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Design, Construction, and Maintenance of Subsurface Drains in Arid and Semiarid Areas

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Developed by the ASAE Drainage of Irrigated Lands Committee; approved by the ASAE Soil and Water Division Standards Committee; adopted by ASAE February 1985; revised August 1995; revised editorially May 1997; reaffirmed January 2001, December 2001, February 2003, February 2008; revised editorially February 2008, revised November 2009; reaffirmed December 2014.

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1 Purpose and Scope

This Engineering Practice is intended as a guide to engineers in the design and construction of subsurface drains in arid and semiarid regions where irrigation is often used to provide adequate water for crops. It is not designed to serve as a complete set of specifications or standards. This Engineering Practice is intended to complement ASABE Engineering Practices, ASAE EP480 Design of Subsurface Drains in Humid Areas and ASAE EP481 Construction of Subsurface Drains in Humid Areas.

2 Normative References

The following standards contain provisions which, through reference in this text, constitute provisions of this Engineering Practice. The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies unless noted. For undated references, the latest approved edition of the referenced document (including any amendments) applies.

ASAE EP480, *Design of Subsurface Drains in Humid Areas*

ASAE EP481, *Construction of Subsurface Drains in Humid Areas*

ASAE EP369, *Design of Agricultural Drainage Pumping Plants*

ASAE EP407, *Agricultural Drainage Outlets — Open Channels*

ASAE S526, *Soil and Water Terminology*

ASTM C14-07, *Standard Specification for Nonreinforced Concrete Sewer, Storm Drain, and Culvert Pipe*

ASTM C118-05a, *Standard Specification for Concrete Pipe for Irrigation or Drainage*

ASTM C150-07, *Standard Specification for Portland Cement*

ASTM C412-05a, *Standard Specification for Concrete Drain Tile*

ASTM C443-05a, *Standard Specification for Joints for Concrete Pipe and Manholes, Using Rubber Gaskets*

ASTM C444-03, *Specification for Perforated Concrete Pipe*

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ASTM D698-07e1, *Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft^3 (600 kN-m/m^3))*

ASTM F405-05, *Standard Specification for Corrugated Polyethylene (PE) Pipe and Fittings*

ASTM F449-02e1, *Standard Practice for Subsurface Installation of Corrugated Polyethylene Pipe for Agricultural Drainage or Water Table Control*

ASTM F667-06, *Tubing Standard Specification for Large Diameter Corrugated Polyethylene Pipe and Fittings*

ASTM F949-06a, *Standard Specification for Poly (Vinyl Chloride)* (PVC) *Corrugated Sewer Pipe with a Smooth Interior and Fittings*

ASTM A760/A769M-06, *Standard Specification for Corrugated Steel Pipe, Metallic-Coated for Sewers and Drains*

ASTM 894 *Specification for 18 to 120 inch diameter pipe and fittings*

OSHA CFR *Part 1926, Subpart D — Occupational Health and Environmental Controls*

USBR *Standard Specifications for Unreinforced Concrete Drainage Pipe (February 15, 1971)*

USBR *Standard Specifications for Corrugated Polyethylene or Polyvinyl-chloride Plastic Corrugated Drainage Tubing (February 1, 1995)*

AASHTO M 252 *Specifications for 3 to 10 inch diameter N12 pipe and fittings*

AASHTO M 294 *Specification for 12 to 36 inch diameter N12 Pipe and fittings*

3 Definitions

3.1 The following terms used in this Engineering Practice are defined in ASAE S526:

consumptive use

deep percolation

gravel filter

ground water

hydraulic conductivity

piezometer

root zone

specific yield

water table

3.2 For the purpose of this Engineering Practice only, the following terms are defined herein:

3.2.1 barrier layer: Any layer in the soil profile that is impermeable or whose hydraulic conductivity is one-fifth or less of the weighted hydraulic conductivity of the overlying saturated soil layers.

3.2.2 ochre: Oxides of iron or manganese mixed with soil, silt, and earthy materials.

3.2.3 depths: Location in soil measured vertically from the ground surface.

