



REGIONE AUTONOMA  
FRIULI VENEZIA GIULIA

Direzione centrale Ambiente ed Energia  
Servizio Difesa del Suolo



**giovedì 26 luglio 2018**

**ore 9.30 - 13.00**

**Auditorium della Regione**

**via Roma 5, Gorizia**

Regolamento recante disposizioni per l'applicazione del principio dell'

## **INVARIANZA IDRAULICA**

di cui all'articolo 14, comma 1, lettera k) della legge regionale 29 aprile 2015, n. 11  
(disciplina organica in materia di difesa del suolo e di utilizzazione delle acque)

**D.P.R. 27/03/2018, n. 083/Pres.**

# **COME E PERCHE' FARE INVARIANZA**

**Dott. ing. Matteo Nicolini**

*Professore aggregato di Costruzioni idrauliche*

*Dipartimento Politecnico di Ingegneria e Architettura*

*Università degli Studi di Udine*



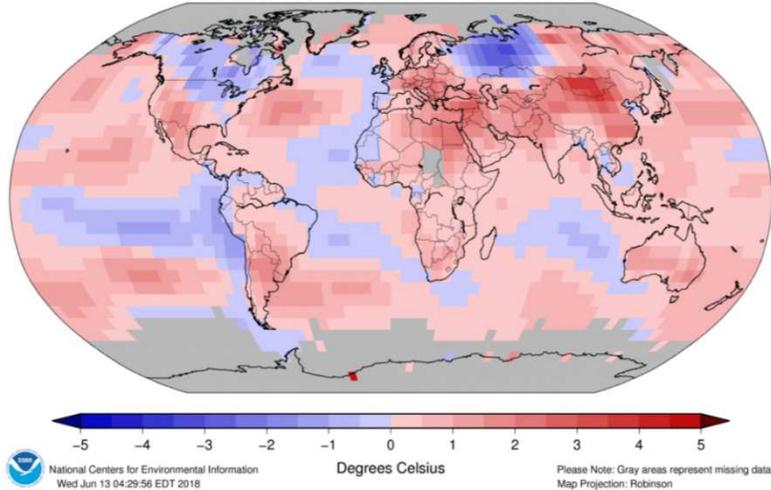
# CAMBIAMENTI CLIMATICI E CONSUMO DI SUOLO

[www.noaa.gov](http://www.noaa.gov)

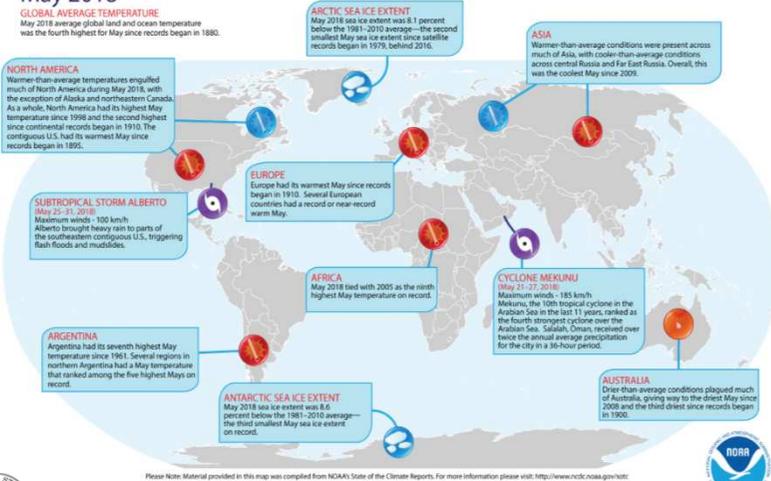
(National Oceanic and Atmospheric Agency)

Land & Ocean Temperature Departure from Average Mar 2018–May 2018  
(with respect to a 1981–2010 base period)

Data Source: GHCN–M version 3.3.0 & ERSST version 4.0.0



## Selected Significant Climate Anomalies and Events May 2018



Please Note: Material provided in this map was compiled from NOAA's State of the Climate Reports. For more information please visit: <http://www.ncei.noaa.gov/stc>

[www.isprambiente.gov.it](http://www.isprambiente.gov.it)



## Consumo di suolo, dinamiche territoriali e servizi ecosistemici

Edizione 2018



288/2018

RAPPORTI



# CONSUMO DI SUOLO

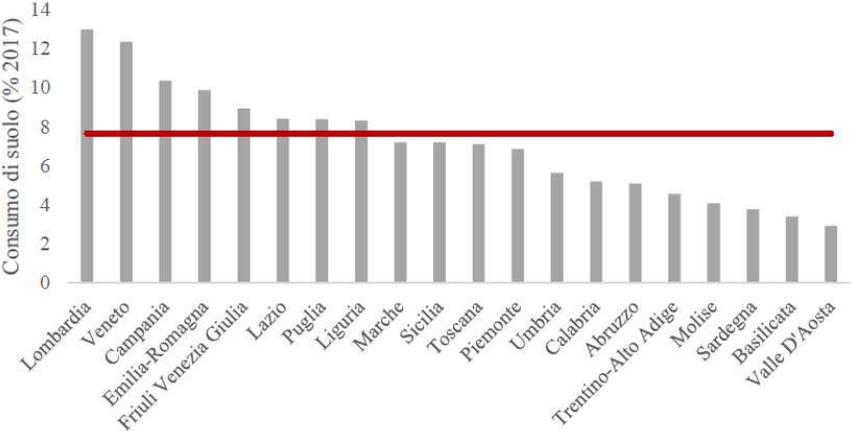


Figura 3 - Consumo di suolo a livello regionale (% 2017). In rosso la media nazionale. Fonte: elaborazioni ISPRA su cartografia SNPA.

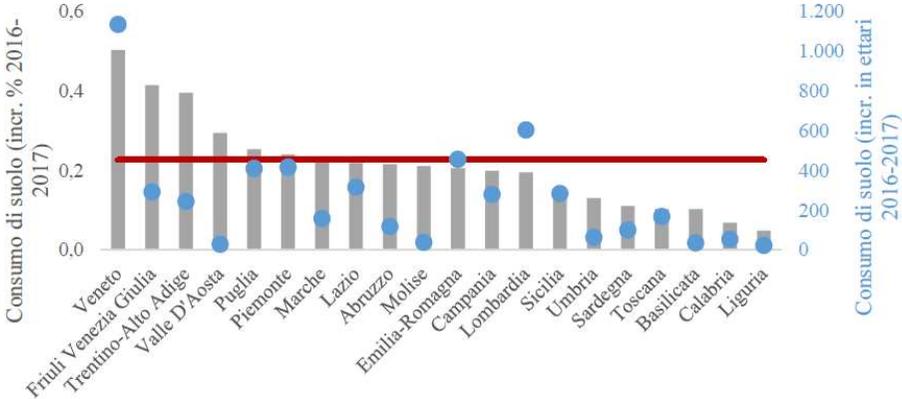


Figura 4 - Consumo di suolo a livello regionale. Incremento percentuale (in grigio) e in ettari (azzurro) tra il 2016 e il 2017. In rosso la media nazionale dell'incremento percentuale. Fonte: elaborazioni ISPRA su cartografia SNPA.

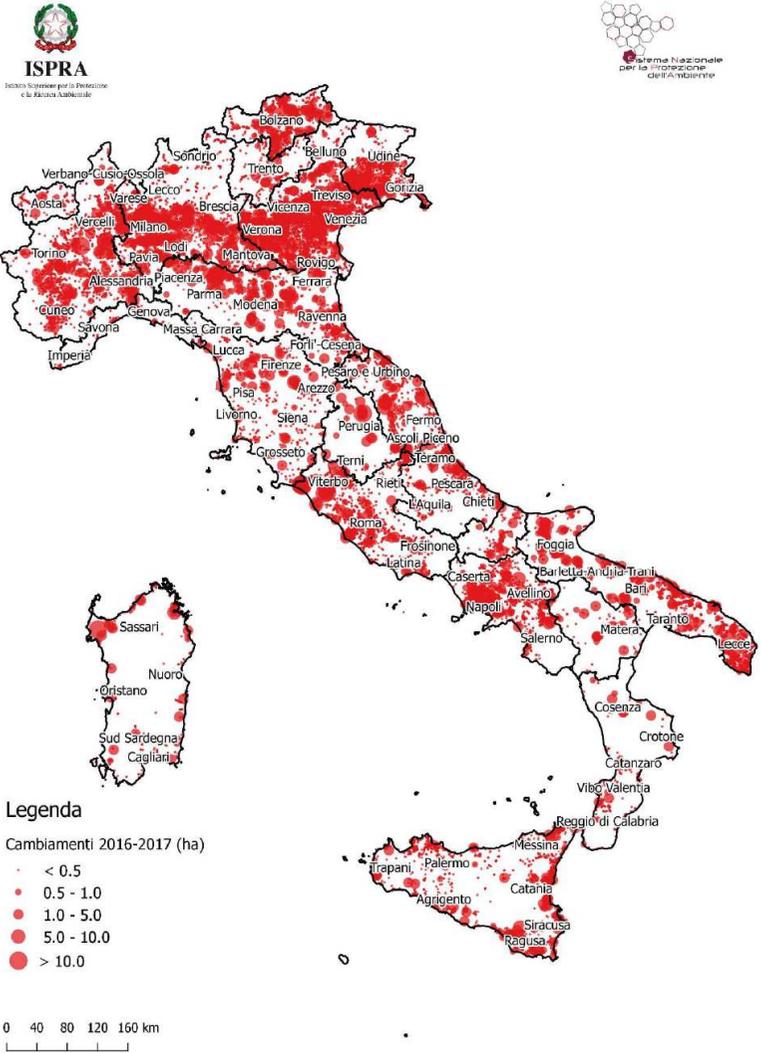


Figura 5 - Localizzazione dei principali cambiamenti dovuti al nuovo consumo di suolo tra il 2016 e il 2017. Fonte: elaborazioni ISPRA su cartografia SNPA.



# CONSUMO DI SUOLO

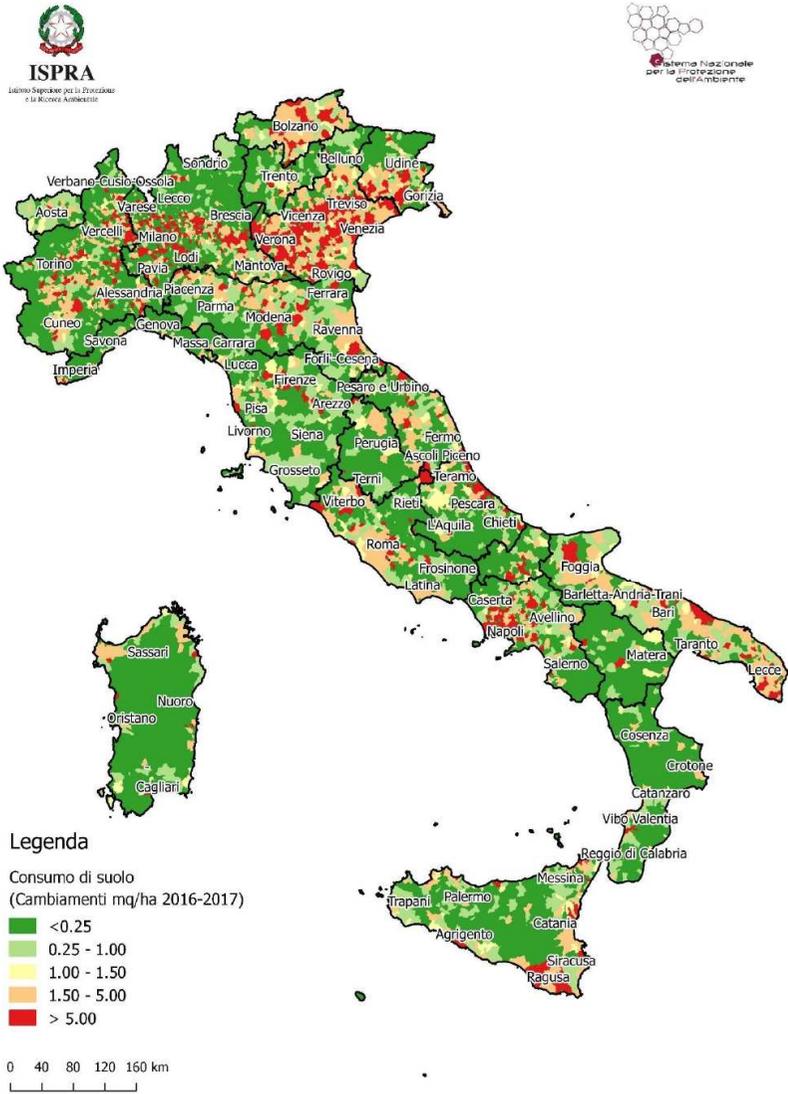


Figura 6 - Densità dei cambiamenti in metri quadrati su ettaro dovuti al nuovo consumo di suolo tra il 2016 e il 2017. Fonte: elaborazioni ISPRA su cartografia SNPA.

