 (0.403-0.548)	0.604 (0.519-0.704)	0.812 (0.699-0.946)	0.984 (0.845-1.15)	1.23 (1.05-1.44)	1.44 (1.21-1.67)	1.66 (1.38-1.93)	1.89 (1.56-2.21)	2.23 (1.80-2.62)	2.51 (1.99-2.96)
2-hr	0.537 (0.469-0.623)	0.683 (0.596-0.792)	0.906 (0.792-1.05)	1.09 (0.952-1.26)	1.37 (1.18-1.58)	1.59 (1.36-1.84)	1.84 (1.55-2.12)	2.11 (1.74-2.44)	2.50 (2.03-2.91)	2.83 (2.25-3.30)
3-hr	0.581 (0.515-0.664)	0.733 (0.647-0.837)	0.951 (0.842-1.09)	1.13 (0.997-1.29)	1.40 (1.22-1.59)	1.62 (1.40-1.85)	1.86 (1.58-2.14)	2.12 (1.78-2.46)	2.51 (2.06-2.94)	2.86 (2.28-3.34)
6-hr	0.697 (0.629-0.782)	0.866 (0.781-0.973)	1.09 (0.982-1.23)	1.28 (1.15-1.44)	1.56 (1.39-1.75)	1.79 (1.58-2.01)	2.03 (1.77-2.28)	2.30 (1.97-2.58)	2.68 (2.24-3.04)	3.00 (2.46-3.42)
12-hr	0.822 (0.744-0.911)	1.02 (0.925-1.13)	1.27 (1.15-1.40)	1.46 (1.32-1.62)	1.74 (1.56-1.91)	1.95 (1.74-2.15)	2.17 (1.92-2.40)	2.40 (2.10-2.67)	2.72 (2.34-3.05)	3.01 (2.55-3.45)
24-hr	0.904 (0.825-0.992)	1.14 (1.03-1.24)	1.43 (1.31-1.57)	1.68 (1.52-1.83)	2.02 (1.82-2.20)	2.28 (2.05-2.49)	2.56 (2.29-2.79)	2.85 (2.54-3.12)	3.25 (2.86-3.57)	3.57 (3.11-3.93)
2-day	1.05 (0.960-1.15)	1.32 (1.20-1.44)	1.65 (1.51-1.80)	1.91 (1.75-2.09)	2.28 (2.07-2.48)	2.57 (2.32-2.79)	2.86 (2.57-3.12)	3.17 (2.83-3.46)	3.58 (3.17-3.92)	3.91 (3.43-4.29)
3-day	1.13 (1.04-1.23)	1.41 (1.30-1.54)	1.76 (1.62-1.92)	2.04 (1.87-2.22)	2.42 (2.21-2.64)	2.72 (2.47-2.96)	3.02 (2.73-3.29)	3.33 (2.99-3.63)	3.75 (3.33-4.11)	4.08 (3.60-4.48)
4-day	1.21 (1.11-1.32)	1.51 (1.39-1.65)	1.88 (1.72-2.04)	2.17 (1.99-2.36)	2.56 (2.34-2.79)	2.87 (2.61-3.12)	3.18 (2.88-3.47)	3.49 (3.14-3.81)	3.92 (3.50-4.29)	4.25 (3.76-4.66)
7-day	1.38 (1.26-1.50)	1.72 (1.57-1.87)	2.13 (1.95-2.31)	2.45 (2.24-2.66)	2.88 (2.63-3.12)	3.21 (2.91-3.48)	3.54 (3.20-3.84)	3.87 (3.48-4.21)	4.30 (3.84-4.69)	4.64 (4.11-5.06)
10-day	1.55 (1.43-1.69)	1.94 (1.78-2.11)	2.40 (2.20-2.61)	2.76 (2.53-3.00)	3.23 (2.95-3.51)	3.58 (3.27-3.90)	3.94 (3.58-4.29)	4.29 (3.89-4.68)	4.75 (4.28-5.20)	5.09 (4.55-5.59)
20-day	2.00 (1.83-2.19)	2.50 (2.28-2.73)	3.09 (2.81-3.37)	3.55 (3.23-3.88)	4.16 (3.78-4.54)	4.62 (4.18-5.05)	5.08 (4.58-5.56)	5.54 (4.97-6.07)	6.14 (5.48-6.75)	6.60 (5.85-7.27)
30-day	2.37 (2.17-2.59)	2.95 (2.70-3.23)	3.63 (3.32-3.98)	4.15 (3.79-4.54)	4.83 (4.39-5.28)	5.32 (4.83-5.82)	5.81 (5.24-6.37)	6.30 (5.66-6.91)	6.91 (6.17-7.60)	7.37 (6.55-8.13)
45-day	2.84 (2.61-3.09)	3.54 (3.26-3.86)	4.35 (4.00-4.74)	4.96 (4.55-5.40)	5.74 (5.25-6.25)	6.31 (5.74-6.87)	6.86 (6.22-7.48)	7.40 (6.68-8.08)	8.08 (7.25-8.85)	8.57 (7.66-9.41)
60-day	3.26 (2.98-3.56)	4.07 (3.72-4.45)	4.97 (4.54-5.45)	5.65 (5.15-6.18)	6.51 (5.92-7.12)	7.12 (6.47-7.79)	7.72 (6.99-8.45)	8.29 (7.48-9.08)	9.01 (8.09-9.90)	9.52 (8.52-10.5)

[1] Precipitation frequency (PF) estimates in this table are based on frequency analysis of partial duration series (PDS).

Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and average recurrence interval) will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.

Please refer to NOAA Atlas 14 document for more information.