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4 Investigations

4.1 Introduction

4.1.1 There are many types of drainage problems. Each will require a unique investigation tailored to the specific problem. Before such investigation is undertaken, the purpose of the investigation should be clearly understood. Plans should be formulated to determine the minimum amount of data required for the specific project or report and the best way of obtaining such data.

4.1.2 In irrigated areas, there is a close relationship between irrigation and drainage. Investigations are needed to determine the amount of drainage water to be removed by subsurface drains and how this is related to the irrigation amounts and management. The environmental impact of the drain water effluent on receiving waters must be considered. Subsurface soil conditions as they relate to the ability of water to move naturally through the soil have a major effect on the volume of drainage effluent. Irrigation data, including infiltration, consumptive use, water quality and salinity, are determined in this phase. Soil data include hydraulic conductivity, specific yield, barrier layer, and depth.

4.2 Pre-reconnaissance investigations

4.2.1 Topographic maps of the area are usually available from the US Geological Survey, the U.S. Bureau of Reclamation, the USDA Natural Resources Conservation Service, or irrigation districts that have done work in the area. The maps should cover the area of interest and also surrounding areas that may contribute to the excess water problem. Topographic maps often contain information relative to seep areas in non-irrigated lands, or areas with a continuing drainage problem.

4.2.2 Standard soil surveys for most irrigated areas have been prepared by the USDA Natural Resources Conservation Service or the USDI Bureau of Reclamation. Soils information may be available from the same agencies that have topographic maps.

4.2.3 Geologic reports for the area should be examined to identify sources of ground water that might influence drainage requirements.

4.2.4 Aerial photographs will indicate seep areas and possible outlets as well as property lines. Infrared photos, especially if taken at the proper time of year, may provide additional information concerning the extent of poorly drained areas.

4.2.5 Well logs and other soil boring logs in the area may provide valuable information about deep barrier layers and possible artesian pressures in areas to be drained. Copies of pertinent logs should be obtained where possible. It should be remembered, however, that well logs are typically not developed with drainage in mind and should be used with caution when planning field investigations.

4.2.6 Climatic records from the US Weather Service are important to determine the pattern of rainfall and the response of fluctuating water tables to natural precipitation.

4.2.7 Local interviews with people cognizant of drainage problems are important. Landowners or farmers in the area have valuable information relative to seasonal variation of drainage problems and the response of the water table and crops to water management practices in the area. Determine whether problems can develop that affect the operation and maintenance of a system, such as deposits of oxides of iron or manganese. Records of observation wells may be available to help assess water table cycles and trends.

4.3 Field reconnaissance. After all reasonably available recorded information has been obtained, it is important to make a field reconnaissance of the area of interest to evaluate the condition of the area, the problems of access, and the locations of possible outlets.

4.3.1 Outlets for subsurface drainage systems in irrigated areas may be difficult to obtain. Pay special attention to the location of possible outlets for planned drainage systems as well as to the capacity and flow characteristics of the outlets. If off-site discharge is not possible, use of other means of disposal shall be

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considered, such as evaporation ponds, reuse for irrigation, or treatment. Determine the need for discharge permits for all outlets.

4.3.2 Existing drainage systems in the area should be noted and marked on the topographic maps as possible outlets and as features to be considered in the design of the new drainage system.

4.3.3 Soils needing drainage, found during the field reconnaissance should be noted on the maps. Some of these areas do not show on topographic maps or aerial photographs.

4.3.4 Existing open cuts should be inspected to help determine subsurface soil characteristics.

4.4 Field investigations. Information common to all types of drainage investigation are, e.g., data on soils, land use and cropping patterns; and information related to irrigation, precipitation, evapotranspiration, runoff, and stream flow. Whether outlet drains are to be open or closed, make profile, cross section, and soil profile investigations along the routes where drains are to be installed. For subsurface drainage, additional information is needed on ground water, perched water tables, salinity, hydraulic conductivity, and conditions below the upper soil horizons.