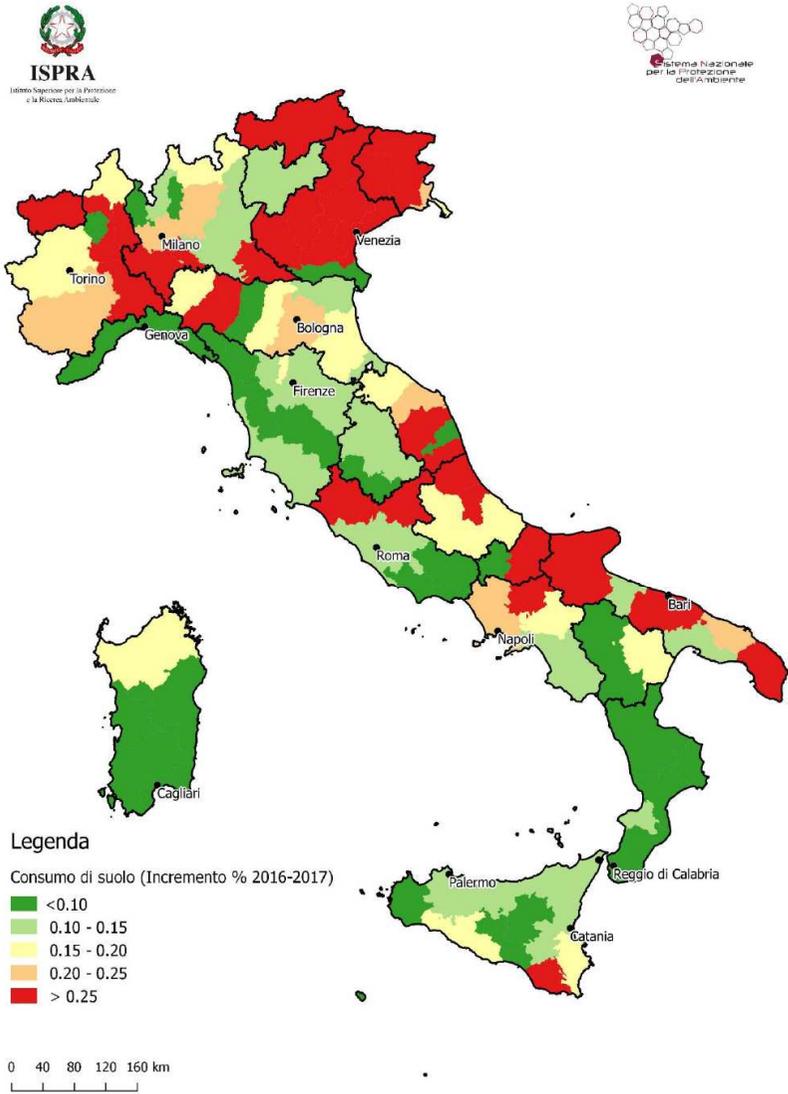
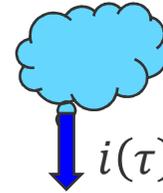


Figura 8 - Consumo di suolo a livello provinciale (incremento % 2016-2017). Fonte: elaborazioni ISPRA su cartografia SNPA.



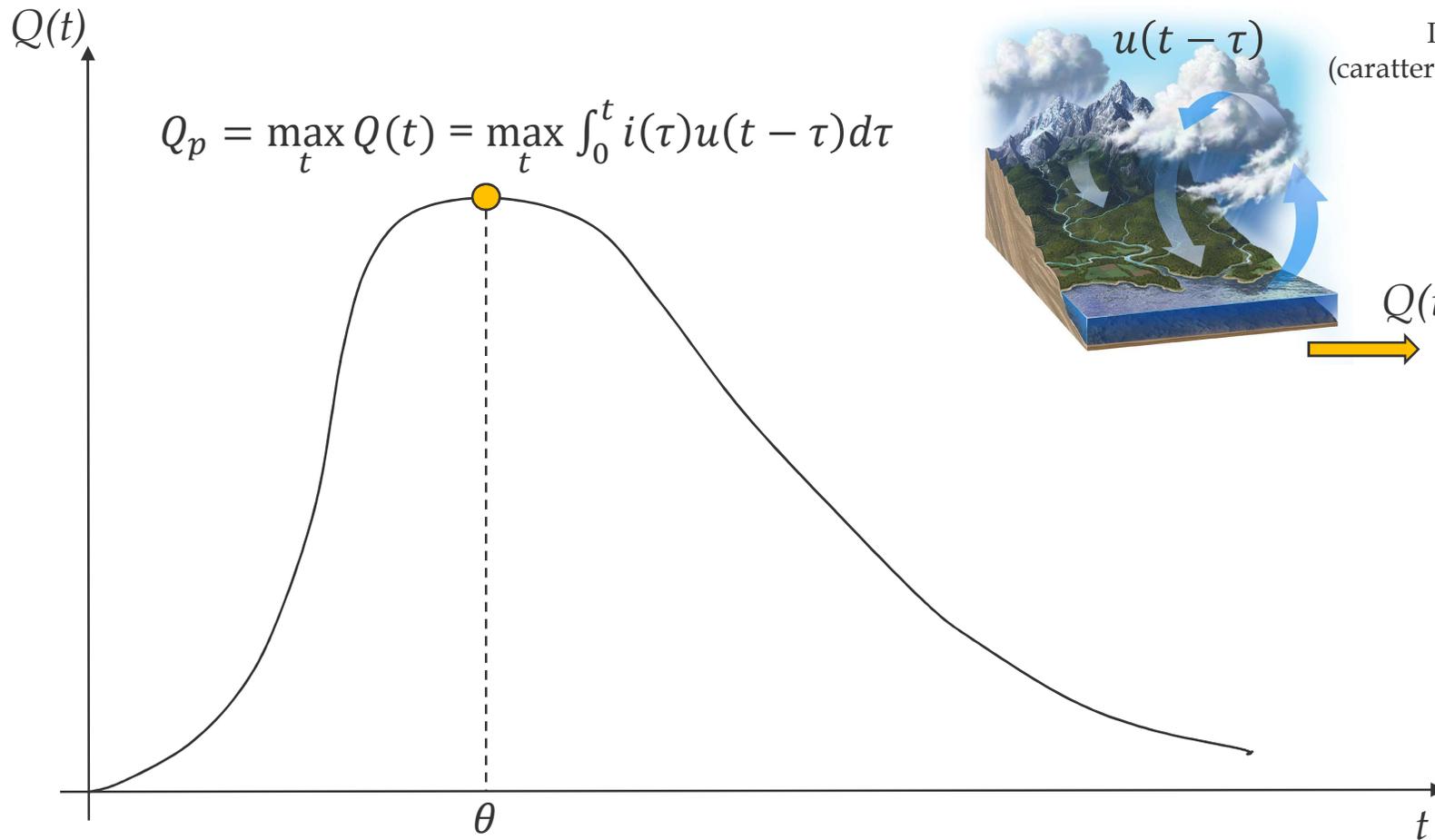
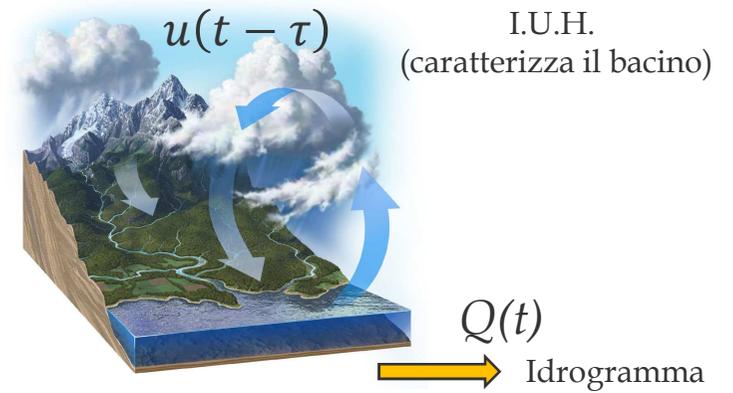
# CONCETTI BASE

L'idrogramma di piena e la portata di picco



$$Q(t) = \int_0^t i(\tau)u(t - \tau)d\tau$$

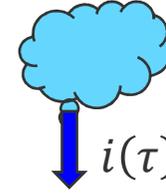
$i(\tau)$  Ietogramma



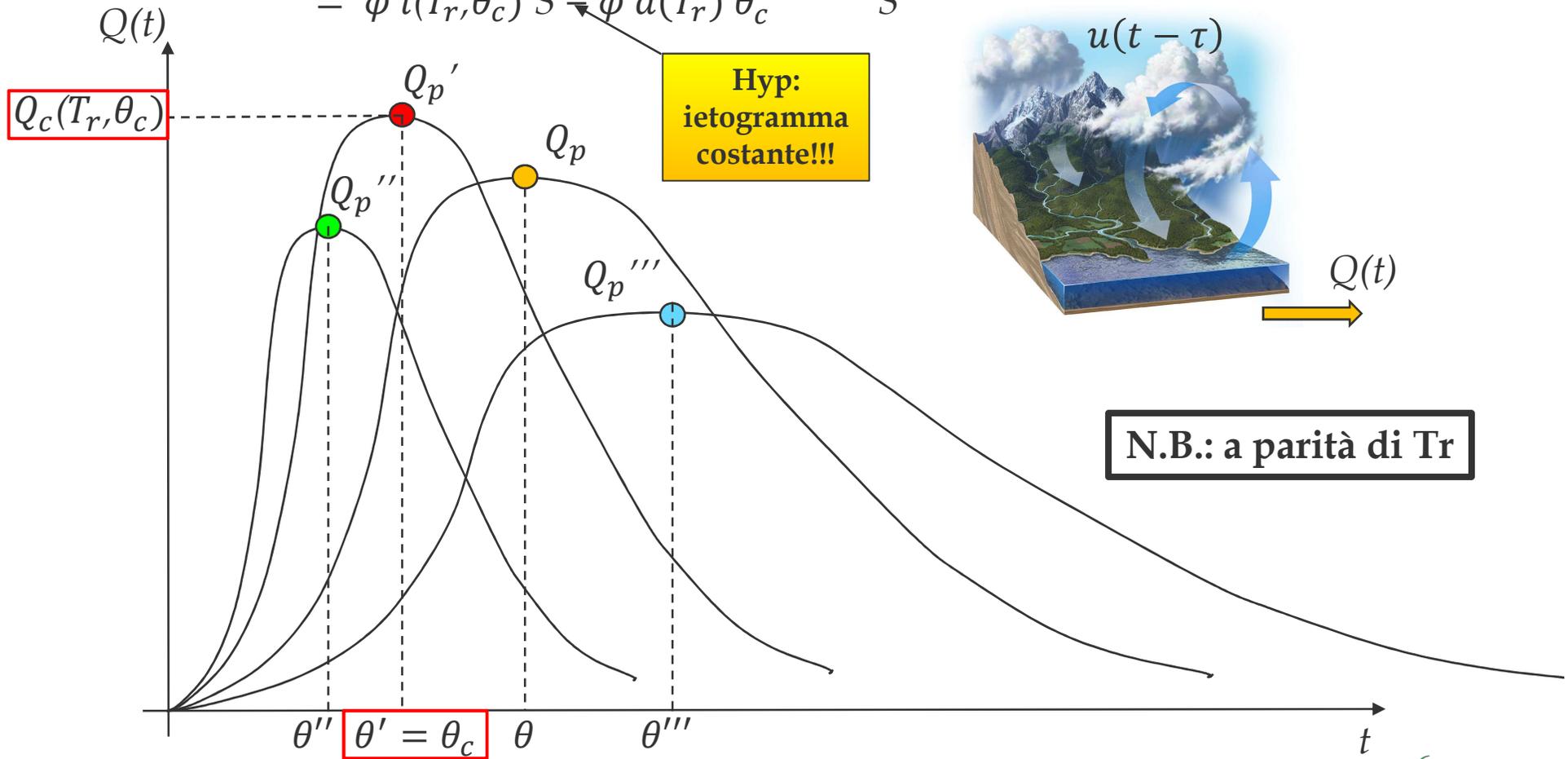
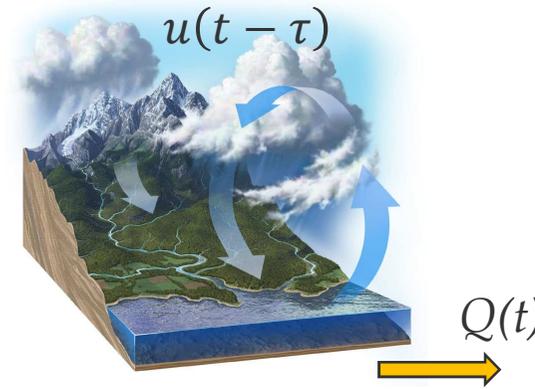
# CONCETTI BASE