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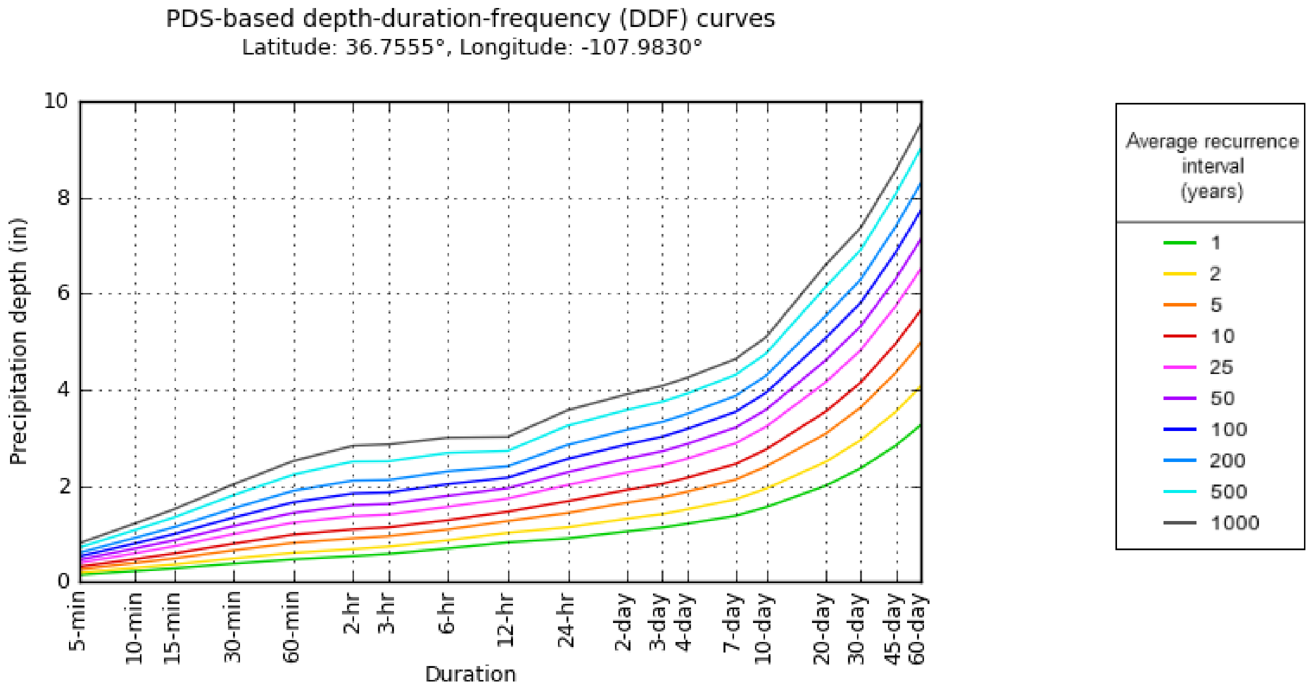
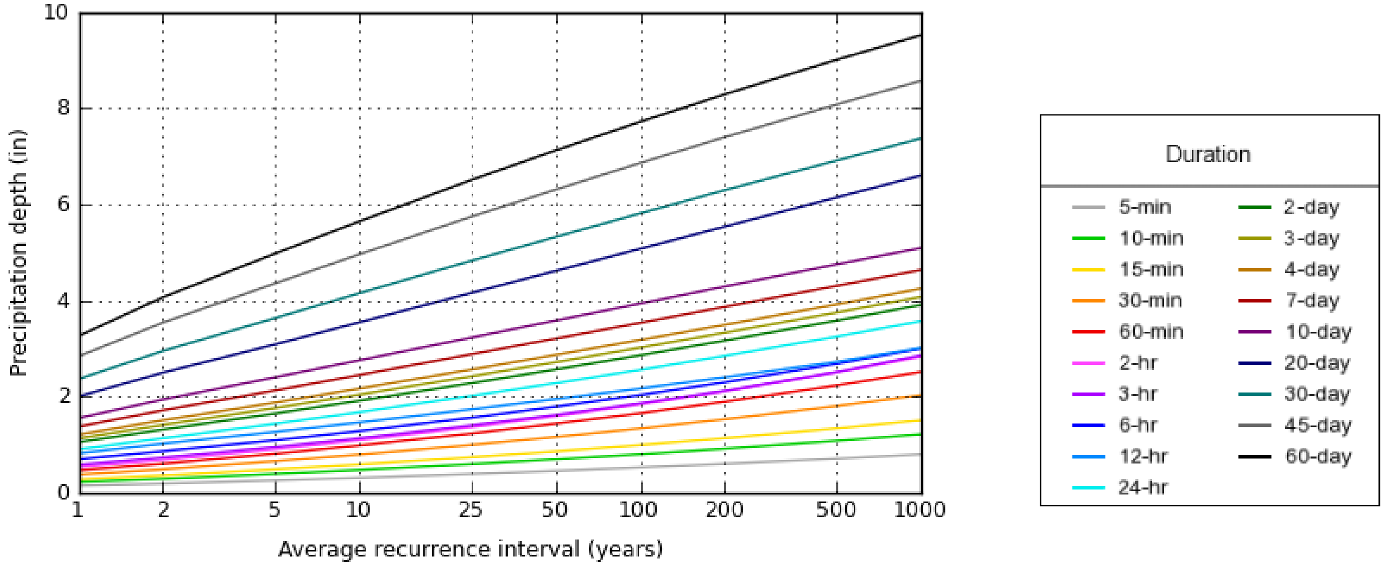
PF graphical





NOAA Atlas 14, Volume 1, Version 5 Created (GMT): Tue Oct 1 21:00:24 2019

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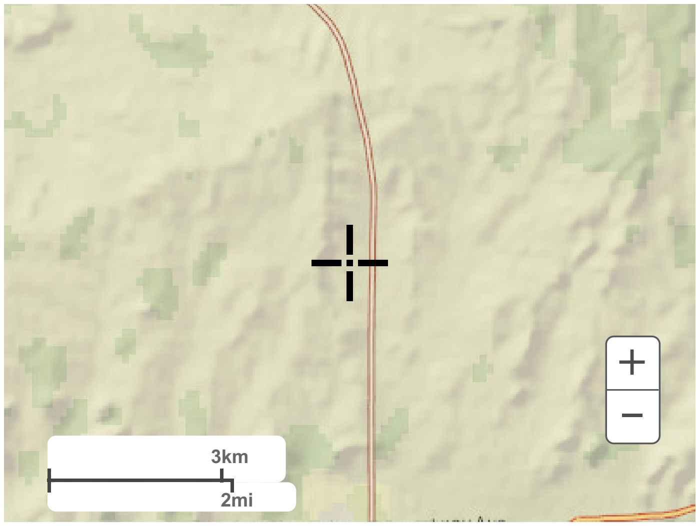
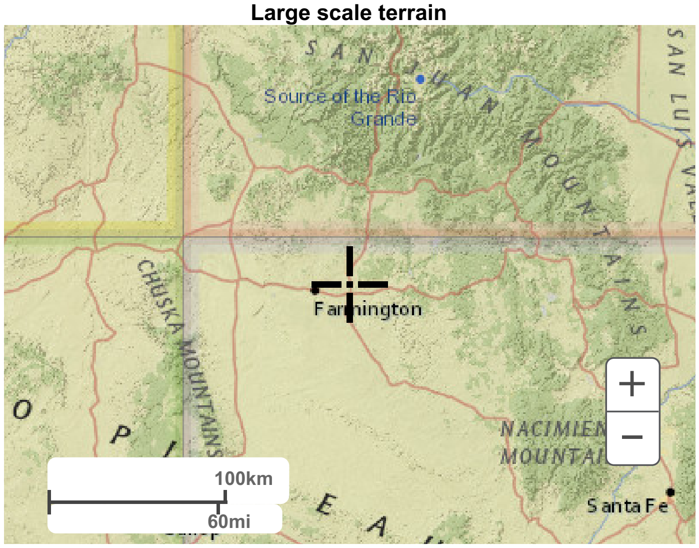
Maps & aerials