4.4.1 Water table levels in the soil are important and should be carefully investigated. Observe water levels in borrow pits, in wells, and in excavations made for other purposes in the area. Establish a number of water table observation wells. These may be open auger holes drilled at various locations for a preliminary investigation, or may be permanent water table observation wells established to collect information over a longer period. Soil profiles should be logged when the water table observation wells are drilled. Observations should be made of free water, mottling of the soil, and estimated hydraulic conductivity of various strata. The diameter of the water table observation well is not important except in fine-textured soils. Large-diameter holes, which may be a danger to animals in the area, should be covered. After the wells are installed, allow for water levels to come to equilibrium.

4.4.1.1 Permanent water table observation wells can be constructed by drilling a 102 mm (4 in.) diameter hole, putting a 25 or 51 mm (1 or 2 in.) diameter perforated plastic or steel pipe in the center of the hole, backfilling the hole to within 0.3 m (1 ft) of the surface with coarse sand, and then packing the upper part of the hole with finer soil material to prevent the entrance of surface water. Bottoms of pipes should be bedded in sand, or closed to prevent the entry of unstable soil materials. If the water table observation well is part of a large network of pipes designed to collect information over a long period, elevations should be obtained for the pipe tops so that direction of ground-water movement can be determined.

4.4.2 Install piezometers in any area where significant upward or downward movement of water is suspected. Piezometers can be installed by jetting, or driving, using standard techniques. Place at least two piezometers in fence lines or in protected areas where they will not be dangerous to farm equipment, tires, or animals. A minimum of two piezometers will be needed to determine direction of flow. Test the sensitivity of the piezometers by periodically filling them with water or by extracting some water and observing the rate of return to equilibrium to determine whether they are functioning properly.

4.4.3 Ground-water sources contributing to the drainage problem should be identified from observations and data obtained using water table observation wells and piezometers. Ground-water contours, depths to water table, and water table fluctuations with time should be plotted on appropriate maps. Such information is important when determining whether interceptor- or relief-type drains should be installed.

4.4.4 Water quality will need consideration in order to evaluate environmental impacts and to comply with federal, local, or state agency discharge regulations. Environmental impact statements may be necessary. In some areas, a permit may be required to discharge drainage water regardless of its quality. Ground-water samples should be collected from the site and analyzed to determine chemicals in the potential drain discharge. Depending on the area, tests should include; Ca, Na, SO_4, PO_4, NO_3, HCO_3, EC, Mg, and K and may also include Cl, B, Se, As, Cd, Mo, Zn, Dr, Hg, V, and Cu, if they are suspect. Consideration should be given for additional testing to determine the presence of pesticides and other potentially damaging chemicals if the conditions would suggest their presence.

4.4.5 Hydraulic conductivity should be carefully determined, since the functioning of any drainage system and the drain spacing is directly dependent on the hydraulic conductivity of the soil. In-place bail-out auger hole

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tests should be made where a high water table exists. Shallow well pumping test should be made if a high water table does not exist. Procedures for determining hydraulic conductivities can be found in either the USBR *Drainage Manual* or *Agricultural Drainage—Agronomy Monograph No. 38.*

4.4.5.1 Since drain spacing and performance are also dependent on the relative location of the barrier layer with respect to the depth of the drains, reasonable efforts should be made to identify subsurface barrier layer conditions. All auger holes made for the investigation of water table position, soil profile characteristics, and hydraulic conductivities should be evaluated at least to the depths that the drains will be installed. One hole in ten should extend to the barrier layer, three holes in ten should extend to a deeper depth than the drain, and six holes in ten should be at least 3 m (10 ft) deep. For layered soils, horizontal *hydraulic conductivities should be determined for each* layer by progressively deepening the auger hole and making a determination for each layer. Procedures for determining the weighted hydraulic conductivity of the saturated profile are given in USBR *Drainage Manual.*

4.4.6 Soil gradation at the depth that the drains are to be installed should be determined for use in the design of drain envelopes. In most arid and semi-arid irrigated areas, soil structural stability is limited and drain envelopes are required. After the soil gradation, or mechanical analysis, has been made, a suitable sand/gravel envelope gradation to protect the drains can be selected. Specifications for sand/gravel envelope design can be found in *Agricultural Drainage (ASA Monograph 38),* SAE Special Publication 903CO466, and the USBR *Drainage Manual*.