Durata critica e portata critica

$$Q_c(T_r, \theta_c) = \max_{\theta} Q_p(\theta) = \varphi i(T_r, \theta_c) S = \varphi a(T_r) \theta_c^{n(T_r)-1} S$$



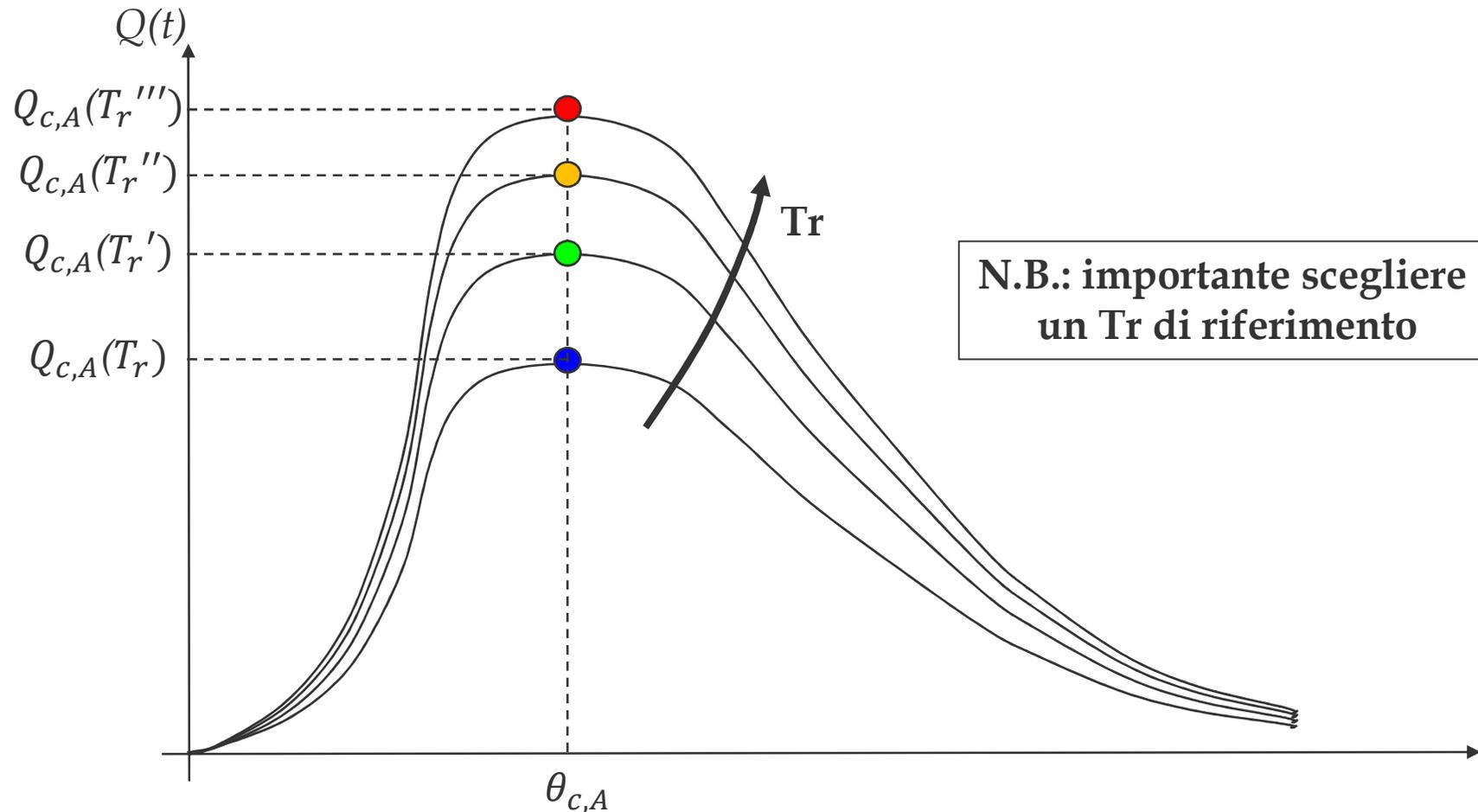
$$Q(t) = \int_0^t i(\tau) u(t - \tau) d\tau$$



# CONCETTI BASE

Situazione 'ANTE' operam: variazione del Tr

$$Q_{c,A}(T_r, \theta_{c,A}) = \varphi_A i(T_r, \theta_{c,A}) S = \varphi_A a(T_r) \theta_{c,A}^{n(T_r)-1} S$$



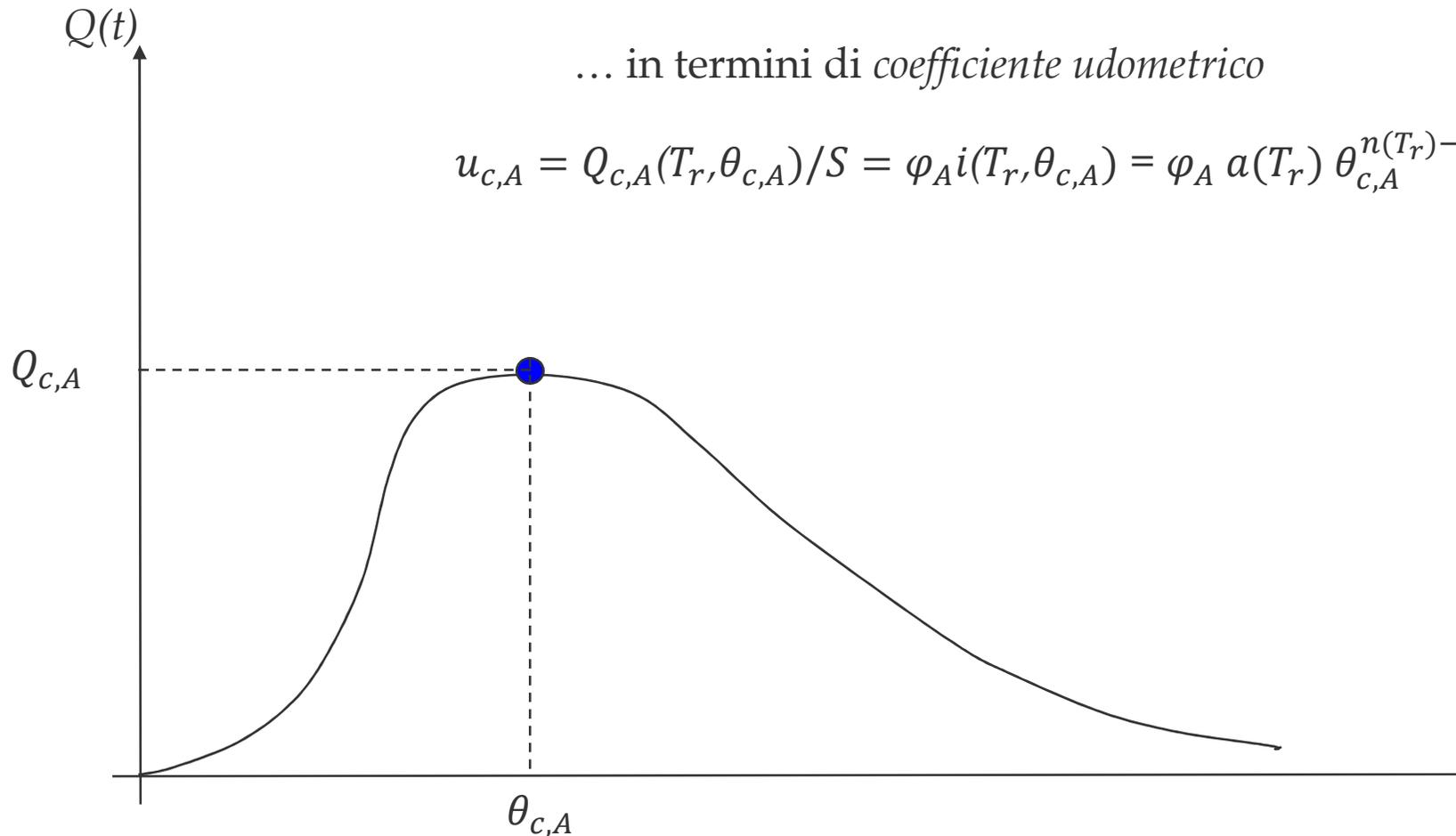
# CONCETTI BASE

Situazione 'ANTE' operam

$$Q_{c,A}(T_r, \theta_{c,A}) = \varphi_A i(T_r, \theta_{c,A}) S = \varphi_A a(T_r) \theta_{c,A}^{n(T_r)-1} S$$

... in termini di *coefficiente udometrico*

$$u_{c,A} = Q_{c,A}(T_r, \theta_{c,A}) / S = \varphi_A i(T_r, \theta_{c,A}) = \varphi_A a(T_r) \theta_{c,A}^{n(T_r)-1}$$

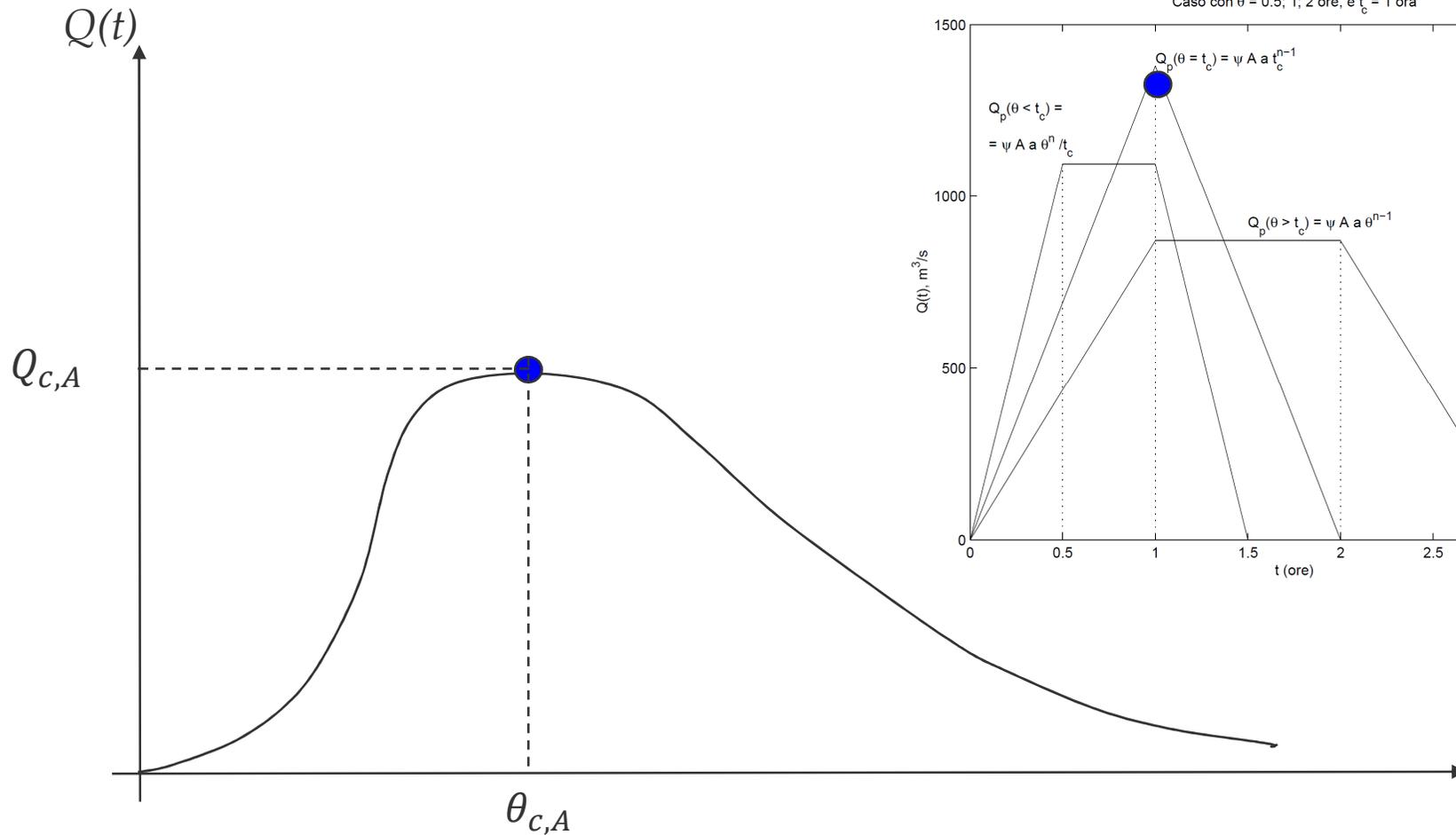


# CONCETTI BASE

Situazione 'ANTE' operam

$$Q_{C,A}(T_r, \theta_{C,A}) = \varphi_A i(T_r, \theta_{C,A}) S = \varphi_A a(T_r) \theta_{C,A}^{n(T_r)-1} S$$