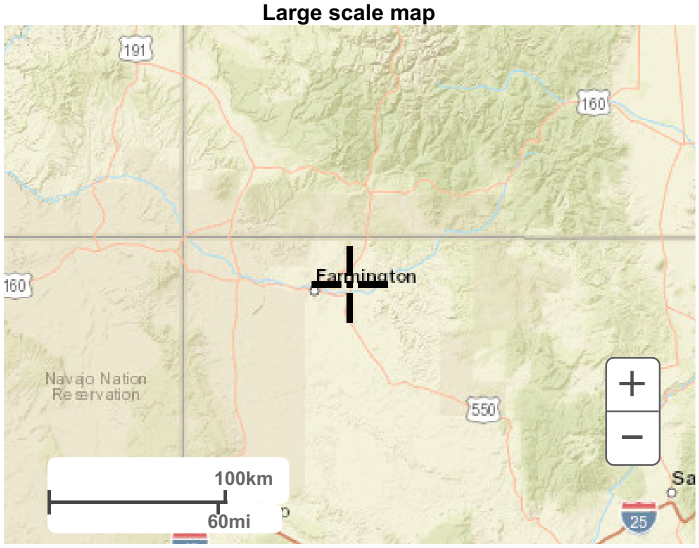
Small scale terrain



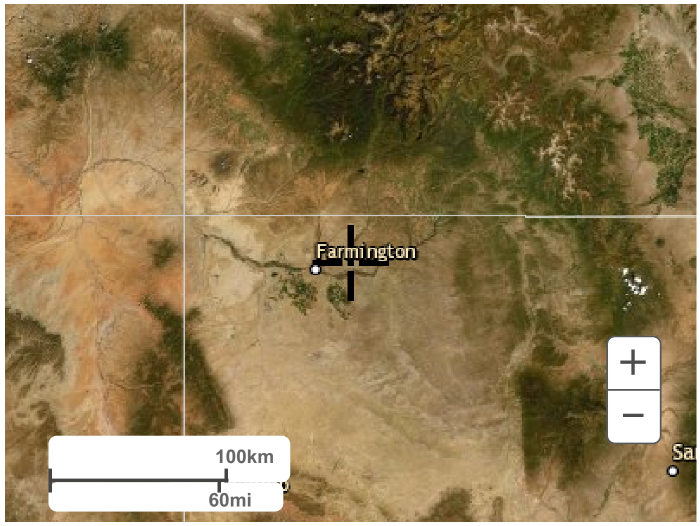
Large scale terrain



Large scale map



Large scale aerial



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US Department of Commerce
National Oceanic and Atmospheric Administration
National Weather Service
National Water Center
1325 East West Highway
Silver Spring, MD 20910
Questions?: HDSC.Questions@noaa.gov

Disclaimer

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1.2	Facility Description	2
2.0	DESIGN CRITERIA	2
3.0	CALCULATION	3
4.0	SUMMARY	3

LIST OF ATTACHMENTS

Attachment No.	Title
III.5.A	LOW COST SHORE PROTECTION: A GUIDE FOR ENGINEERS AND CONTRACTORS (U.S. ARMY CORPS OF ENGINEERS 2004
III.5.B	WATER-RESOURCES ENGINEERING (LINSLEY & FRANZINI 1979)

1.0 INTRODUCTION

Basin Disposal, Inc. (BDI) is an existing Surface Waste Management Facility (SWMF) providing oil field waste liquids (OFWL) disposal services. The existing BDI facility is subject to regulation under the New Mexico Oil and Gas Rules, specifically 19.15.36 NMAC, administered by the Oil Conservation Division (OCD) of the NM Energy, Minerals, and Natural Resources Department (NMEMNRD). This document is a component of the "Application for Permit Renewal" that proposes continued operations of the existing approved waste processing and disposal capabilities. The Facility is designed in compliance with 19.15.36 NMAC, and is operated in compliance with a Surface Waste Management Facility Permit issued by the OCD. The Facility is owned and operated by, Basin Disposal Inc.

BDI only accepts liquid waste from the production and exploration of oil fields in northwest New Mexico and the surrounding areas. The existing facility is organized in a pattern that allows for specific liquid waste acceptance, treatment, evaporation, or injection of clean liquid.

1.1 Site Location

BDI is located in unincorporated San Juan County on 27.77 acres entirely within Section 3, Township 29 North, Range 11 West approximately 3 miles north of the intersection of Highway 550 and 64 (**Figure II.1.1**). Coordinates for the approximate center of the BDI site are Latitude 36°45'19.92" and Longitude -107°58'58.73". The site is situated approximately 4 miles north of the San Juan River, and about 4.7 miles south of the Animas River on Crouch Mesa, about 500 feet and 400 feet in elevation above these respective river plains. The site occupies the West Fork of Bloomfield Canyon, an ephemeral drainage channel that drains south to the San Juan River. The site slopes gently to the east and southeast, from a maximum elevation of 5,750 feet to less than 5,700 feet. Detailed site characterization documentation is provided in **Volume IV**.

1.2 Facility Description

The existing BDI facility is comprised of 27.77 acres and is comprised of the following:

- 2 existing evaporation ponds (1 pending construction)
- 12 existing receiving tanks (6 pending construction)
- 4 existing oily water receiving tanks
- 3 existing skimmed oil tanks
- 3 existing oil heating tanks
- 3 existing settling tanks
- 7 existing oil sales tanks (2 pending construction)
- 3 existing filtered water tanks
- 4 existing bleach tanks
- 1 existing concrete sludge solidification basin
- 2 existing covered below grade tanks (containment sumps)
- 1 existing UIC Class II injection well for disposal of produced water
- 2 existing separation tanks
- Various support facilities including an office, a maintenance building, roads, and a storm water detention basin.

Oil field wastes are delivered to the BDI SWMF from oil and gas exploration and production operations in northwestern New Mexico and southwest Colorado. The Site Plan provided as **Figure II.1.2** identify the locations of the Disposal facilities, evaporation/storage ponds, and all structures. Perimeter of the site is surrounded by commercial/industrial businesses on three sides and buffered by a bluff on the west side of the Facility.

2.0 DESIGN CRITERIA

The purpose of the Wave Action Calculations presented herein is to provide the wave height and run-up for the evaporation ponds for the Basin Disposal Processing Area. The Basin Disposal Processing Area is designed to include 3 evaporation ponds, approximately 420 feet (ft) in length and 200 ft in width, each with a capacity of approximately 9.5 acre-ft. These calculations assume a pond length of 420 ft and a conservative wind speed of 75 miles per hour (mph). Wave height and run-up must be less than the 3.5 ft of freeboard provided in the pond design. The methodology applied for determining wave height and run-up in reservoirs for the Wave Action Calculations is provided in two documents, *Low Cost Shore Protection: A Guide for Engineers and Contractors* (U.S. Army Corps of Engineers 2004; (**Attachment III.5.A**); and *Water-Resources Engineering* (Linsley & Franzini 1979; **Attachment III.5.B**).

3.0 CALCULATION

The fastest mile wind speed for a 25-year return period was obtained from Figure 16, **Attachment III.5.A**. The fastest mile wind speed is approximately 75 mph for the Basin Disposal site vicinity.

Wave height in a pond is estimated using the following equation (i.e., page 166, Equation 7-4, **Attachment III.5.B)**:

$Z_w = 0.034\ (V_w)^{1.06}\ F^{0.47}$

Where:

Z_w	=	height of wave (feet)
V_w	=	wind speed (mph) = 75 mph
F	=	fetch length (miles) = 420 feet/5,280 feet/mile = 0.080 miles

Therefore:

$Z_w = 0.034\ (75\ \text{mph})^{1.06}\ (0.080\ \text{miles})^{0.47}$

$Z_w = 0.034\ (97.2)\ (0.30)$

$Z_w = 0.99$ feet = height of wave in pond due to a 75 mph wind

The height of wave runup for a smooth (i.e., HDPE liner) surface can be obtained from Table 11, **Attachment III.5.A**. On Table 11, R = 1.75H for a 2.5H:1V smooth slope and R = 1.50H for a 4.0H:1V smooth slope. Interpolating between these two values a value of R = 1.68H is obtained for a 3.0H:1V smooth slope. Therefore:

Wave Runup = 1.68H = 1.68 (0.99 feet) = 1.66 feet for a 3H:1V smooth sideslope.