4.4.7 Recharge rate, or drainage coefficient, should be determined. Local experience in drain design should be considered. Drainage coefficients may be available from local government agencies. Estimates of recharge rates can be made from data on irrigation efficiency, evapotranspiration, leaching fraction, and irrigation interval by observing water table responses of existing systems to irrigation and rainfall events.

5 Design

5.1 Outlets for buried pipe drains

5.1.1 Open channels. A stream or open ditch should be large enough to provide a free-flowing outlet for subsurface drains within a reasonable period (approximately 24 h) after peak storm or other short duration flows, and should be large enough to remove normal surface runoff and operational water from irrigated lands. ASAE EP407 provides planning design, construction, and maintenance information for open channels.

5.1.1.1 The outlet channel should have adequate depth and capacity to ensure that the minimum flow line (invert) of the main subsurface drain at the outlet will be a minimum of 150 mm (6 in.) above the normal water surface. The flow capacity and the normal water surface in the outlet channel should be considered, given the possibility of discharge from additional drains that may be constructed upstream of the drains currently being designed.

5.1.1.2 Where an open channel is either nonexistent or unsatisfactory for use as an outlet, a new channel should satisfy the criteria mentioned above. Some general guidelines for design of open drains can be found in USBR *Drainage Manual, Agricultural Drainage—Agronomy Monograph No. 38*, or TR-25, *Planning and Design of Open Channels*, as well as many other books on hydraulics and open channel flow.

5.1.2 Existing buried pipe drains. An existing buried pipe drain should be used as an outlet for a proposed system only if it is in good structural condition, free of roots and/or sediment that would impair flow, deep enough for adequate drainage, and large enough to carry the added drainage water. If the existing subsurface drain does not have sufficient capacity, a separate main outlet should be installed for the additional drains, or the existing main should be enlarged. The resultant outlet should be of sufficient size to handle both systems. An observation well or a junction box should be installed

5.1.3 When a suitable gravity outlet for the subsurface drainage system is not available, a pump outlet may be the only alternative. The pumping outlet should have sufficient capacity to remove the maximum flow expected from the area to be drained. Possible future additions to the drainage system should be considered when sizing the pumping of the plant. ASAE EP369

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5.2 Field investigations preliminary to design. A properly designed drainage system depends upon accurate and adequate field data. Details of field investigation procedures can be found in USBR *Drainage Manual*. Basic field data are necessary for the proper design of a subsurface drainage system irrespective of the procedure used to determine the system layout.

5.2.1 Soil texture. Sufficient subsurface investigations should be conducted to determine the texture of the soil materials from the ground surface to the drainage barrier layer throughout the area proposed for drainage (see 4.2.2 and 4.4.6).

5.2.2 Barrier layer. The depth to barrier layer throughout the area proposed for drainage should be determined.

5.2.3 Hydraulic conductivity. The horizontal hydraulic conductivity is required for the various soil textures throughout the area requiring drainage. The weighted hydraulic conductivity for the soil from the barrier layer to the maximum allowable water table height should be used in the drain spacing formula (see 5.3.7).

5.2.4 Water table. Water table elevations and piezometric heads, and their fluctuations, should be determined before the design is begun (see 4.4.1 and 4.4.2).

5.3 Drain spacing. Drain spacing methods can be divided into two categories, steady-state methods such as Donnan's formula (see 5.3.7.1), and transient flow methods (see 5.3.7.2) used by the US Bureau of Reclamation. Strong consideration should be given to spacing methods that have proved successful in the area of the proposed project. In addition to design parameter values determined by field investigations, values for the following additional parameters shall be selected by the design engineer for use in the drain spacing computations.

5.3.1 Root zone depth. The root zone depth is the minimum design depth to the water table. A value of 1.2 m (4 ft) is normally used as a design value for most crops in arid regions. A value of 1 m (3.3 ft) can sometimes be used in semiarid regions.