Metodo cinematico  
(o della corrivazione)

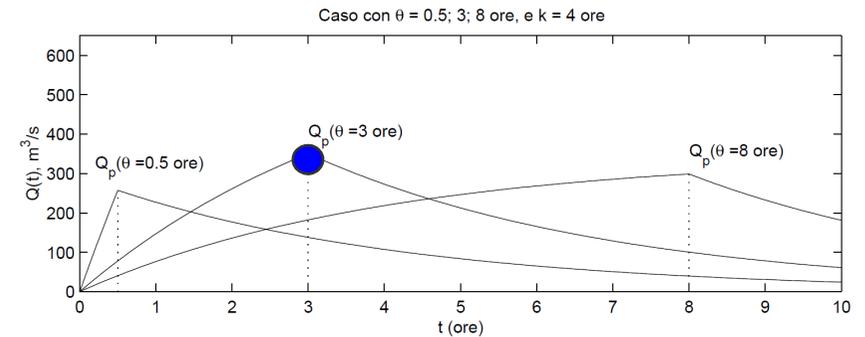
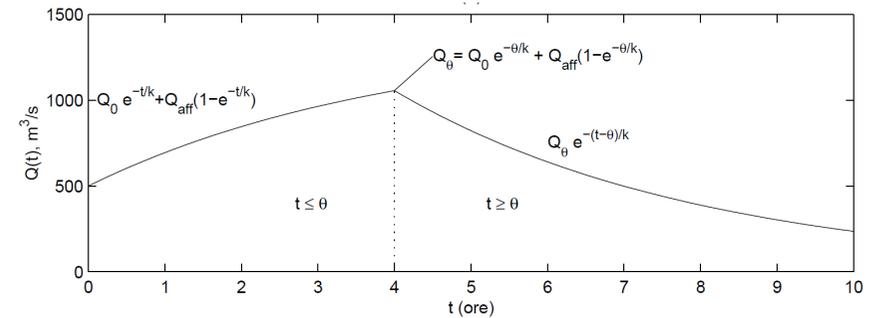
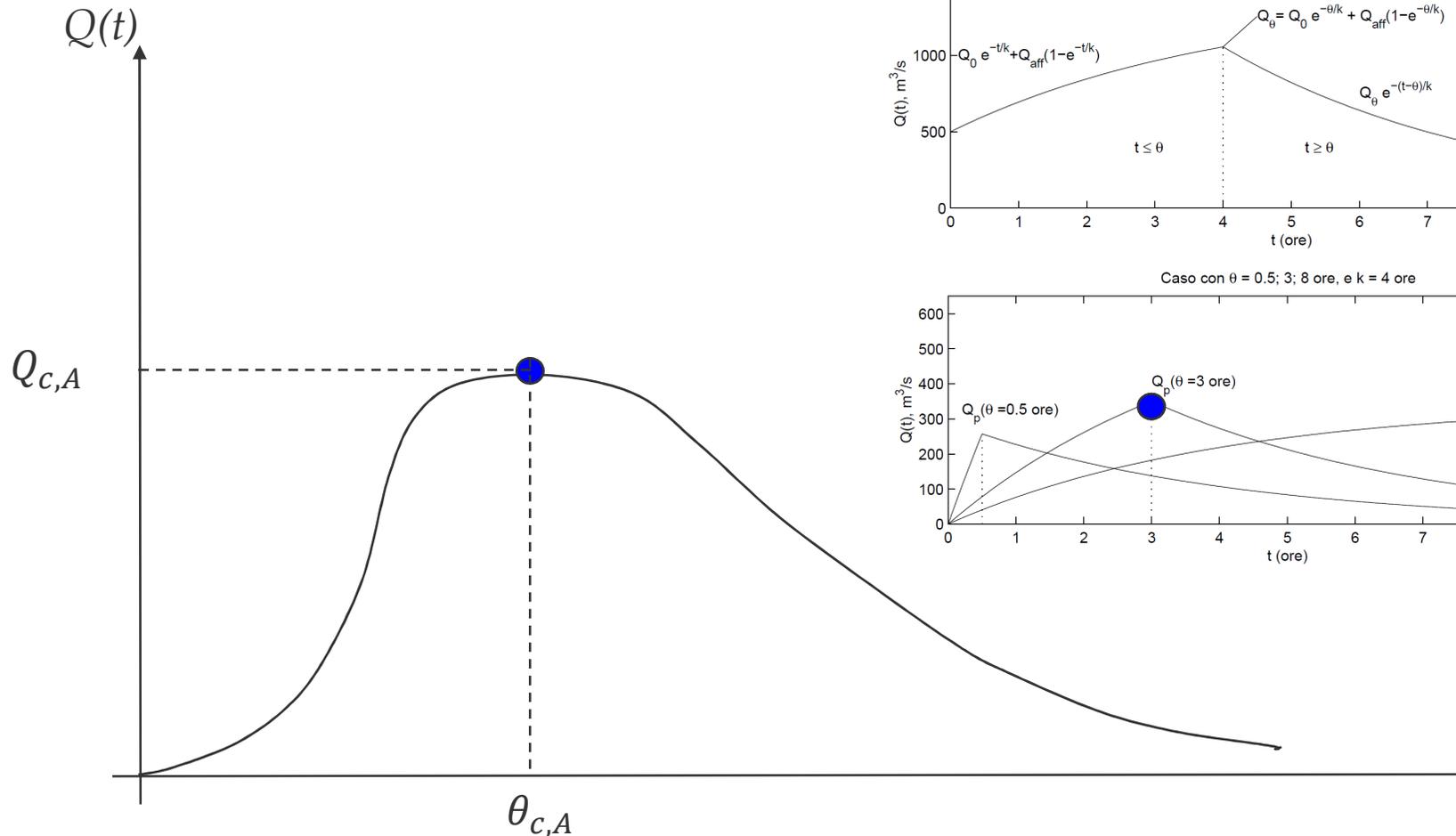


# CONCETTI BASE

Situazione 'ANTE' operam

$$Q_{C,A}(T_r, \theta_{C,A}) = \varphi_A i(T_r, \theta_{C,A}) S = \varphi_A a(T_r) \theta_{C,A}^{n(T_r)-1} S$$

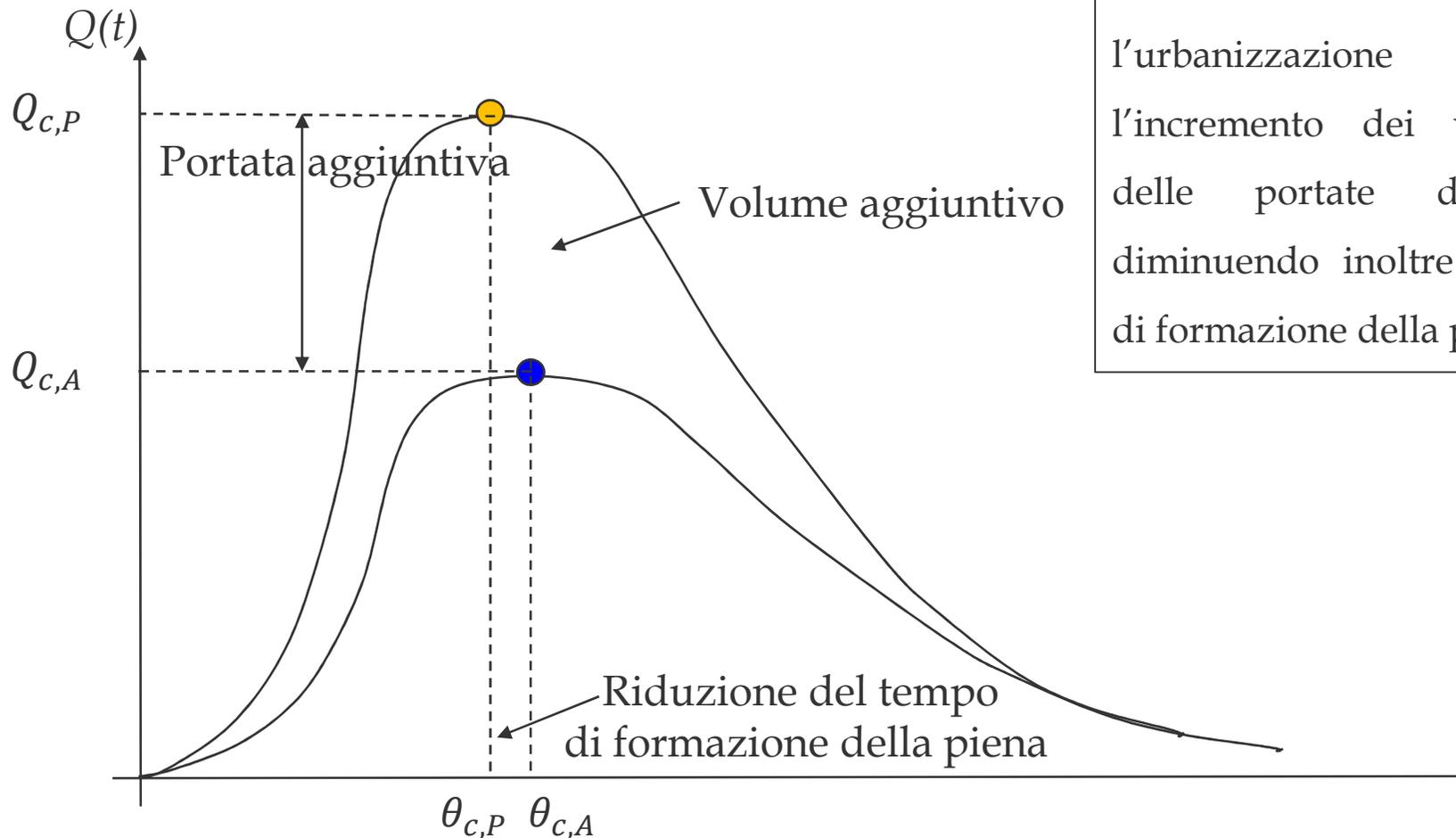
Metodo del serbatoio lineare  
(anche invaso italiano)



# PERCHE' FARE INVARIANZA

Situazione 'POST' operam: effetti dell'urbanizzazione

$$Q_{C,P}(T_r, \theta_{C,P}) = \varphi_P i(T_r, \theta_{C,P}) S = \varphi_P a(T_r) \theta_{C,P}^{n(T_r)-1} S$$

