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# Drainage Investigations for the Design of Water Table Management Systems in AEC&RI, Kumulur, Trichy District, Tamil Nadu

**A. Selvaperumal[1*], I. Muthuchamy[1], S. Vallalkannan[2] and H. V. Hemakumar[3]**

*[1]Department of Soil and Water Conservation Engineering, Agricultural Engineering College and Research Institute (AEC & RI), Trichy - 621712, Tamil Nadu, India.*
*[2]Department of Agricultural Science and Engineering, Agricultural Engineering College and Research Institute (AEC & RI), Trichy, Tamil Nadu, India.*
*[3]Department of Agricultural Structures, College of Agricultural Engineering, Bapatla, India.*

***Authors' contributions***

*This work was carried out in collaboration between all authors. Author AS designed the study of controlled drainage for alleviating soil problem and wrote the first draft of the manuscript. Authors IM, HVH and SV read and approved the final manuscript.*

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## ABSTRACT

A water table management system synonymously referred as Controlled Drainage and Subirrigation system or controlled and Reversible Drainage System was designed and executed in Eastern Farm A Block, Agricultural Engineering College and Research Institute Kumulur. This research article reports the pre-drainage investigations carried out in the study area for arriving at certain important design parameters for the design of water table management system for both drainage and subirrigation modes separately. Steady state hooghoudt equation was used for the design of drainage spacing and similarly the procedure followed by Doty at North Carolina University using Moody Equation and convergence analysis was used for subirrigation mode spacing. The spacing arrived for drainage mode was 15 m to that of subirrigation was 10 m respectively. Considering the feasibility of operation of both subsurface drainage and subirrigation, the spacing of 15 m could be recommended for water table management system of Eastern Farm A Block in AEC &RI kumulur, Tamil Nadu.

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**Corresponding author: E-mail: selvabtech.agri@gmail.com;*

*Keywords: Controlled drainage; drainage coefficient; hydraulic conductivity; subirrigation.*

## 1. INTRODUCTION

In Tamil Nadu state, parts of Trichy, Tanjore, Nagapattinam, Tiruvarur, Erode districts are frequently under the problem of waterlogging during North-East monsoon heavy rainfall periods (October – December). At the same time, the above areas are under the realms of water scarcity for a few months (Februrary-May) during canal non supply periods. Exact quantification of this seasonal waterlogging is not available for the state. Essentially drainage technology is vital to alleviate the waterlogging problem, but at the same time, the same system technically, if used for irrigation through conjunctive strategy of ground water in the above areas, the crop production and productivity could be increased all round the year (2 to 3 crops).

Many researchers studies in the advanced countries were carried out to accomplish dual purposes with water table management system synonymously referred as controlled Drainage and Subirrigation system. Procedure of subirrigation systems design and requirements reported by [1]. They have evolved criteria for subirrigation, the design dimensions of feeder ditch. Movement of water table for subirrigation conditions was characterized by numerically solving a non linear differential equation describing unsteady flow above a horizontal impervious layer. Solutions were presented for both initial draining and horizontal water table profiles [2]. Majority of drainage systems were over-draining, as they were removing more salt than applied by irrigation water and that the drainage rates exceeded those reasonably required to control water tables and waterlogging according to design coefficients. They discussed the need for water table management system to reduce their downstream environmental impacts whilst maintaining agricultural production [3]. Controlled drainage is a method used for the integration of irrigation management with drainage management. It replies the reduction of drainage flow in order to maximize the crop water utilization [4]. Water table management strategies can be grouped into 3 categories namely, i) Sub Surface Drainage (SSD) which mainly lowers the water table during wet periods until an equilibrium condition exists. ii) Controlled Drainage (CD) which is subsurface drain outlet to control the rate of outflow. iii) Controlled Drainage/ Sub irrigation (CD-SI). They also reported that several advantages of CD-SI system are: i) Low labour requirement ii) Single system provides both drainage and irrigation iii) Low maintenance requirements iv) No delays in culture practices because of irrigation. V) Little or no nutrient leaching from the root zone [5]. [6] concluded that reductions of 88 per cent and 39 per cent of the outflow volumes for the summer-fall and spring periods, respectively, when using controlled drainage, for an annual average reduction of 20 per cent to 25 per cent. Hence the present studies the following objectives are i) To study the principle of water table management system, ii) To evaluate the field investigation with reference to hydraulic conductivity, depth to impervious layer and drainage coefficient iii) to design the water table management system with reference to spacing between drains and drain depth and diameter of drain tubes.