5.3.2 Drain depth. Drain depth is dependent on root zone depth, soil properties, availability of a suitable outlet, economics and environmental considerations. Normally, the minimum drain depth is about 2 m (6.5 ft) in arid regions and about 1.5 m (5 ft) in supplemental irrigated lands in semiarid regions. The geology and hydrology of the irrigated area will be used to determine the actual depth of installation. The type of drain installation equipment available in the area will have a definite impact on drain depths and drain construction costs.

5.3.3 Deep percolation. Deep percolation from any source causes the water table to rise. The transient flow method for calculating drain spacing requires that deep percolation and water table response from each source of recharge (rainfall, snow melt or irrigation) be estimated and accounted for in the calculation. The average deep percolation rate becomes the recharge rate for steady-state spacing computations (see 4.4.7 and 5.3.6).

5.3.3.1 In the planning stage of new surface irrigation projects or in areas where values are not available for deep percolation, Table 1 may be used to arrive at an approximate value. For sprinkler, trickle, or other specialized methods of irrigation, deep percolation may be different than those shown in Table 1.

Table 1 – Approximate deep percolation from surface irrigation (percent of net input into soil)

Soil texture	Percent
LS	30
SL	26
L	22
SiL	18
SCL	14
CL	10
SiCL	6
SC	6
C	6

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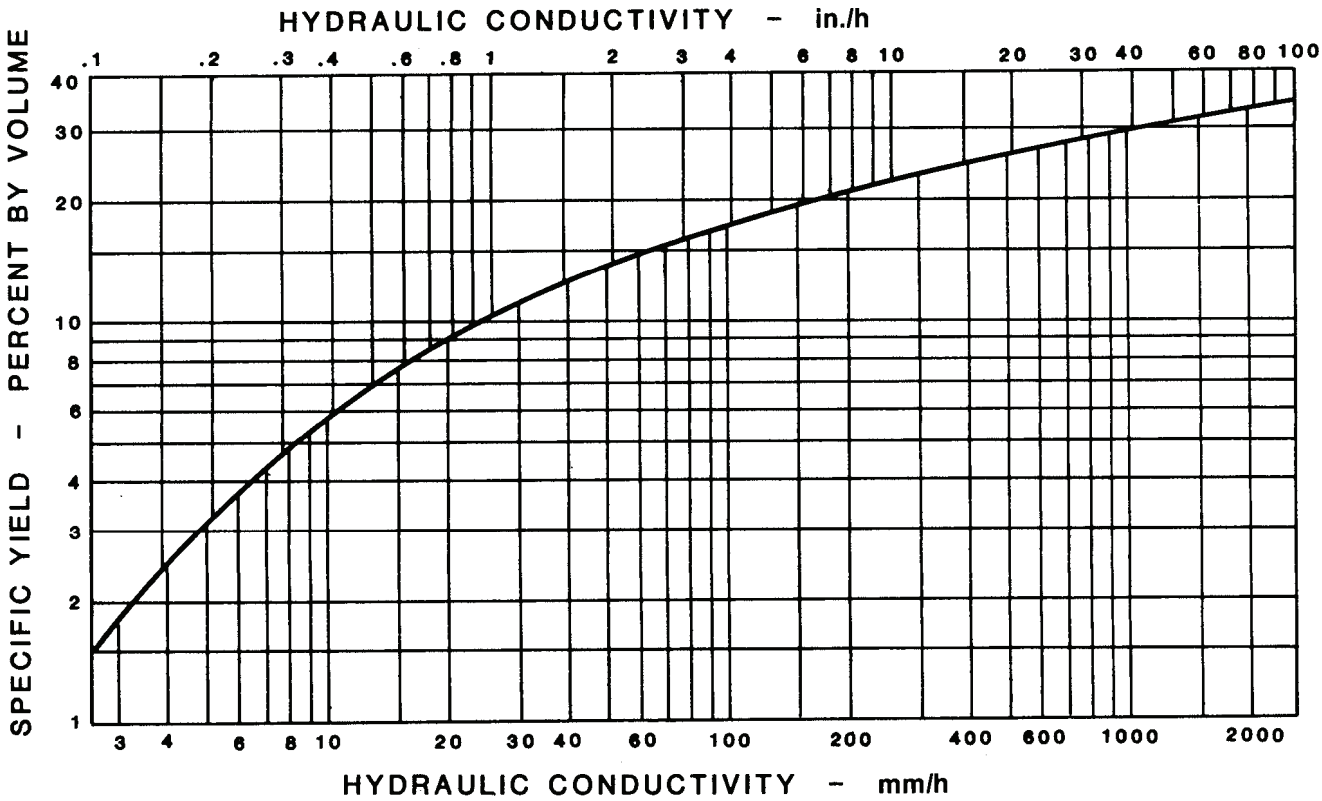