Total: Wave height + Wave run-up = 0.99 feet + 1.66 feet = 2.65 feet

4.0 SUMMARY

When considering a conservative 75 mph wind across the length of the pond, a wave height of 0.99 ft is calculated. This wave will run-up approximately 1.66 ft up the sideslope of the pond. The ponds have been designed with a minimum freeboard of 3.5 ft which will provide adequate protection against the combined potential impact of waves, wave run-up, and simultaneous rainfall event (i.e., 25-year, 24-hour rainfall = 4.48”) with a sufficient Factor of Safety (FS) of over 0.5 ft. In addition, the berm to be constructed around the entire pond area is lined to an additional height of at least 10 ft, providing additional potential drift protection (see **Permit Plans, Volume III.1**)

ATTACHMENT III.5.A

LOW COST SHORE PROTECTION: A GUIDE FOR ENGINEERS AND CONTRACTORS

(U.S. ARMY CORPS OF ENGINEERS 2004)

LOW COST SHORE PROTECTION

... a Guide for Engineers and Contractors

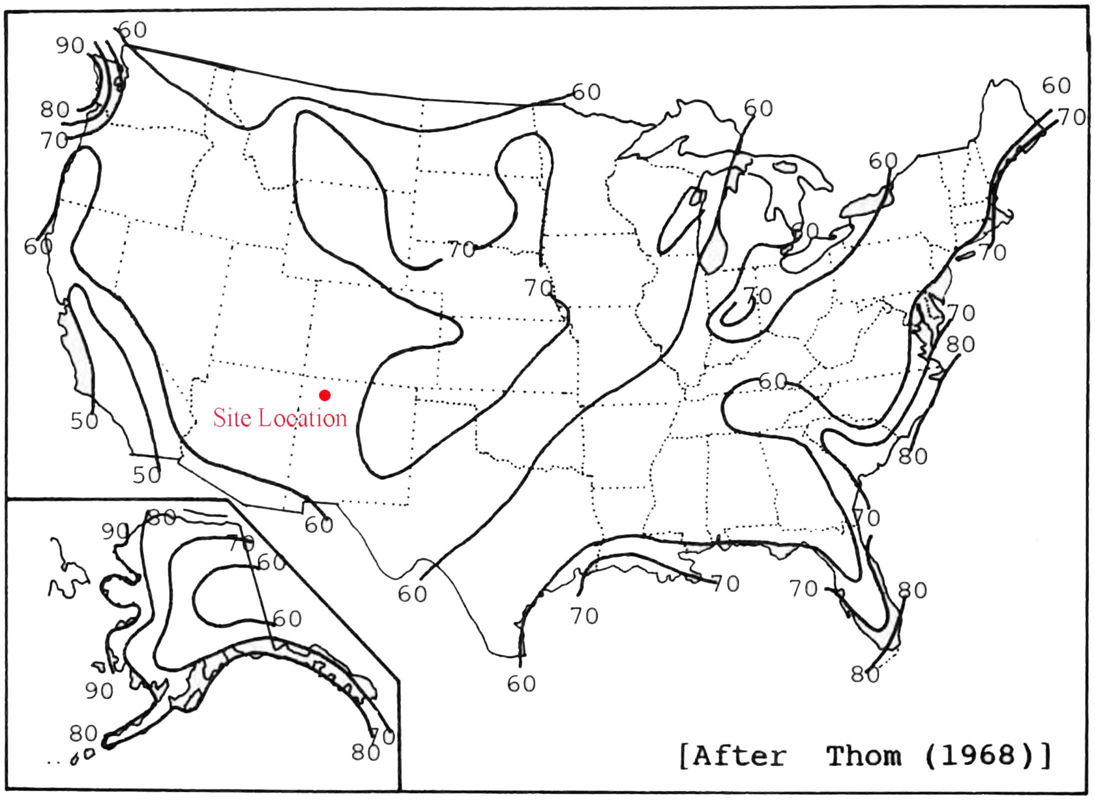


Figure 15 Fastest-Mile Wind Speeds: 10-year Return Period

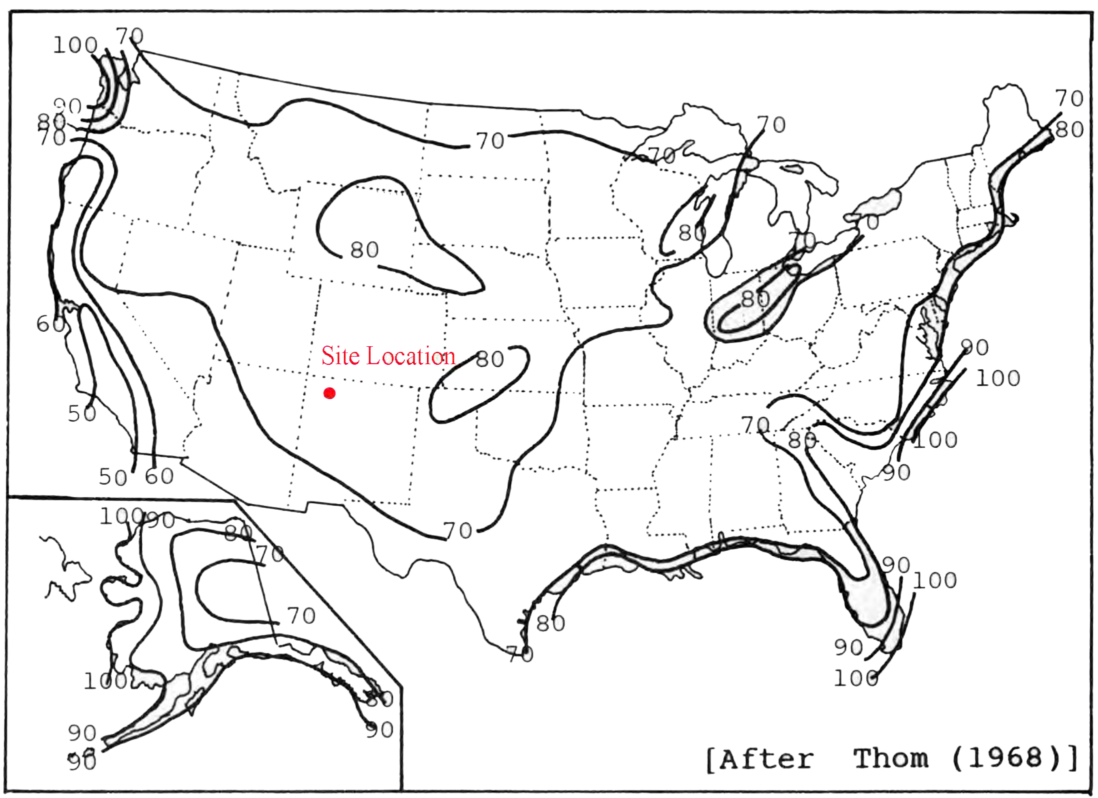


Figure 16 Fastest-Mile Wind Speeds: 25-year Return Period

Structure Height

Waves breaking against an inclined structure will run up to an elevation higher than the Stillwater level depending on the roughness of the structure. Smooth concrete surfaces experience higher runup than rough stone slopes. Vertical structures also cause splashing and can experience overtopping. If possible, the structure should be built high enough to preclude severe overtopping. White spray does little damage, but solid jets of "green" water should be avoided. The required height of the structure will depend on the computed runup height based on the wave and structure characteristics. Detailed guidance is presented in Stoa (1978) and (1979). The runup height, R, can be found by a more approximate method as given below.