## 2. MATERIALS AND METHODS

The experiment was laid out and conducted experiment during February 2015 to September 2016 under wetland ecosystem, to study the effect of controlled drainage for alleviating problem soil on sandy loam soil, at 10° 56' 34.05" N latitude and 78° 49’34” E longitude with mean altitude of 72.2376 m above the mean sea level at Eastern Farm A Block, Agricultural Engineering College and Research Institute Kumulur. Topography of the experimental plot was uniform and levelled. The project site has a serious problem of water logging due to seepage of water from the lake located adjoining to the study area, which is the water harvesting source for kumulur watershed. Most of the fields in the experimental site are connected to natural drain but the drain is at field level and causes back flow. The irrigation channels that exist in the site are used as open drains and field to field carrying drain. Rice based cropping system is prevailing cropping system in this area.

### 2.1 Principle of Watertable Management System

The working principle of water table management system is that it should function efficiently both under subirrigation and drainage modes fulfilling both the needs. Water table management system synonymously known as controlled drainage subirrigation system. Controlled drainage operates as a traditional drainage system during wet periods, excess water is removed from the field through a system of underground drain tubes which conveys outlet to a main drain tube and it should remove the excess waterlogging and keep the crop in congenial condition. Under subirrigation mode, the upward flux and the discharge rate must satisfy the plant's life saving irrigation needs. The same system can furnish water to plants through subirrigation during dry periods. A single system operates both drainage and irrigation. The following Figs. 1 and 2 shows the principle of water table management system in the field.

## 2.2 Design Parameters

### 2.2.1 For both subirrigation and subsurface drainage

1. Depth to the lateral pipe
2. Diameter of the lateral pipe
3. Minimum grade of lateral pipe
4. Length of the lateral pipe

### 2.2.2 For subirrigtion

1. Depth to water table at lateral
2. Depth to water table at midpoint

### 2.2.3 For subsurface drainage

1. Depth to water table at lateral
2. Depth to water table at midpoint
3. Design subirrigation rate
4. Design subsurface drainage rate
5. Saturated hydraulic conductivity

## 2.3 Measurement of *In-situ* Hydraulic Conductivity

Hydraulic conductivity test kid was used to conduct auger hole experiment. Hooghoudt's equation was used for finding out the hydraulic conductivity. It will be very much essential for the design of water table management system. From standard Hooghoudt's equation,

$$K_S = \frac{2.3aS}{(2D+A)\Delta t}\log_{10}\frac{y_0}{y_1} \qquad .......Eq.1$$

where,

$K_s$ = saturated hydraulic conductivity
a = radius of the auger hole
d = depth of the hole below ground level
s is defined by ad /0.19
$y_0$ and $y_1$ over a particular time interval the initial and final water level.

## 2.4 Spacing Calulations under Drainage System Mode Operations

Drain spacing could be computed by several formulae developed from the theories of ground water flow substituting the appropriate soil and other parameters. Broadly speaking the drainage spacing formulae are based on a) steady state flow and homogeneous b) non-steady state flow conditions, a steady-state flow conditions. For the present study as the profile in the experimental site is homogeneous and isotropic, Hooghoudt's equation was used for computing the drain spacing [7]

$$S^2 = \frac{4KH\left(2d_e+H\right)}{R} \qquad ......Eq.2$$

where,

q = drainage co-efficient or drain discharge rate per unit surface area, m/d
K = hydraulic conductivity of the soil, m/d
$d_e$ = Equivalent depth, m
h = Height of water table above the water level in the drain, m
L = drain spacing, m