Figure 1 – Curve showing general relationship between specific yield and hydraulic conductivity

5.3.4 Specific yield. Estimated values for specific yield may be obtained from Figure 1, developed by the US Bureau of Reclamation. The specific yield value is required in the US Bureau of Reclamation's transient flow procedure. The *USBR Drainage Manual* provides figures for estimating specific yield and deep percolation.

5.3.5 Water table buildup. The water table rise used in the transient flow equation is determined by dividing the total deep percolation from the recharge event, expressed as a depth, by the specific yield.

5.3.6 Recharge rate. The recharge rate (Q_d) used in the steady state calculations is determined by dividing the deep percolation expressed as a depth by the shortest time interval between deep percolation events, usually the time between irrigations at the peak of the season.

5.3.7 Drain spacing equations. Numerous methods for calculating drain spacing exist, but the Donnan steady-state equation and the US Bureau of Reclamation transient flow method are in common use.

5.3.7.1 Steady-state method. Donnan's steady-state equation can be expressed as:

$$L^2 = \frac{4K(b^2 - a^2)}{Q_d}$$

where

L is drain spacing, m (ft);

K is hydraulic conductivity, m/day (ft/day);

a is distance from drain depth to barrier layer, m (ft);

b is distance from maximum allowable water table height to the barrier layer;

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Q_d is recharge rate, m/day (ft/day) (see 5.3.6).

When the drain is to be placed on or near the barrier layer, it has been found through field experience by the US Bureau of Reclamation that drain spacing can be calculated by the following equation:

$$L^2 = \frac{8Kb^2}{Q_d}$$

Example:

Steady-state with drain above the barrier layer:

L is drain spacing, m (ft);

K is 3.05 m/day (10 ft/day);

a is 6.71 m (22 ft);

b is 7.92 m (26 ft);

deep percolation/irrigation is 25.4 mm (1 in.);

time between irrigations at peak of season is 14 days.

$$Q_d = \frac{25.4\text{mm}}{14 \text{ days } (1000\text{mm/m})} = 0.00181\text{m/day}$$

$$L^2 = \frac{4(3.05)(7.92^2 - 6.71^2)}{14 \text{ days } (1000\text{mm/m})}$$

$$L = 345 \text{ m}$$

$$Q_d = \frac{1\text{in.}}{14 \text{ days } (12\text{in./ft})} = 0.00595\text{ft/day}$$

$$L^2 = \frac{4(10)(26^2 - 22^2)}{0.00595}$$

$$L = 1{,}136 \text{ ft}$$

5.3.7.2 Transient flow method. The US Bureau of Reclamation's transient flow method for determining drain spacing takes into account the transient nature of ground-water recharge and discharge. This method simulates actual fluctuations of the water table to drain spacings that meet the requirement of keeping the water table below a specified depth. Figure 2 shows the dimensionless parameters Y/Y_0 vs. KDt/SL^2 and Z/H vs. KHt/SL^2 based on the transient flow theory. This figure shows the relationship for the water height at the midpoint between drains for cases in which drains are located above a barrier layer or on a barrier layer. Figure 2 can be used to find the proper drain spacing for dynamic equilibrium of the water table. However, water table elevations should be computed for an entire year to account for water removal by the drains during non-irrigated periods. Table 2 shows an example of computed water table fluctuations with a drain spacing of 442 m (1,450 ft) and with the drain above a barrier layer, using the transient flow method.

In Table 2, *K* to hydraulic conductivity, m/day (ft/day) and *S* to specific yield (from Figure 1). For definition of other parameters see Figure 2.

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