First, find the wavelength at the structure by using either Figure 26 or Equation (3) with the known depth at the structure and the design wave period. The definition sketch for runup is shown on Figure 27. For SMOOTH impermeable slopes, the runup, R, is given in Seelig (1980) by,

$R = HC_1 (0.12L/H)\wedge(C_2 (H/d_s)^{0.5} + C_3)$

where: L = the local wavelength from Figure 26 or Eq. (3),
d_s = the depth at the structure (feet),
the approaching wave height (feet), and
C_1, C_2, C_3 = coefficients given below.

Structure Slope *	C_1	C_2	C_3
Vertical	0.96	0.23	+0.06
1 on 1.0	1.47	0.35	-0.11
1 on 1.5	1.99	0.50	-0.19
1 on 2.25	1.81	0.47	-0.08
1 on 3.0	1.37	0.51	+0.04

*Interpolate linearly between these values for other slopes.

For ROUGH slopes, Seelig (1980) gives the runup as,

$$R = (0.69\xi/1+0.5\xi)H \qquad (14)$$

$$\xi = \tan\theta/(H/L_o)^{0.5} \qquad (15)$$

$$L_o = 5.12\, T^2 \qquad (16)$$

θ = structure of the slope (e. g., $\tan\theta = 0.25$ for a slope of 1V on 4H

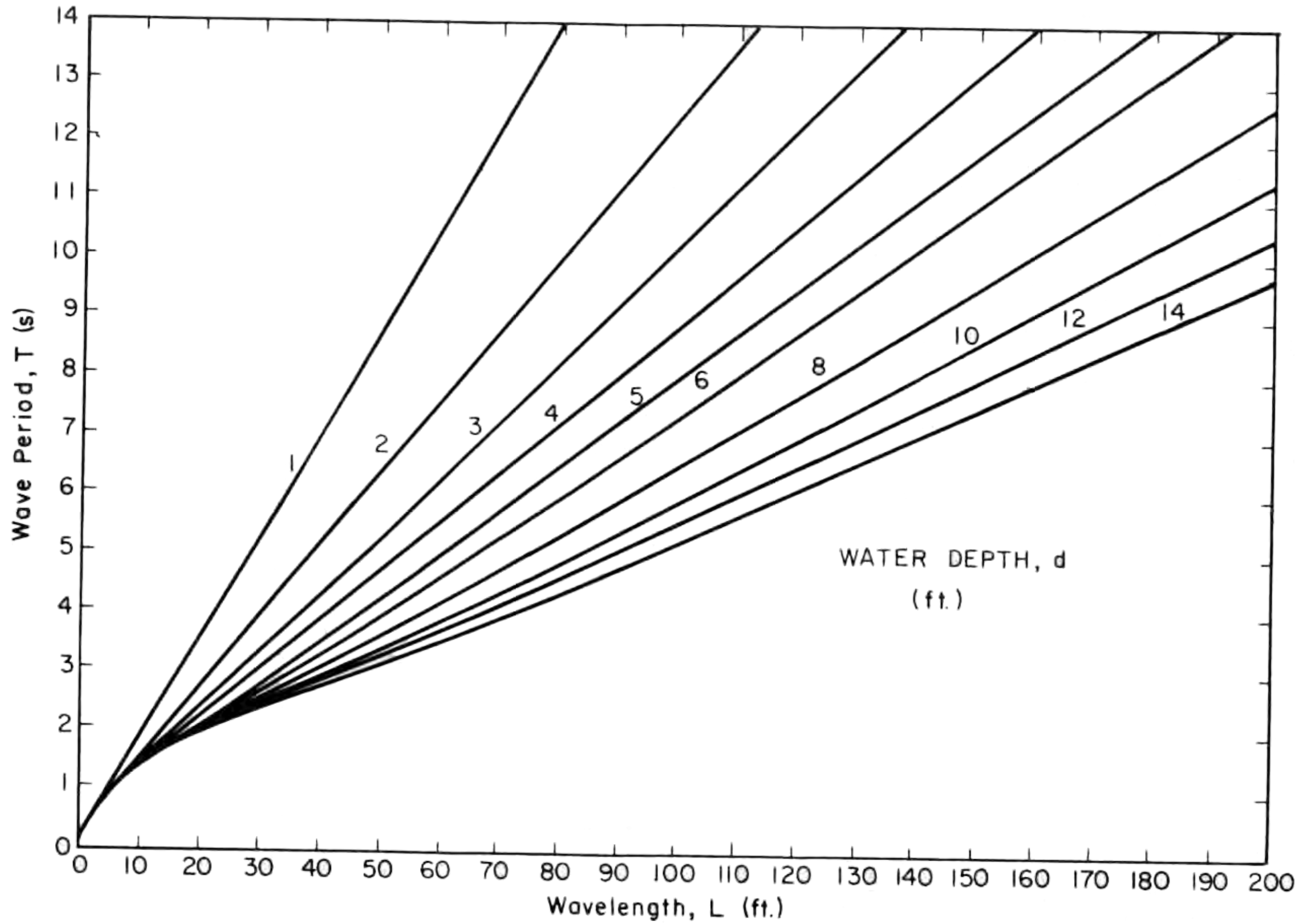


Figure 26 Local Wavelength Given Depth and Period [After Giles and Eckert (1979)]

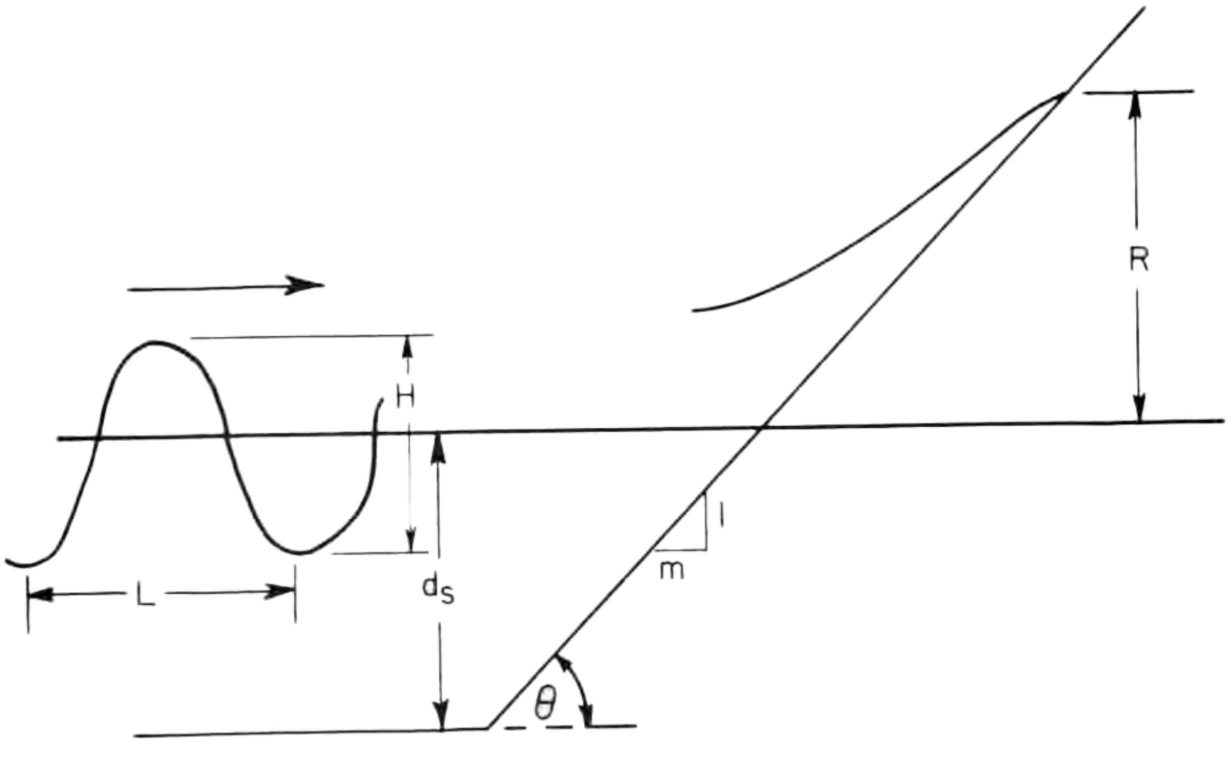


Figure 27 Wave Runup Definition Sketch

For STEPPED slopes, Stoa (1979) recommends using 70 to 75 percent of the smooth slope runup if the risers are vertical, and 86 percent if the edges are rounded.