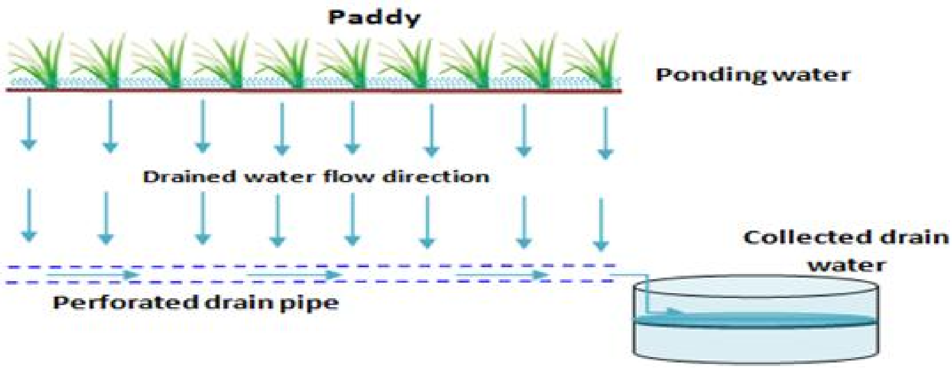


**Fig. 1. Principle of subsurface drainage mode**

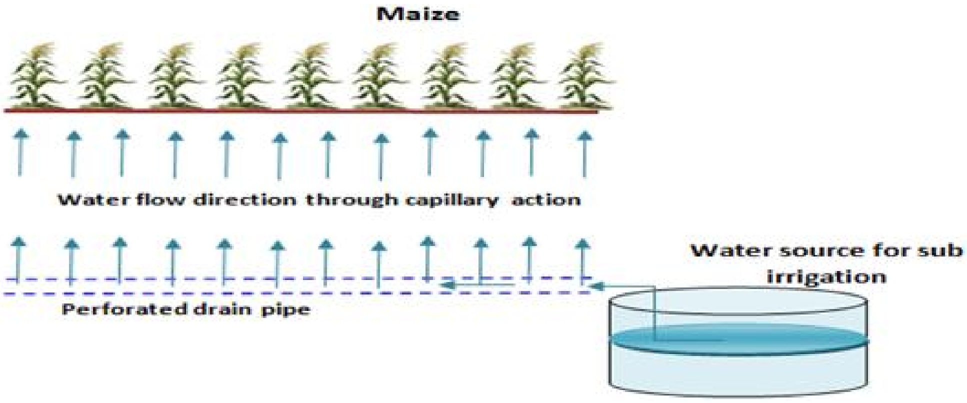


**Fig. 2. Principle of subirrigation mode**

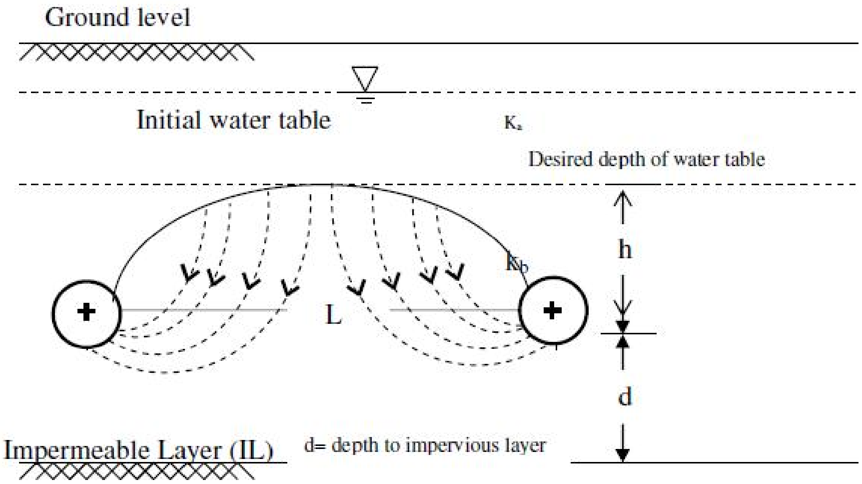


**Fig. 3. Possible pattern of flow in closed subsurface drain**

## 2.5 Design of Subirrigation System

Water table movement between parallel drains can be predicted by solving Boussinesq equation for the appropriate initial and boundary condition. Boussinesq equation neglects flow in the unsaturated zone and is based on continuity, Darcy's law and the Dupit Forchheimer assumptions

$$f = \frac{\partial h}{\partial t} = K\frac{\partial}{\partial x}\left[h\frac{\partial h}{\partial x}\right] + e \qquad ....Eq.3$$

h = elevation of watertable above the impermeable layer
t = time
x = horizontal position
e = rate of vertical infiltration into the saturated zone ('e' is negative for evaporation or vertical seepage)
K = lateral saturated hydraulic conductivity
f = drainable porosity