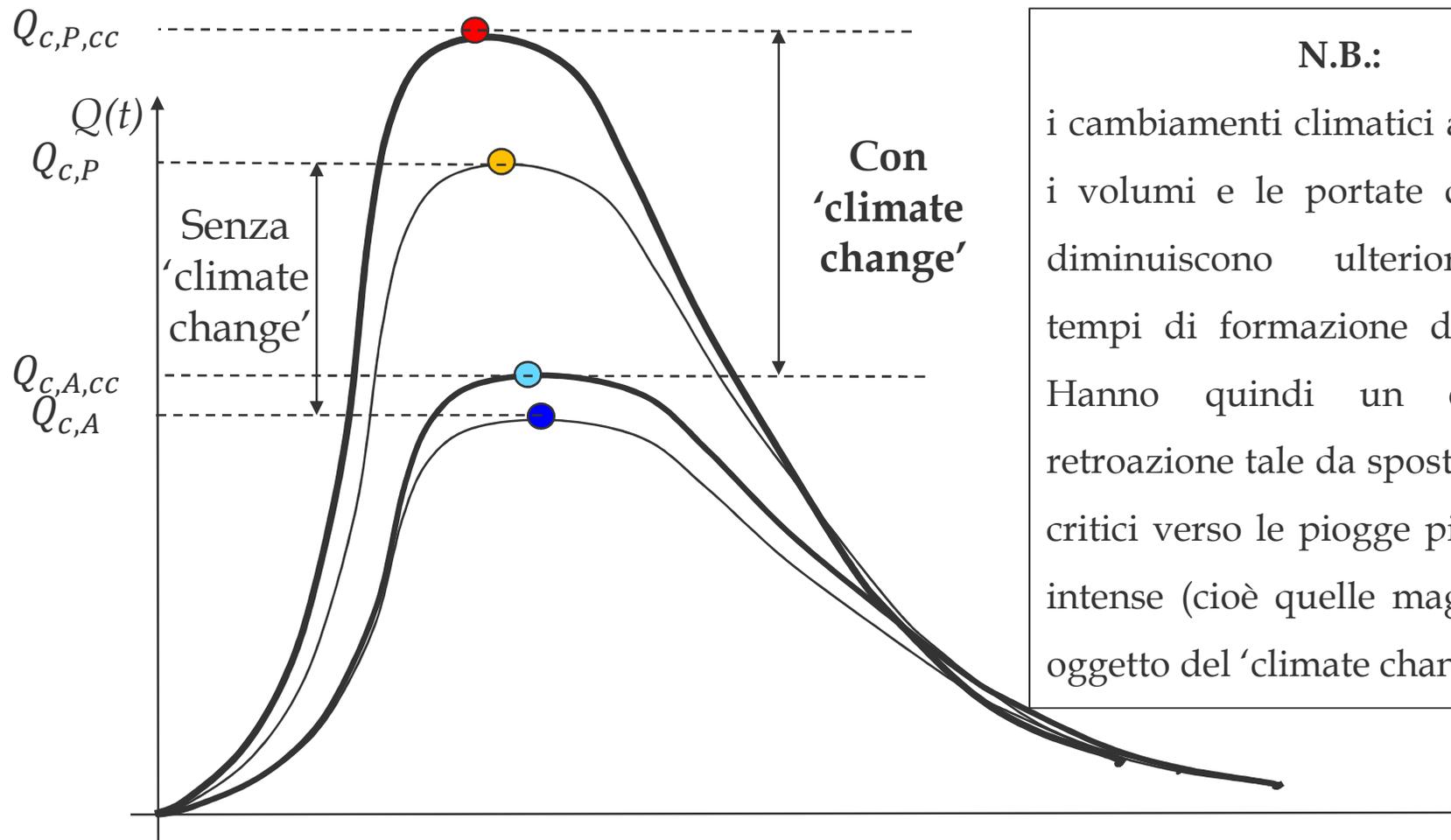


**N.B.:**  
l'urbanizzazione determina l'incremento dei volumi e delle portate di picco, diminuendo inoltre il tempo di formazione della piena.

# PERCHE' FARE INVARIANZA

Situazione 'POST' operam: effetti dell'urbanizzazione + cambiamenti climatici

$$Q_{C,P,CC}(T_r, \theta_{C,P,CC}) = \varphi_P i_{CC}(T_r, \theta_{C,P,CC}) S = \varphi_P a_{CC}(T_r) \theta_{C,P,CC}^{n_{CC}(T_r)-1} S$$



**N.B.:**  
 i cambiamenti climatici aumentano i volumi e le portate di picco, e diminuiscono ulteriormente i tempi di formazione della piena. Hanno quindi un effetto di retroazione tale da spostare i tempi critici verso le piogge più brevi ed intense (cioè quelle maggiormente oggetto del 'climate change').



# COME FARE INVARIANZA

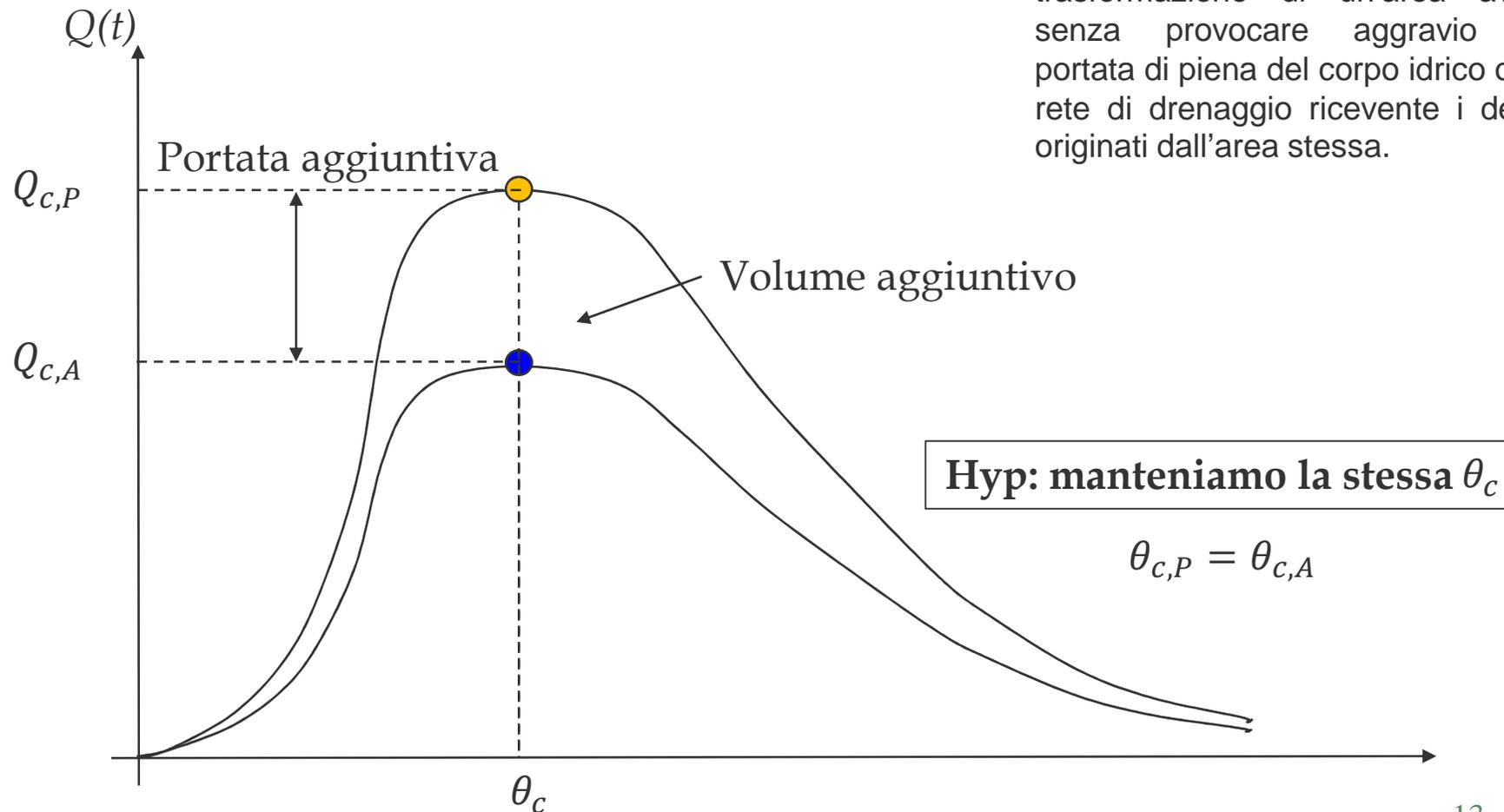
Situazione 'POST' operam

Art. 3, comma 1, lett. m)

$$Q_{C,P}(T_r, \theta_c) = \varphi_P i(T_r, \theta_c) S = \varphi_P a(T_r) \theta_c^{n(T_r)-1} S$$

**invarianza idraulica:**

principio secondo il quale la trasformazione di un'area avviene senza provocare aggravio della portata di piena del corpo idrico o della rete di drenaggio ricevente i deflussi originati dall'area stessa.



# COME FARE INVARIANZA

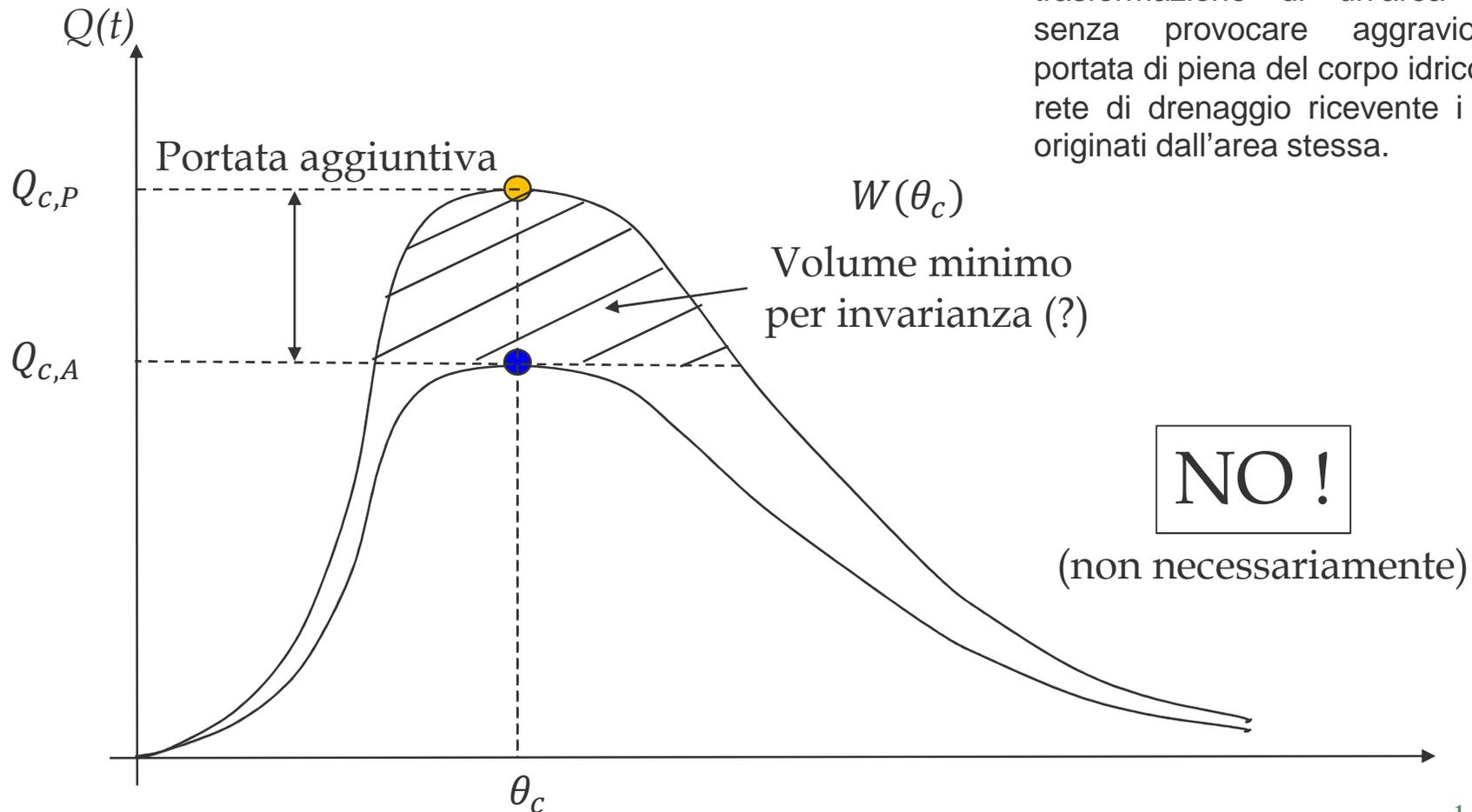
Situazione 'POST' operam

$$Q_{C,P}(T_r, \theta_c) = \varphi_P i(T_r, \theta_c) S = \varphi_P a(T_r) \theta_c^{n(T_r)-1} S$$