A rough approximation of the runup height can be obtained from Table 11. However, the values in the table tend to represent the upper bound of the available data and may result in over design. Equations (13) and (14) or the methods given in Stoa (1978) and (1979) are recommended.

If it is impossible or undesirable to build a structure to the recommended height, a splash apron should be provided at the top of the structure. These are generally constructed of rock and they prevent the ground at the top from being eroded and undermining that portion of the structure.

Environmental Factors

Many different materials can be used to construct shore protection structures, including rock, concrete, timber, metal and plastics. The choice often depends on the desired permanence of the protection. Durable materials usually cost considerably more than shorter-lived materials used for temporary protection. The choice of materials is important because the coastal environment is a harsh testing ground for all man-made structures. Aside from wave forces, which are formidable in and of themselves, a host of chemical, biological and other factors can degrade structural materials. A brief review of these follows.

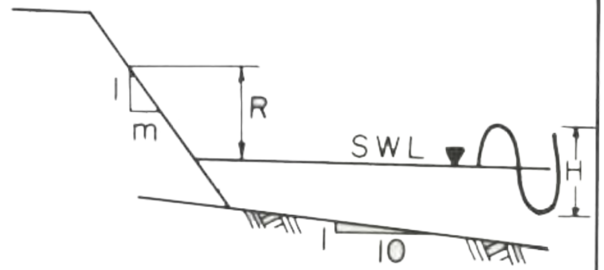
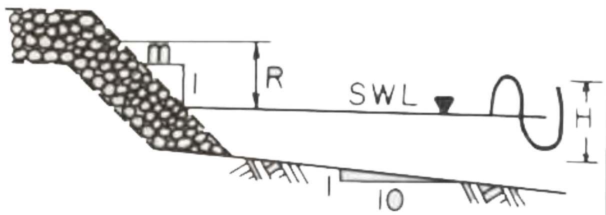
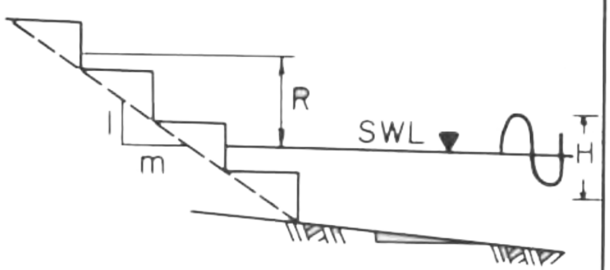
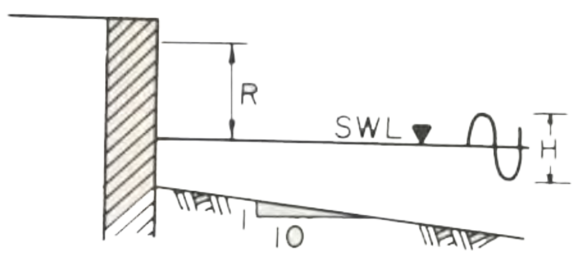
	m	R
 SMOOTH FACE	1.5 2.5 4.0	2.25H 1.75H 1.50H
 ROUGH FACE	1.5 2.5 4.0	1.25H 1.00H 0.75H
 STEPPED FACE	1.5	2.00H
 VERTICAL FACE	—	2.00H

Table 11 Wave Runup Heights

ATTACHMENT III.5.B

WATER-RESOURCES ENGINEERING

(LINSLEY & FRANZINI 1979)

WATER-RESOURCES ENGINEERING

THIRD EDITION

Ray K. Linsley

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Stanford University
Partner, Linsley, Kraeger Associates

Joseph B. Franzini

Professor of Civil Engineering
Associate Chairman, Department of Civil Engineering
Stanford University

McGraw-Hill Book Company

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Paris São Paulo Singapore Sydney Tokyo Toronto

by ordinary earth-moving methods would be expensive unless the excavated sediment has some sales value.

7-9 Wind setup and waves in reservoirs Earth dams must have sufficient freeboard above maximum pool level so that waves cannot wash over the top of the dam. Waves in reservoirs may also damage shoreline structures and embankments adjacent to the water and interfere with navigation. Part of the design of any reservoir is an estimate of wind setup and wave height.

Wind setup is the tilting of the reservoir water surface caused by the movement of the surface water toward the leeward shore under the action of the wind. This current of surface water is a result of tangential stresses between the wind and the water and of differences in atmospheric pressure over the reservoir. The latter, however, is, typically, a smaller effect. As a consequence of wind setup, the reservoir water surface is above normal still-water level on the leeward side and below the still-water level on the windward side. This results in hydrostatic unbalance, and a return flow at some depth must occur. The water-surface slope which results is that necessary to sustain the return flow under conditions of bottom roughness and cross-sectional area of flow which exist. Wind setup is generally larger in shallow reservoirs with rough bottoms.

Wind setup may be estimated from

$$Z_s = \frac{V_w^2 F}{1400d} \tag{7-3}$$

where Z_s is the rise in feet (meters) above still-water level, V_w is the wind speed in miles (kilometers) per hour, F is the *fetch* or length of water surface over which the wind blows in miles (kilometers), and d is the average depth of the lake along the fetch in feet (meters). In SI metric units, the constant in the denominator becomes 63,200.

Equation (7-3) is modified[1] from the original equation developed by Dutch engineers on the Zuider Zee. Additional information and techniques are given in other references.[2] Wind-setup effects may be transferred around bends in a reservoir and the value of F used may be somewhat longer than the straight-line fetch.

When wind begins to blow over a smooth surface, small waves, called capillary waves, appear in response to the turbulent eddies in the wind stream. These waves grow in size and length as a result of the continuing push of the wind on the back of the waves and of the shearing or tangential force between the wind and the water. As the waves grow in size and length, their speed increases until they move at speeds approaching the speed of the wind. Because growth of a wave depends in part upon the difference between wind speed and wave speed, the growth rate approaches zero as the wave speed approaches the wind speed.

[1] T. Saville, Jr., E. W. McClendon, and A. L. Cochran, Freeboard Allowances for Waves in Inland Reservoirs, *J. Waterways and Harbors Div., ASCE*, pp. 93–124, May, 1962.

[2] Shore Protection, Planning and Design, *Tech. Rept.* 3, 3d ed., U.S. Army Coastal Engineering Research Center, June, 1966.