Position and shape of the water table during steady state subirrigation can be approximated by making the dupit forecheimer assumption. Water movement in the unsaturated zone is neglected, spacing of drains and could be determined from

$$L = \left(\frac{4K_s M\left(2h_0 - M\right)}{e}\right)^{\frac{1}{2}} \qquad ....Eq.4$$

$or$

$$L = \left(\frac{4K_s\left(h_0^2 - h_1^2\right)}{e}\right)^{\frac{1}{2}} \qquad ......Eq.5$$

$K_S$ = Saturated hydraulic conductivity (m/day)
$h_0$ = Water table height above the drains (m)

$h_1$ = Water table at midway between drains (m)
e = Evaporation rate (m/day)

Equivalent depth from the drain to the impermeable layer, $d_e$ can be calculated from

$$d_e = \frac{d}{\left[1+\frac{d}{l}\left(\frac{8}{\pi}\ln\frac{d}{r_e}-3.4\right)\right]} \qquad .....Eq.6$$

**$r_e$** is the effective drain tube radius which is smaller than the actual radius because the tube wall is not permeable but has only a small percentage of open area
d is the depth from drains to layer

By taking the suitable corrections for convergence, the final equation for spacing reduces to

$$L = \left(\frac{4K_s M\left(2h_0' - \frac{h_0'}{h_0}M\right)}{e}\right)^{\frac{1}{2}} \qquad ....Eq.7$$

M = Difference between water table levels = $h_0 - h_1 = h_0' - h_1'$
$h_0$ equivalent water table elevation = $d_e + y_0$

For both subirrigtion trials, the design spacing must be smaller than for drainage spacing. Subirrigation in the transient state water table rise was not analysed in view of cumbersome involved in acquiring the accuracy in parameter estimation for Indian condition. Based on the spacing arrived under both drainage and subirrigation modes, and on the optimum parameters chosen, experimental layout for suiting to the field's natural conditions, following the lines of experimental design, the layout of the water table management system was prepared.

## 3. RESULTS AND DISCUSSION

The results obtained in the summary of design parameter of controlled drainage and subirrigation system were presented in Table 1. It is evident that the irrigation water is of non saline in nature. Only waterlogging is constraint.

### 3.1 Steady State Spacing under Drainage Mode for the Water Table Management System

Initial drainage coefficient
= Depth of irrigation x Apparent specific gravity x drainable porosity
= 5 cm x 1.45 x 0.15
= 1.0875 cm/day
= 0.0108 m/day

**Table 1. Summary of design parameter of controlled drainage system**

| | |
|---|---|
| Area covered | 1.5 acre |
| Hydraulic Conductivity | 0.35 m/d |
| Average Rainfall | 864 mm |
| Drainage Coefficient | 1.08 cm/d |
| Water table height above drains at midpoint between drains | 0.5 m |
| Depth to impervious Layer | 4 m |
| Observation well material | PVC |
| Length of observation well | 1.3 – 1.5 m |
| Depth of observation well | 0.6 - 0.8 m |
| Envelope | Coconut Coir |
| Size of perforation of drain pipes | 8 mm |
| Size of perforation of observation wells | 3 mm |
| Evapotranspiration rate | 5 mm/day |
| Drainable porosity | 15 percent |
| **Soil sample analysis** | |
| Soil texture | Sandy Loam |
| Soil Ph | 9.1 |
| EC | 3.28 dS/m |
| ESP | 33 per cent |
| **Crop parameters** | |
| Controlled Drainage | Paddy: BPT 5204 |
| Subirrigation | Maize: COHM6 (hybrid) |