Art. 3, comma 1, lett. m)

**invarianza idraulica:**

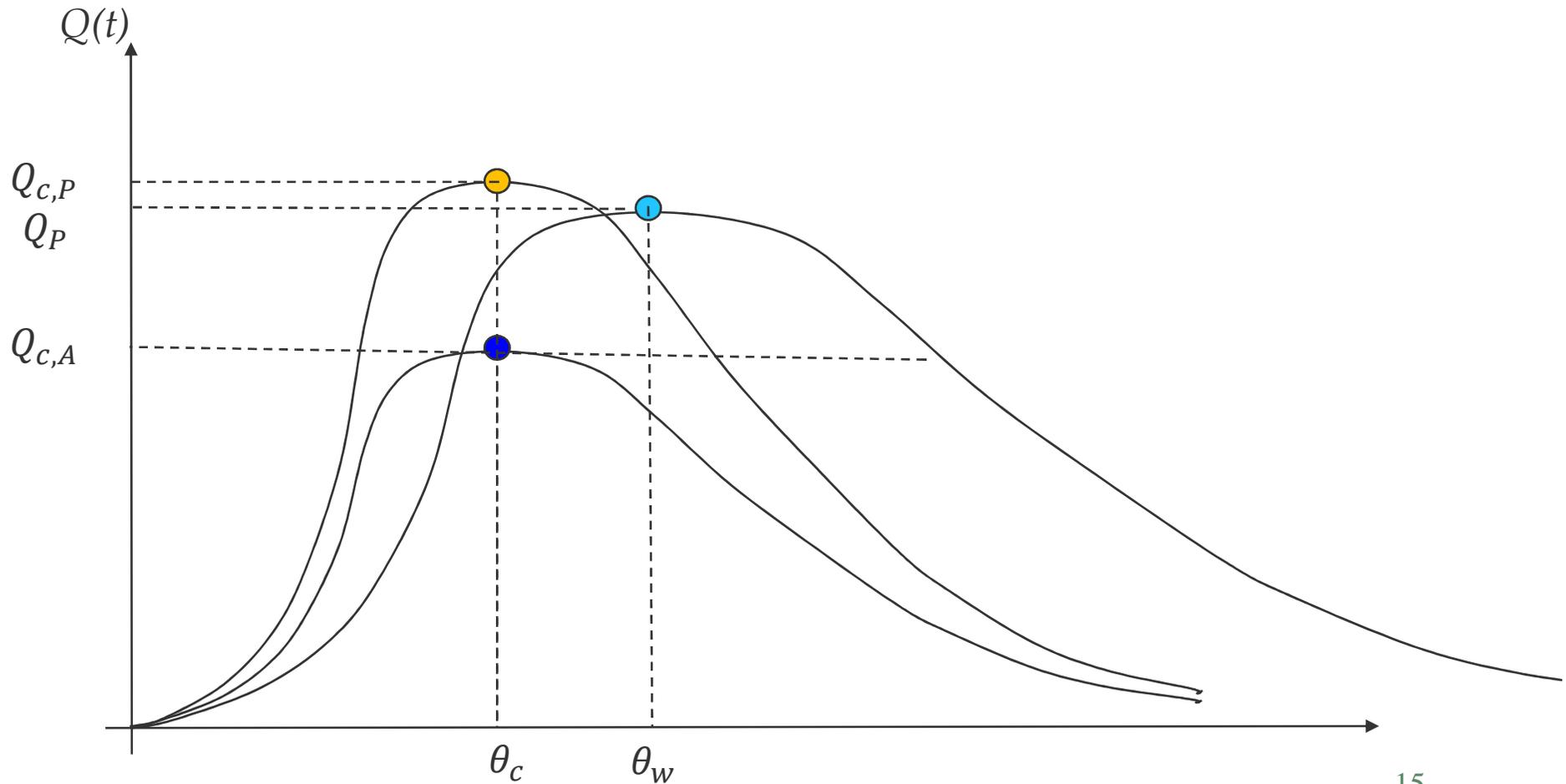
principio secondo il quale la trasformazione di un'area avviene senza provocare aggravio della portata di piena del corpo idrico o della rete di drenaggio ricevente i deflussi originati dall'area stessa.



# COME FARE INVARIANZA

Situazione 'POST' operam

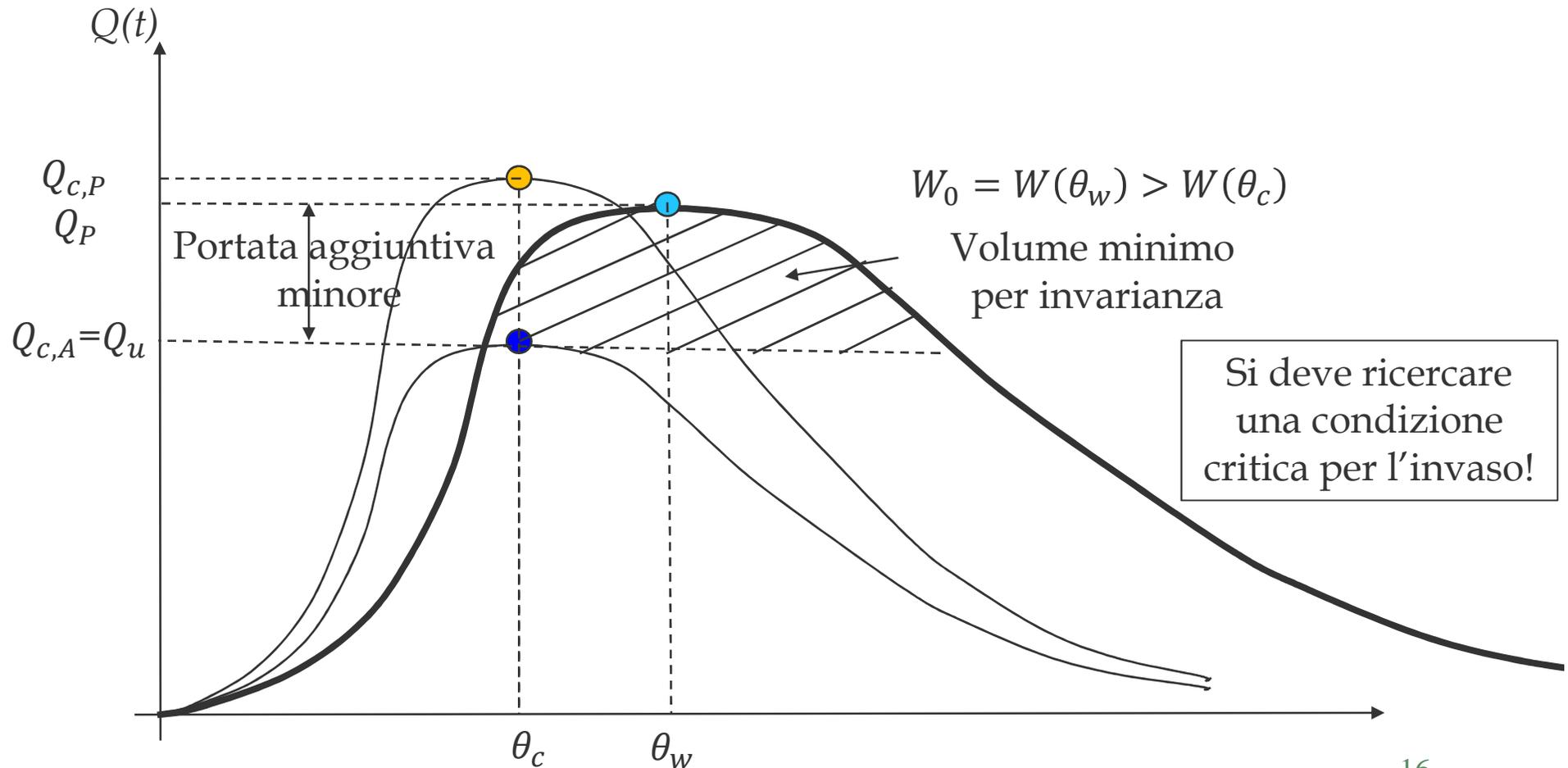
$$Q_{C,P}(T_r, \theta_c) = \varphi_P i(T_r, \theta_c) S = \varphi_P a(T_r) \theta_c^{n(T_r)-1} S$$



# COME FARE INVARIANZA

Situazione 'POST' operam

$$Q_{c,P}(T_r, \theta_c) = \varphi_P i(T_r, \theta_c) S = \varphi_P a(T_r) \theta_c^{n(T_r)-1} S$$

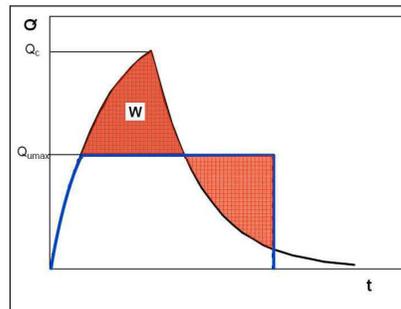


# COME FARE INVARIANZA

- Metodo dell'invaso (Paoletti e Rege-Gianas, 1979):

$$G(n, m) = g(n, m) \cdot F(n, m) = \frac{W}{k \cdot Q_c}$$

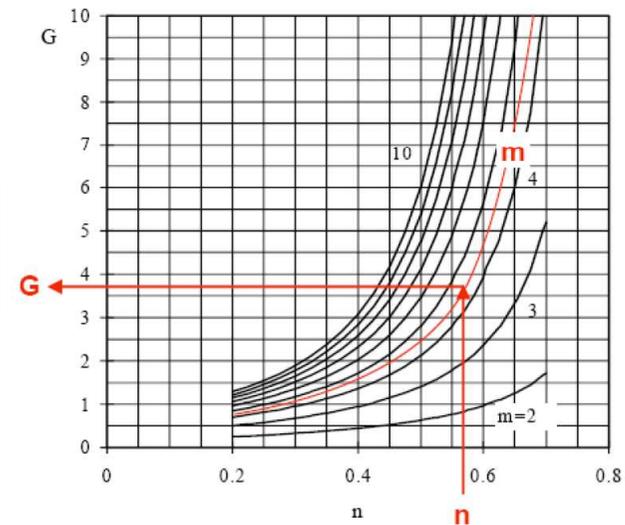
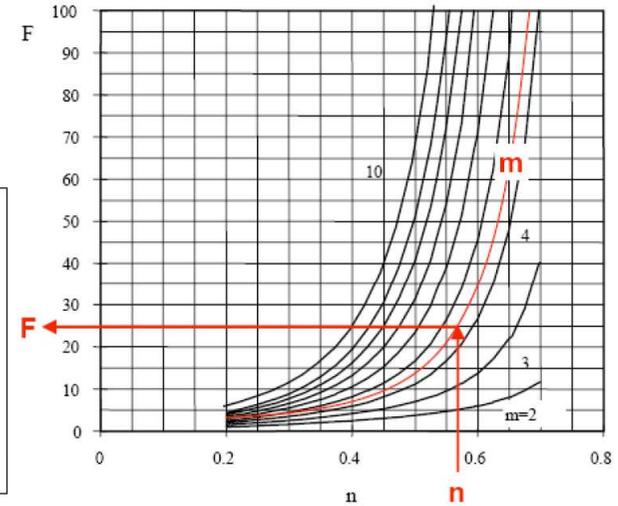
$$F(n, m) = \frac{\theta_w}{k}$$



$$n \cdot F + (1 - n) \cdot \ln \left( \frac{\frac{m}{D} \cdot F^{n-1}}{\frac{m}{D} \cdot F^{n-1} - 1} \right) - \frac{D}{m} \cdot F^{2-n} = 0$$

$$g(n, m) = \frac{F^{n-1}}{D} - \frac{F^{n-2}}{D} \cdot \ln \left( \frac{\frac{m}{D} \cdot F^{n-1}}{\frac{m}{D} \cdot F^{n-1} - 1} \right) - \frac{1}{m} - \frac{1}{m \cdot F} \cdot \ln \left[ \left( \frac{m \cdot F^{n-1}}{D} - 1 \right) \cdot (1 - e^{-F}) \right]$$