The duration of the wind and the time and direction from which it blows are important factors in the ultimate height of a wave. The variability of the wind and the amazingly complex and yet to be fully understood response of the water surface to the wind lead to a wave pattern that is a superposition of many waves. The pattern is often described by its energy distribution or spectrum. The growth of wind waves as a function of fetch, wind speed, and duration can be calculated from knowledge of the mechanism of wave generation and use of collected empirical results.[1] The duration of the wind and the fetch play an important role because a wave may not reach its ultimate height if the wave passes out of the region of high wind or strikes a shore during the growth process. The depth of water also plays a key role, tending to yield smaller and shorter waves in deep water.

Wave-height data gathered at two major reservoirs[2] confirm the theoretical and experimental data for ocean waves if a modified value of fetch is used. The derived equation is

$$z_w = 0.034 V_w^{1.06} F^{0.47} \tag{7-4}$$

[1] W. J. Pierson, Jr., and R. W. James, Practical Methods for Observing and Forecasting Ocean Waves, *U.S. Navy Hydrographic Office Pub.* 603, 1955 (reprinted 1960).

[2] T. Saville, Jr., E. W. McClendon, and A. L. Cochran, Freeboard Allowances for Waves in Inland Reservoirs, *J. Waterways and Harbors Div., ASCE*, pp. 93–124, May, 1962.

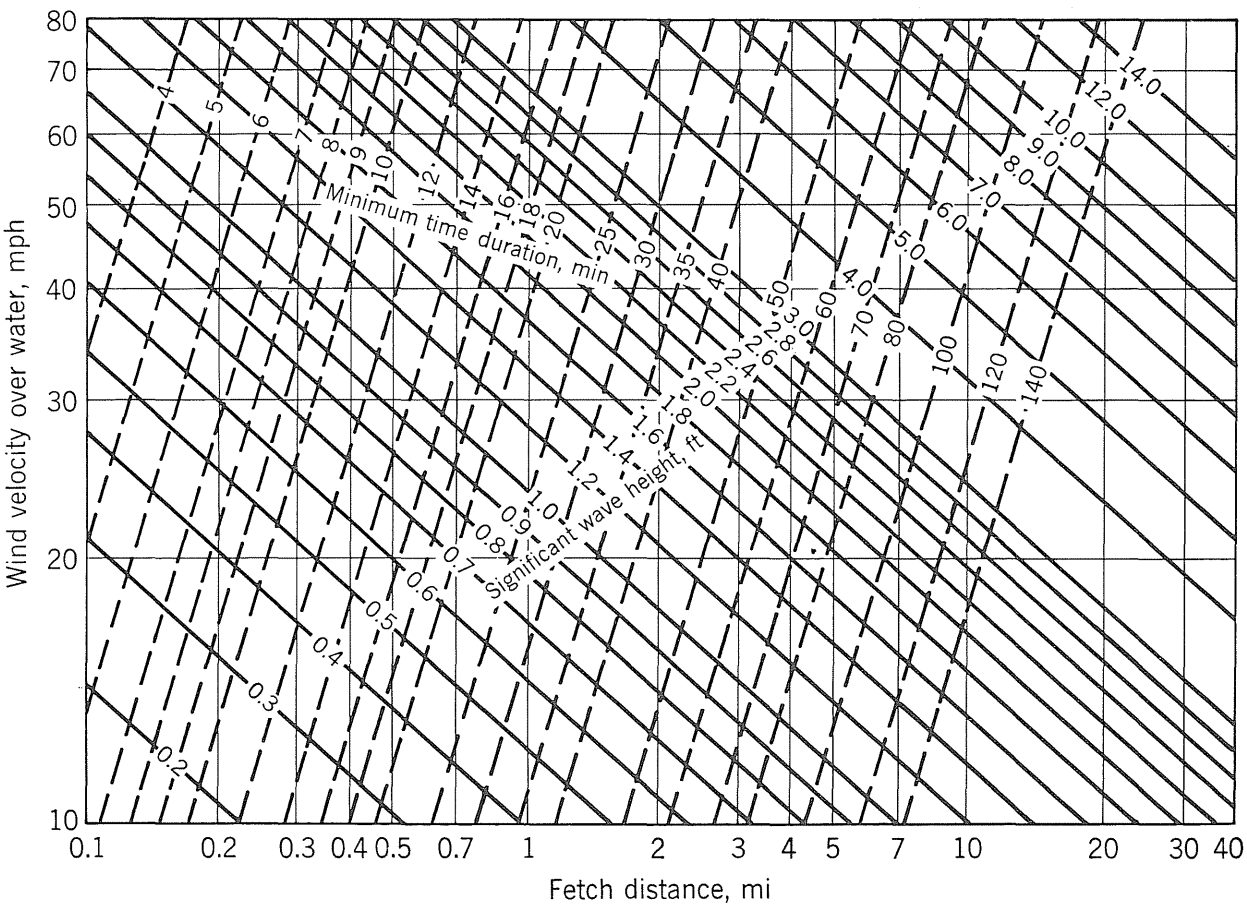
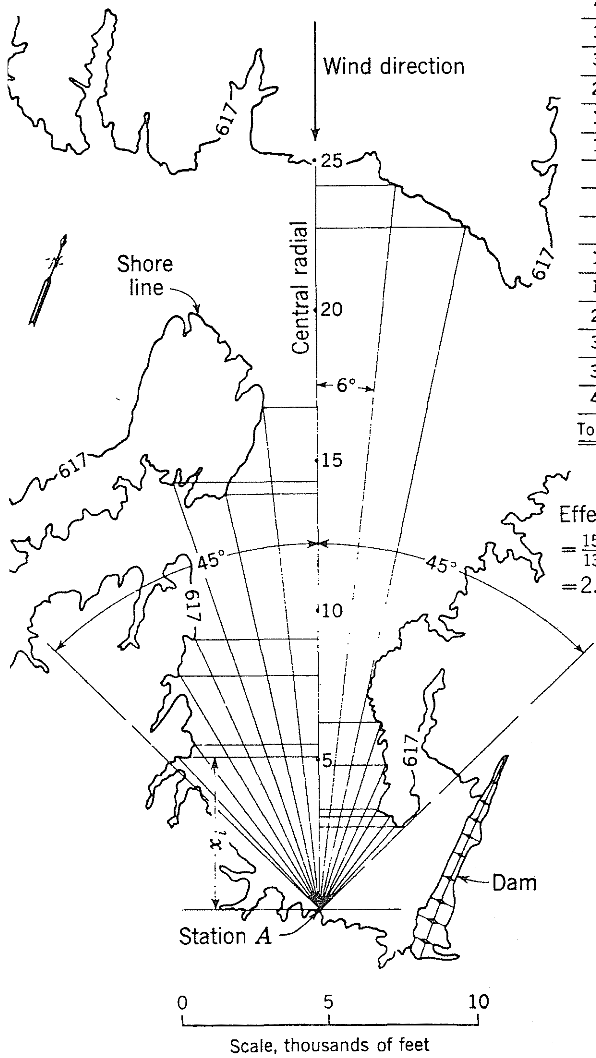


Figure 7-14 Significant wave heights and minimum wind durations (*from Saville, McClendon, and Cochran*). For metric version see Appendix B.