### 3.1.1 Equivalent depth

$$q = \frac{8KDh + 4Kh^2}{L^2}$$

Where

K = Hydraulic conductivity (m/day)
D = Depth to impervious layer (m)
h = Height of water table above the water level in the drain (m)
L = Spacing of drain (m)
q = Drainage coefficient (m/day)

$$L^2 = \frac{(8x0.35x4x0.5) + 4x0.35x0.5^2}{0.0108}$$

L = 23.45 m
**L = 23 m**
D < L/4 = 1 < 23.45/4 = 5.86

$$d_e = \frac{D}{\frac{8D}{\pi L}\ln\frac{D}{u} + 1}$$

u = Π x 0.036
= 0.113

$$d_e = \frac{4}{\frac{8x4}{3.14x23.45}\ln\frac{4}{0.113} + 1}$$

**$d_e$ = 1.58 m**

### 3.1.2 Hooghoudt's equation for steady state condition

$$L^2 = \frac{4Kh(2d_e + h)}{q}$$

Where

$d_e$ = equivalent depth (m)

$$L^2 = \frac{4x0.35x0.5(2x1.58 + 0.5)}{0.0108}$$

**L = 15 m**

### 3.1.3 Diameter of drain pipe

Q = length of field x width of field x drainage coefficient
i = 0.3% 0.003

### 3.1.4 Wesslings equation

$$Q = 89(d_l)^{2.716} x(i)^{-0.572}$$

Spacing = 7.5 m
Q = 0.0108x7.5x30
**Q= 2.43 $m^3$/day**

$$2.43 = 89(d_l)^{2.716} x(0.003)^{-0.572}$$

**$d_L$ = 82 mm**

similarly,

**spacing = 10.0 m ; $d_L$ = 91 mm**
**spacing = 12.5 m ; $d_L$ = 99 mm**
**spacing = 15.0 m ; $d_L$ = 106 mm**

## 3.2 Design Consideration under Subirrigation Mode for the Water Table Management System

$$L^2 = \frac{4K(h_0^2 - h_1^2)}{e}$$

L = Spacing of drain (m)
e = Evaporation rate (m/day)
k = Hydraulic conductivity (m/day)
$h_0$ = Difference between depth to impervious layer to effective root zone of the crop
$h_1$ = Difference between depth to impervious layer to height of water table above the water level in the drain
Effective root zone of the crop – 0.3 m
Evapotranspirtaion rate – 5 mm/day

$$L^2 = \frac{4K(h_0^2 - h_1^2)}{e}$$

$h_0$ = 4.0 – 0.3
**$h_0$ = 3.7 m**
$h_1$ = 4.0 – 0.5
**$h_1$= 3.5**

$$L^2 = \frac{4x0.35(3.7^2 - 3.5^2)}{0.005}$$

**L = 20.07 m**

### 3.2.1 Equivalent depth for subirrigation

$$d_e = \frac{D}{1 + \frac{D}{L}(\frac{8}{\pi}\ln\frac{D}{r_e} - 3.4)}$$

$$d_e = \frac{4}{1 + \frac{4}{20.07}\left(\frac{8}{3.14}\ln\frac{4}{0.036} - 3.4\right)}$$