$$m = \frac{1}{\eta} = \frac{Q_c}{Q_u}$$

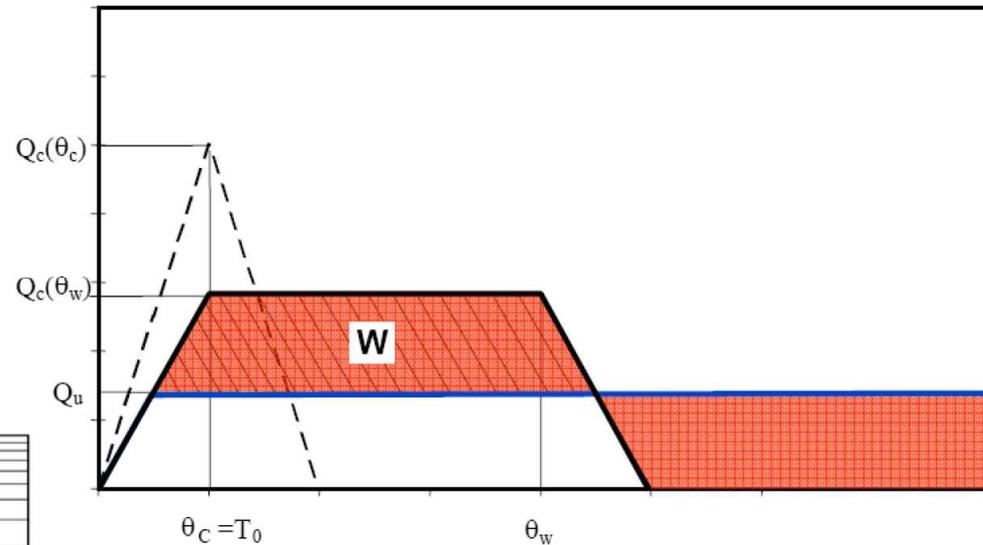
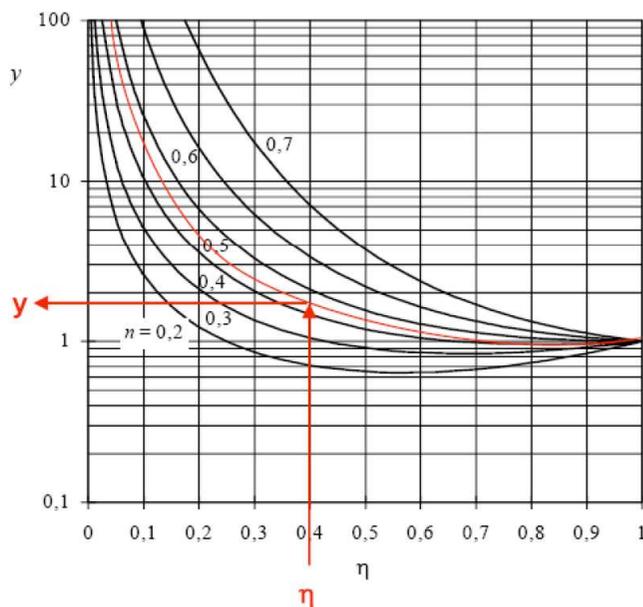


# COME FARE INVARIANZA

- Metodo cinematico (Alfonsi e Orsi, 1979):

$$\eta = \frac{Q_u}{Q_c}$$

$$y = \frac{\theta_w}{T_0}$$

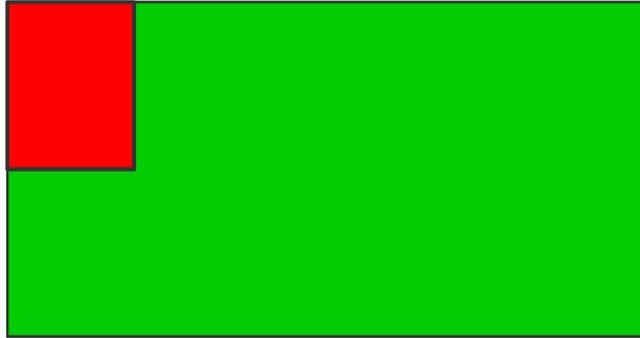


$$W = \varphi \cdot A \cdot a \cdot \theta^n + T_0 \cdot Q_u^2 \cdot \frac{\theta^{1-n}}{\varphi \cdot A \cdot a} - Q_u \cdot \theta - Q_u \cdot T_0$$

$$\frac{dW(\theta)}{d\theta} = 0$$

$$n \cdot \varphi \cdot A \cdot a \cdot \theta_w^{n-1} + (1-n) \cdot T_0 \cdot Q_u^2 \cdot \frac{\theta_w^{-n}}{\varphi \cdot A \cdot a} - Q_u = 0$$

## ESEMPIO PRATICO: METODO CINEMATICO



$$S_{\text{tot}} = 1 \text{ ha} = 10000 \text{ m}^2$$

$$\varphi_A = 0.2$$

$$S_{\text{intervento}} = 0.1 \text{ ha} = 1000 \text{ m}^2$$

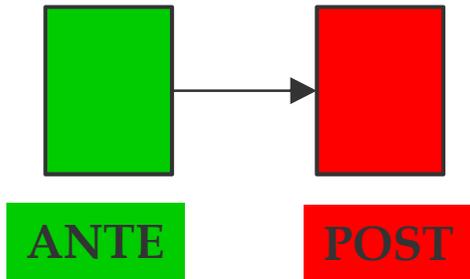
$$\varphi_P = 0.9$$

$$a(T_r = 50) = 75 \text{ mm/ora}^n$$

$$n(T_r) = 0.4 \quad (\text{scrosci})$$

$$n(T_r) = 0.3 \quad (\text{p. orarie})$$

# ESEMPIO PRATICO: METODO CINEMATICO



$$S_{\text{tot}} = 1 \text{ ha} = 10000 \text{ m}^2 \quad \varphi_A = 0.2$$

$$S_{\text{intervento}} = 0.1 \text{ ha} = 1000 \text{ m}^2 \quad \varphi_P = 0.9$$

$$a(T_r = 50) = 75 \text{ mm/ora}^n$$

$$n(T_r) = 0.4 \quad (\text{scrosci})$$

$$n(T_r) = 0.3 \quad (\text{p. orarie})$$

APPROCCIO CON SUPERFICIE DI RIFERIMENTO PARI A  $S_{\text{intervento}}$

**ANTE**

$t_c$ (min)	$Q_{c,A}$ (l/s)	$u_{c,A}$ (l/s/ha)
3	25.2	252
6	16.6	166
12	10.9	109
30	6.3	63

**POST**

$t_c$ (min)	$Q_{c,P}$ (l/s)	$Q_u$ (l/s)	$\theta_w$ (min)	$Q_p$ (l/s)	$W$ (m <sup>3</sup> )
3	113.2	25.2	9.6	57.6	15.4
6	74.7	16.6	18.6	38.0	20.4
12	49.3	10.9	37.2	25.1	26.9
30	28.4	6.3	92.4	14.5	38.8

# ESEMPIO PRATICO: METODO CINEMATICO



$$S_{\text{tot}} = 1 \text{ ha} = 10000 \text{ m}^2$$

$$S_{\text{intervento}} = 0.1 \text{ ha} = 1000 \text{ m}^2$$

$$a(T_r = 50) = 75 \text{ mm/ora}^n$$

$$n(T_r) = 0.4 \text{ (scrosci)}$$

$$n(T_r) = 0.3 \text{ (p. orarie)}$$

~~$$\varphi_A = 0.2$$~~

~~$$\varphi_P = 0.9$$~~

$$\varphi_P = (0.2 * 0.9 + 0.9 * 0.1)$$

$$\varphi_P = 0.27$$

APPROCCIO CON SUPERFICIE DI RIFERIMENTO PARI A  $S_{\text{tot}}$

**ANTE**

$t_c$ (min)	$Q_{c,A}$ (l/s)	$u_{c,A}$ (l/s/ha)
12	109.5	109.5
18	85.9	85.9
30	63.2	63.2
45	49.5	49.5
<b>3</b>	<b>251.6</b>	<b>251.6</b>

**POST**

$t_c$ (min)	$Q_{c,P}$ (l/s)	$Q_u$ (l/s)	$\theta_w$ (min)	$Q_p$ (l/s)	$W$ (m <sup>3</sup> )
12	147.9	109.5	11.6	150.5	7.1
18	115.9	85.9	17.5	117.3	8.3
30	85.3	63.2	29.1	86.9	10.2
45	66.9	49.5	43.7	68.1	12.1
<b>3</b>	<b>339.7</b>	<b>251.6</b>	<b>2.9</b>	<b>345.9</b>	<b>4.1</b>



# ESEMPIO PRATICO: METODO ITALIANO



$$S_{\text{tot}} = 1 \text{ ha} = 10000 \text{ m}^2 \quad \varphi_A = \phi_0 = 0.2$$

$$S_{\text{intervento}} = 0.1 \text{ ha} = 1000 \text{ m}^2 \quad \varphi_P = \phi = 0.9$$

$$a(T_r = 50) = 75 \text{ mm/ora}^n \quad I = 1, P = 0$$

$$n(T_r) = 0.4 \text{ (scrosci)} \quad W_0 = 40 \div 50 \text{ m}^3/\text{ha}$$

$$n(T_r) = 0.3 \text{ (p. orarie)} \quad W = 476 \div 598 \text{ m}^3/\text{ha}$$

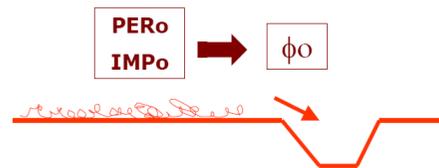
$$W_{\text{vasca}} = 48 \div 60 \text{ m}^3$$

APPROCCIO CON SUPERFICIE DI RIFERIMENTO PARI A  $S_{\text{intervento}}$

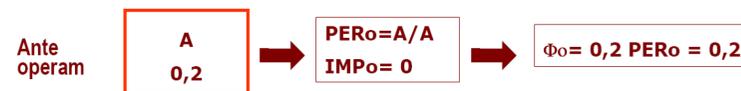
$$w = w_0 \left( \frac{\phi}{\phi_0} \right)^{\frac{1}{1-n}} - 15 I - w_0 P$$

$$w = w_0 \left( \frac{\phi}{\phi_0} \right)^{\frac{1}{1-n}} - 15 I - w_0 P$$

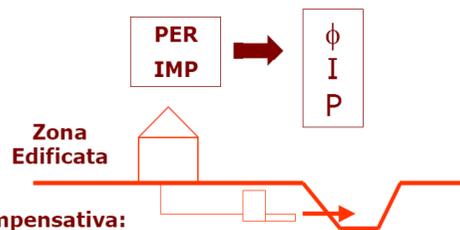
Ante operam



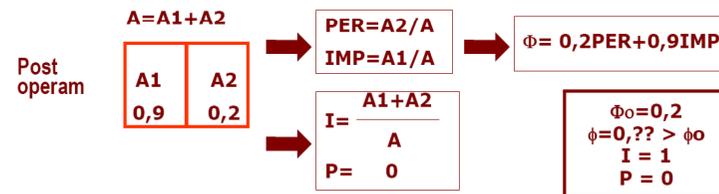
**TRASFORMAZIONE TOTALE DI LOTTO AGRICOLO IN LOTTO EDIFICATO**



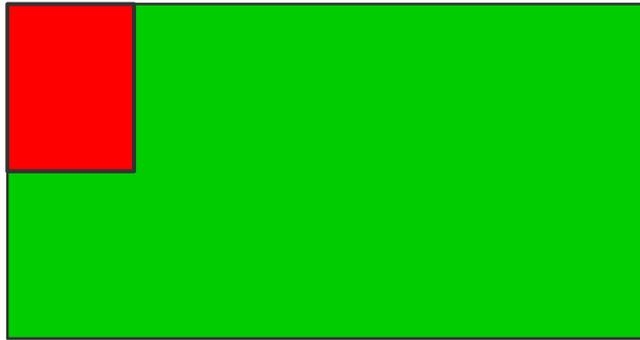
Post operam



Azione compensativa:  
Volume  $W + D_n$  scarico



# ESEMPIO PRATICO: METODO ITALIANO



$$S_{\text{tot}} = 1 \text{ ha} = 10000 \text{ m}^2 \quad \varphi_A = \phi_0 = 0.2$$

$$S_{\text{intervento}} = 0.1 \text{ ha} = 1000 \text{ m}^2 \quad \varphi_P = \phi = 0.27$$

$$a(T_r = 50) = 75 \text{ mm/ora}^n \quad I = 0.1, P = 0.9$$

$$n(T_r) = 0.4 \text{ (scrosci)} \quad W_0 = 40 \div 50 \text{ m}^3/\text{ha}$$

$$n(T_r) = 0.3 \text{ (p. orarie)} \quad W = 28.5 \div 35.9 \text{ m}^3/\text{ha}$$