θ	cos θ	x_i	x_i cos θ
42	0.743	5.1	3.79
36	0.809	5.5	4.45
30	0.866	7.8	6.75
24	0.914	9.0	8.23
18	0.951	14.2	13.50
12	0.978	13.8	13.50
6	0.995	16.7	16.62
0	1.000	24.7	24.70
6	0.995	24.1	23.98
12	0.978	22.7	22.20
18	0.951	6.2	5.90
24	0.914	4.8	4.39
30	0.866	3.3	2.86
36	0.809	3.1	2.51
42	0.743	2.8	2.08
Total	13.512		155.46



Effective fetch $= \frac{155.46}{13.512} \times 10^3 = 11{,}510$ ft $= 2.18$ mi

igure 7-15 Computation of effective fetch. (*Modified from Saville, McClendon, and Cochran*)

vhere z_w is the average height in feet (meters) of the highest one-third of the waves nd is called the *significant wave height*, V_w is the wind velocity in miles (kil-meters) per hour about 25 ft (7.6 m) above the water surface, and F is the fetch in niles (kilometers). In SI metric units the coefficient becomes 0.005. The equation s shown graphically in Fig. 7-14[1] together with lines showing the minimum dura-ion of wind required to develop the indicated wave height. Figure 7-15 shows the nethod of computing the effective fetch for a narrow reservoir.

Since the design must be made before the reservoir is complete, wind data ver land must generally be used. Table 7-2 gives ratios of wind speed over land to hose over water and may be used to correct observed wind to reservoir condi-ions. Waves are critical only when the reservoir is near maximum levels. Thus in electing the critical wind speed for reservoirs subject to seasonal fluctuations,

[1] A graph for the solution of Eq. (7-4) in SI metric units is given in Appendix B-1.

Table 7-2 Relationship between wind over land and that over water. (After Saville, McClendon, and Cochran)

Fetch, mi (km)	0.5 (0.8)	1 (1.6)	2 (3.2)	4 (6.5)	6 (9.7)	8 (12.9)
V_{water}/V_{land}	1.08	1.13	1.21	1.28	1.31	1.31

only winds which can occur during the season of maximum pool levels should be considered. The direction of the wind and the adopted fetch must also be the same.

The height of the significant wave is exceeded about 13 percent of the time. If a more conservative design is indicated, a higher wave height may be chosen. Table 7-3 gives ratios of z'/z_w for waves of lower exceedance.

When a wave strikes a land slope, it will *run up* the slope to a height above its open-water height. The amount of run-up depends on the surface. Figure 7-16 shows the results of small-scale experiments[1] on smooth slopes and rubble mounds. Height of run-up z_r is shown as a ratio z_r/z_w and is dependent on the ratio of wave height to wavelength (wave steepness). Wavelength λ for deep-water waves may be computed from

$$\lambda = 5.12t_w^2 \text{ ft} \qquad \text{or} \qquad \lambda = 1.56t_w^2 \text{ m} \tag{7-5}$$

where the wave period t_w is given by

$$t_w = 0.46V_w^{0.44}F^{0.28} \tag{7-6}$$

For shallow-water waves other length relations are appropriate.[2] In metric units the coefficient of Eq. (7-6) becomes 0.32. The curves for rubble mounds represent extremely permeable construction, and for more typical riprap on earth embankments the run-up may be somewhat higher, depending on both the permeability and the relative smoothness of the surface.

[1] T. Saville, Jr., Wave Run-up on Shore Structures, *Trans. ASCE*, Vol. 123, pp. 139–158, 1958; R. Y. Hudson, Laboratory Investigation of Rubble-mound Breakwaters, *Trans. ASCE*, Vol. 126, Part IV, pp. 492–541, 1962.

[2] Shore Protection, Planning and Design, *Tech. Rept.* 3, 3d ed., U.S. Army Coastal Engineering Research Center, June, 1966.

Table 7-3 Percentage of waves exceeding various wave heights greater than z_w. (After Saville, McClendon, and Cochran)

z'/z_w	1.67	1.40	1.27	1.12	1.07	1.02	1.00
Percentage of waves > z'	0.4	2	4	8	10	12	13

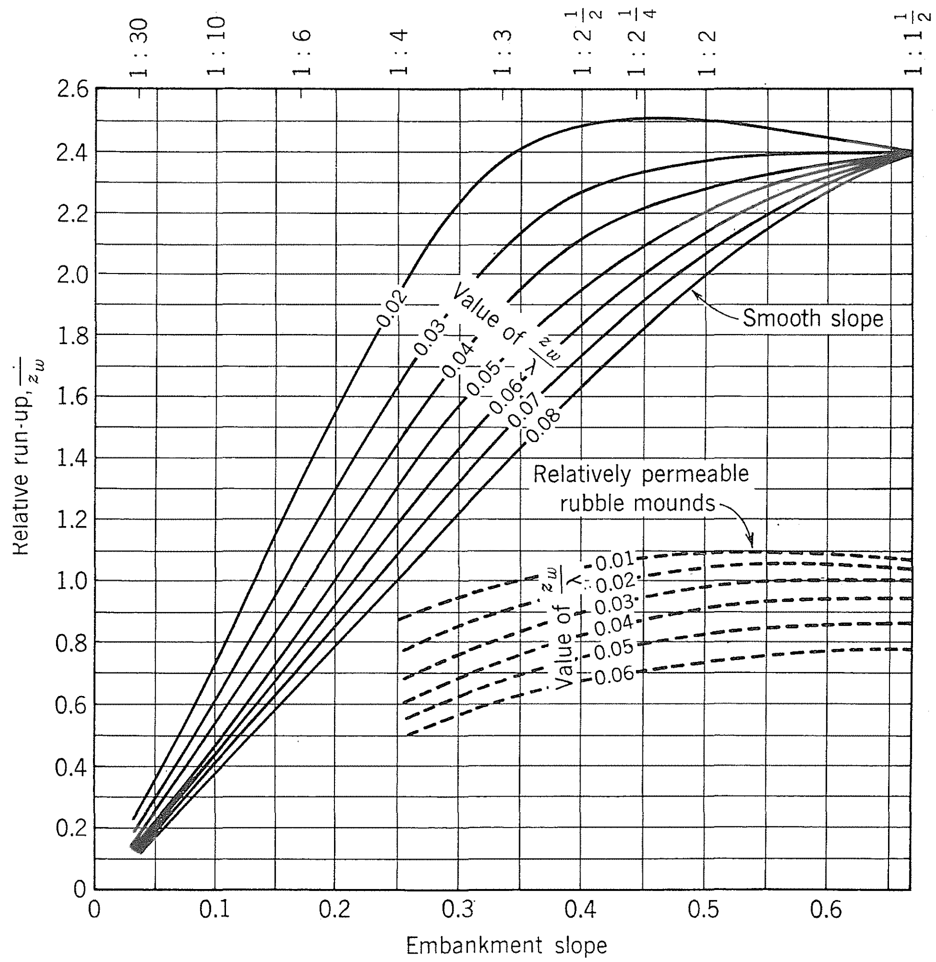


Figure 7-16 Wave run-up ratios versus wave steepness and embankment slopes. (*From Saville, McClendon, and Cochran*)

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Energy, Minerals and Natural Resources
Oil Conservation Division
1220 S. St Francis Dr.
Santa Fe, NM 87505

CONDITIONS

Action 455598

CONDITIONS

Operator:	
BASIN DISPOSAL INC P.O. Box 100 Aztec, NM 87410	OGRID: 1739
	Action Number: 455598
	Action Type: [C-137] Non-Fee SWMF Submittal (SWMF NON-FEE SUBMITTAL)

CONDITIONS

Created By	Condition	Condition Date
lbarr	None	4/25/2025