**$d_e$ = 0.39 m**
$m = h_0 - h_1$
$m = 3.7 - 3.5$
**m = 0.2**

$$L^2 = \frac{4km\left(2h_0^{'} - \frac{h_0^{'}}{h_0}m\right)}{e}$$

$h_0^{'}$ = $d_e$+h
= 0.39 +0.5
$h_0^{'}$ = 0.89 m

$$L^2 = \frac{4x0.35x0.2\left(2x0.89 - \frac{0.89}{3.7}x0.2\right)}{0.005}$$

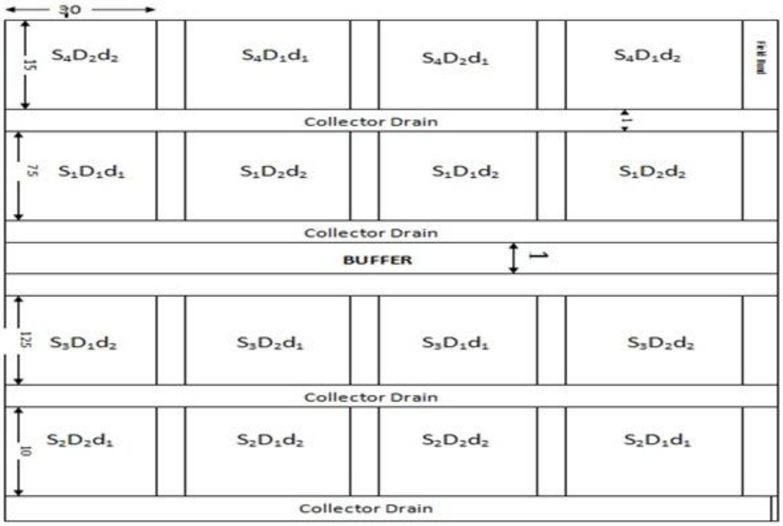
**L = 10 m**

The system of water table management system was installed with the design spacing of 15 m which could be functionally adaptable for both subsurface drainage and subirrigation. It was successfully implemented in the study area (1.5 acre) in Eastern Farm A block at Agricultural Engineering College and Research Institute, Kumulur, Tamil Nadu. The system was efficiently functioning both under subsurface drainage system for rice crop in one season in the year 2015, and subsequently for taking maize crop with subirrigation mode in the consecutive season (2015-2016).

**Table 2. Summary of design parameter of estimated for spacing under subirrigaton mode for water table management system**

| S. no. | Design parameters | Specification | |
|---|---|---|---|
| | | Controlled draianage | Subirrigation |
| 1. | Hydraulic conductivity | 0.35 m/day | 0.35 m/day |
| 2. | Draiange coefficient | 0.0108 m/day | 0 |
| 3. | Hydraulic head above the drains | 0.5 m | 0.5 m |
| 4. | Equivalent depth | 1.58 m | 0.39 |
| 5. | Evapotranspiration rate | 5 mm/day | 5 mm/day |
| 6. | Effective radius | 0.036 m | 0.036 m |
| 7. | Drain spacing | 15m | 10 m |

## 3.3 Design Layout



All dimensions in m

**Table 3. Design: Split plot design**

| Main plot treatments: (at 4 levels of drain spacing) | Subplot treatments: (at 2 levels of depth and diameter) |
|---|---|
| $S_1$ = 7.5 m spacing between drains | $D_1d_1$= Depth of drain at 75 cm + 100 mm diameter |
| $S_2$ = 10 m spacing between drains | $D_1d_2$= Depth of drain at 75 cm + 75 mm diameter |
| $S_3$ = 12.5 m spacing between drains | $D_2d_1$= Depth of drain at 60 cm + 100 mm diameter |
| $S_4$ = 15.0 m spacing between drains | $D_2d_2$= Depth of drain at 60 cm + 75 mm diameter |

### 3.4 Results for Water Table Management System

The experiment revealed that the water table steadily declined and attained the value below drains and similarly drainage coefficient was also reduced after few hours. The treatments under 75 cm of drain depth areas showing more depth to water table in all days of observations. The drain discharge rate was high in 7.5 m spacing when compared to all other spacing due to the more influence of area of contributing drain pipes (0.44 cm/day). The electrical conductivity (EC) value for pre drainage is 3.28 dS/m and 2.78 dS/m in post drainage. This may be due to decrease in the soils salinity values indicated the leaching of the salts. The pH of soil values for pre drainage is 9.1 and 8.7 in post drainage. The hydraulic conductivity decreased by 2 per cent when compared to pre drainage. This may be due to reduction in salinity and increase in alkalinity proportion in the drained area. The results showed that the treatments of 7.5 m drain spacing at 75 cm depth with 100 mm diameter ($S_1D_1d_1$) were high in drainage coefficient, depth to water table and crop yield. From the economic viability, it was observed that the 15 m drain spacing at 75 cm drain depth with 100 mm diameter ($S_4D_1d_1$) were economically viable with the highest profit than the other treatments.

## 4. CONCLUSION

Pre drainage investigation carried out in the study area for arriving at certain important design parameters for the design of water table management system for both drainage and subirrigation modes separately. Steady state Hooghoudt equation was used for the design of drainage spacing and the procedure followed by Doty, at North Carolina University using Moody Equation and convergence analysis was used for subirrigation mode spacing. The spacing arrived for drainage mode was 15 m and to that of subirrigation was 10 m respectively. Considering the feasibility of operation of both subsurface drainage and subirrigation, the spacing of 15 m could be recommended for water table management system of Eastern Farm A Block in AEC &RI kumulur, Tamil Nadu.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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