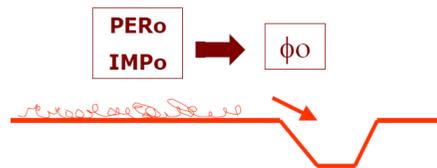
$$W_{\text{vasca}} = 29 \div 36 \text{ m}^3$$

APPROCCIO CON SUPERFICIE DI RIFERIMENTO PARI A  $S_{\text{tot}}$

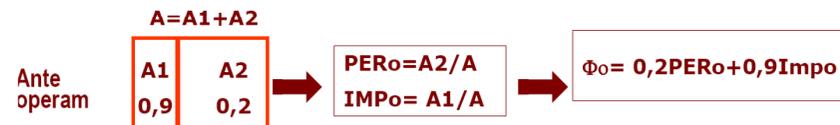
$$w = w_0 \left( \frac{\phi}{\phi_0} \right)^{\frac{1}{1-n}} - 15 I - w_0 P$$

$$w = w_0 \left( \frac{\phi}{\phi_0} \right)^{\frac{1}{1-n}} - 15 I - w_0 P$$

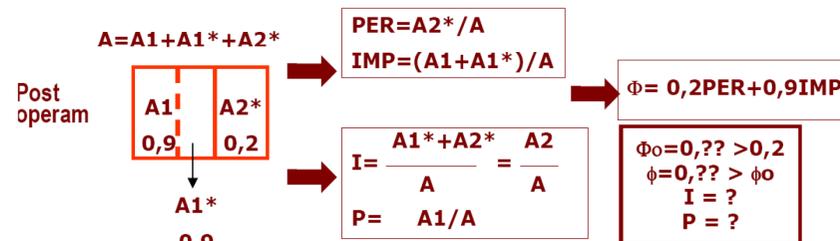
Ante operam



**AMPLIAMENTO DI LOTTO PARZIALMENTE EDIFICATO**

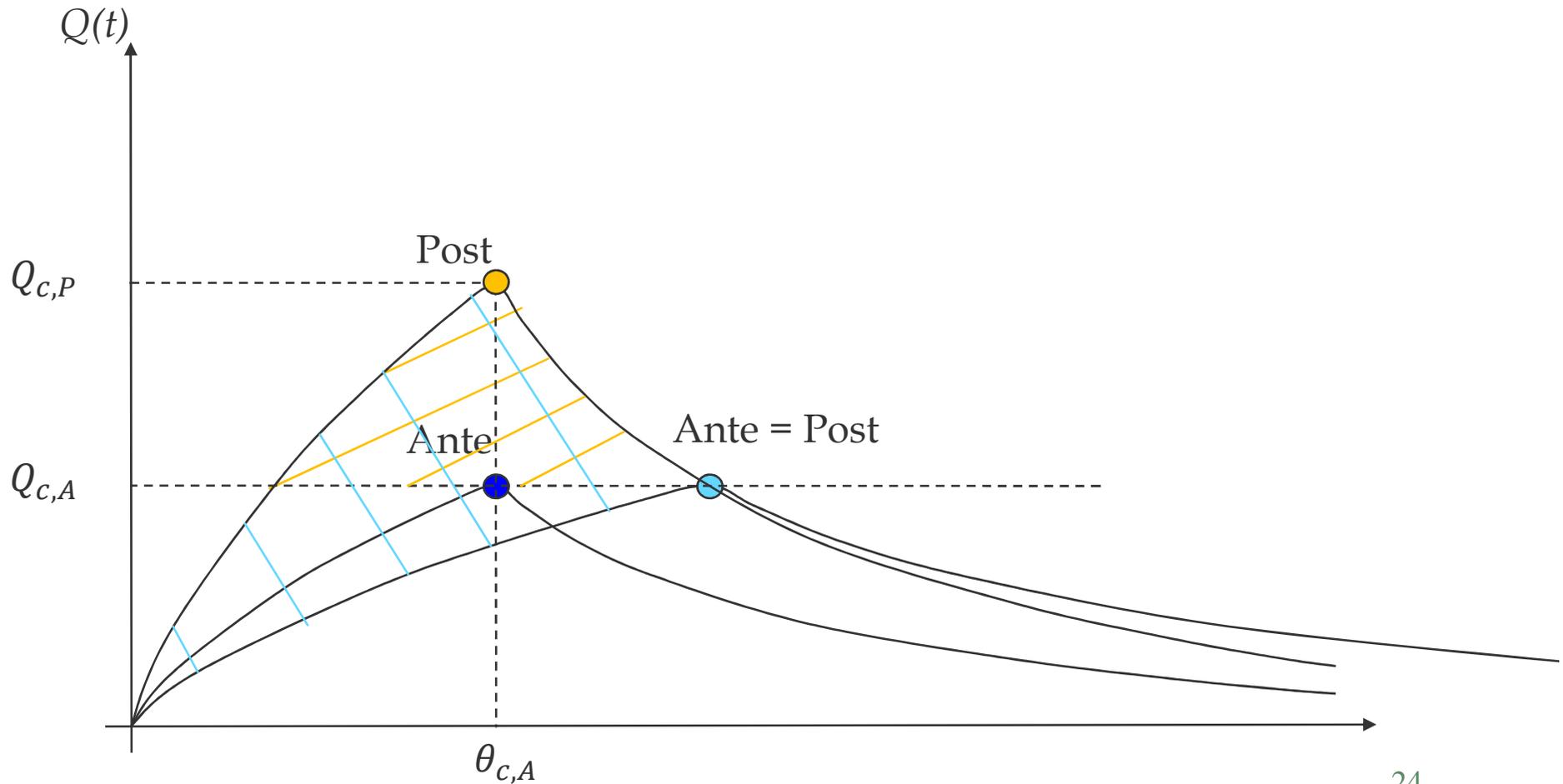


Post operam

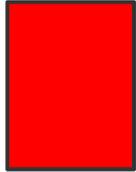


# ESEMPIO PRATICO: METODO ITALIANO

Perché fornisce valori più alti:



# ESEMPIO PRATICO: METODO SOLE PIOGGE



$$S_{\text{tot}} = 1 \text{ ha} = 10000 \text{ m}^2 \quad \varphi_A = \phi_0 = 0.2$$

$$S_{\text{intervento}} = 0.1 \text{ ha} = 1000 \text{ m}^2 \quad \varphi_P = \phi = 0.9$$

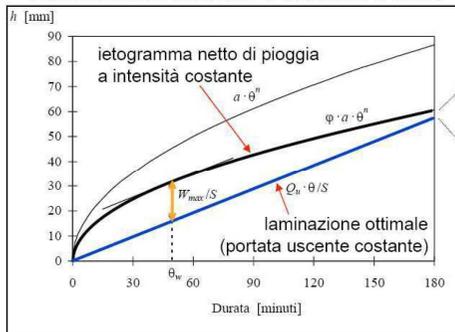
$$a(T_r = 50) = 75 \text{ mm/ora}^n$$

$$n(T_r) = 0.4 \quad (\text{scrosci})$$

$$n(T_r) = 0.3 \quad (\text{p. orarie})$$

APPROCCIO CON SUPERFICIE DI RIFERIMENTO PARI A  $S_{\text{intervento}}$

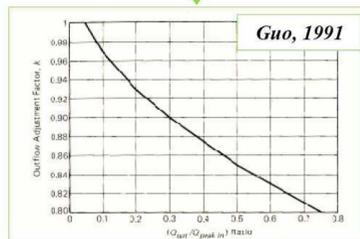
Volumi riferiti all'unità di area del bacino a monte



$$W_e = S \cdot \varphi \cdot h(\theta) = S \cdot \varphi \cdot a \cdot \theta^n$$

$$W = W_e - W_u = S \cdot \varphi \cdot a \cdot \theta^n - Q_u \cdot \theta$$

$$W_u = Q_u \cdot \theta$$



$$W_u = k \cdot Q_u \cdot \theta$$

$$\frac{dW(\theta)}{d\theta} = 0 \Rightarrow \theta_w = \left( \frac{Q_u}{S \cdot \varphi \cdot a \cdot n} \right)^{\frac{1}{n-1}}$$

$$W = S \cdot \varphi \cdot a \cdot \left( \frac{Q_u}{S \cdot \varphi \cdot a \cdot n} \right)^{\frac{n}{n-1}} - Q_u \cdot \left( \frac{Q_u}{S \cdot \varphi \cdot a \cdot n} \right)^{\frac{1}{n-1}}$$

Ottenuti con il Metodo cinematico

$t_c$ (min)	$Q_u$ (l/s)	$\theta_w$ (min)	$W$ (m <sup>3</sup> )	$\theta_w$ (min)	$W$ (m <sup>3</sup> )
3	25.2	8.0	18.1	9.6	15.4
6	16.6	16.0	23.8	18.6	20.4
12	10.9	31.9	31.5	37.2	26.9
30	6.3	79.8	45.4	92.4	38.8



# ESEMPIO PRATICO: METODO SOLE PIOGGE



$$S_{\text{tot}} = 1 \text{ ha} = 10000 \text{ m}^2 \quad \varphi_A = \phi_0 = 0.2$$

$$S_{\text{intervento}} = 0.1 \text{ ha} = 1000 \text{ m}^2 \quad \varphi_P = \phi = 0.27$$

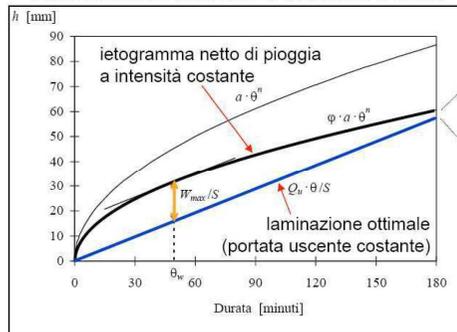
$$a(T_r = 50) = 75 \text{ mm/ora}^n$$

$$n(T_r) = 0.4 \quad (\text{scrosci})$$

$$n(T_r) = 0.3 \quad (\text{p. orarie})$$

## APPROCCIO CON SUPERFICIE DI RIFERIMENTO PARI A $S_{\text{tot}}$

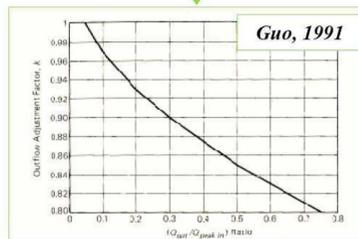
Volumi riferiti all'unità di area del bacino a monte



$$W_e = S \cdot \varphi \cdot h(\theta) = S \cdot \varphi \cdot a \cdot \theta^n$$

$$W = W_e - W_u = S \cdot \varphi \cdot a \cdot \theta^n - Q_u \cdot \theta$$

$$W_u = Q_u \cdot \theta$$



$$W_u = k \cdot Q_u \cdot \theta$$

$$\frac{dW(\theta)}{d\theta} = 0 \Rightarrow \theta_w = \left( \frac{Q_u}{S \cdot \varphi \cdot a \cdot n} \right)^{\frac{1}{n-1}}$$

$$W = S \cdot \varphi \cdot a \cdot \left( \frac{Q_u}{S \cdot \varphi \cdot a \cdot n} \right)^{\frac{n}{n-1}} - Q_u \cdot \left( \frac{Q_u}{S \cdot \varphi \cdot a \cdot n} \right)^{\frac{1}{n-1}}$$

Ottenuti con il Metodo cinematico

$t_c$ (min)	$Q_u$ (l/s)	$\theta_w$ (min)	$W$ (m <sup>3</sup> )	$\theta_w$ (min)	$W$ (m <sup>3</sup> )
12	109.5	4.3	42.0	11.6	7.1
18	85.9	6.4	49.7	17.5	8.3
30	63.2	10.7	61.0	29.1	10.2
45	49.5	16.1	71.8	43.7	12.1

