Application of the drought management guidelines in Italy: the Simeto river basin [Part 2. Examples of application]

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Chapter 18. Application of the Drought Management Guidelines in Italy: The Simeto River Basin

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SUMMARY – The present report summarizes the results of the application of the proposed methodologies for Drought Identification and Characterization, Risk Analysis and Risk Management for Water Supply Systems to the Italian Case Study, namely the Simeto River Basin in Sicily. In particular, after a general description of the case study (Section 2), the results of the drought identification study, carried out by means of several indices and methods such as SPI, Palmer indices and run method, are presented (Section 3). The application of a methodology proposed for the assessment of the return periods of drought events identified on the historical annual precipitation series is also presented. In Section 4, after a general classification of drought mitigation measures, the drought mitigation measures historically adopted for the Simeto River Basin to reduce drought impacts in urban and agricultural sectors are described. Then, in Section 5, the methodology for risk analysis presented in Chapter 6 is applied to the Salso-Simeto water supply system, which is a part of the larger system of the Simeto river. In particular, a Montecarlo simulation of the system, making use of synthetically generated hydrological series and a water supply system simulation model, is carried out in order to assess both unconditional (long term) and conditional (short term) drought risk. Finally impact assessment on rainfed agriculture is presented.

Key words: Water supply system, characterization, risk analysis, shortage, conditional, unconditional, simulation.

The Simeto Basin

The Italian case-study of the Medroplan project is the Simeto River Basin (see Fig. 1), located in Eastern Sicily. The mean annual precipitation over the basin is about 600 mm. The climatic conditions are typical of a Mediterranean semi-arid region, with a moderately cold and rainy winter and a generally hot and dry summer.

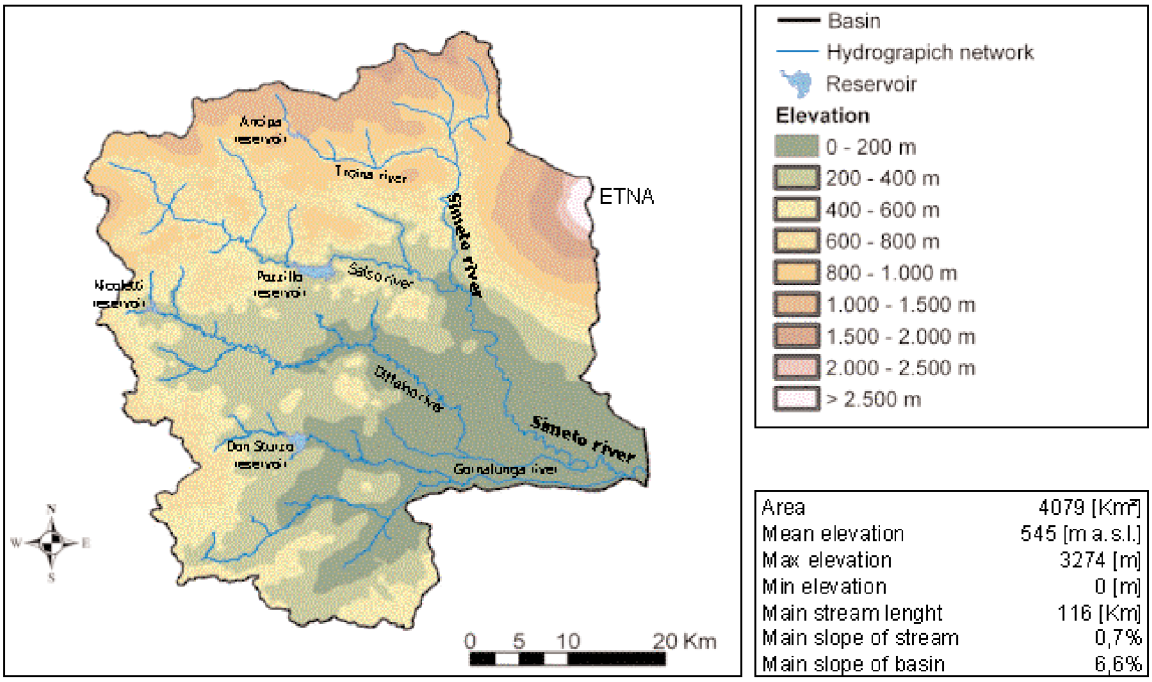


Fig. 1. The Simeto River Basin.

The basin includes various agricultural, municipal and industrial uses and is mainly supplied by a set of multipurpose plants for regulation and diversion of streamflows. As shown in Fig. 2, the current water supply system can be divided in two sub-systems: the Salso-Simeto system and the Dittaino-Gornalunga system.

The Salso-Simeto system has been built during the 50's. It includes two dams, Pozzillo on Salso River and Ancipa on Troina River, three intakes located on the Simeto River (S. Domenica, Contrasto and Ponte Barca), and five hydropower plants operated by the Electric Energy Agency (Enel). The Ancipa reservoir has a net design capacity of $27.8 \cdot 10^6$ m^3, which is currently limited, due to structural problems, to $9.35 \cdot 10^6$ m^3. A small portion of the its releases are used to supply several municipalities in central Sicily, whereas the remaining portion is used for hydropower generation and irrigation purposes. The Pozzillo reservoir, which is mainly devoted to irrigation, has a current storage capacity of $123 \cdot 10^6$ m^3. Most of the releases are routed for hydropower generation and irrigation of the main district of Catania Plain (irrigated area is about 18,000 ha), whose water conveyance and distribution network is operated and managed by the Land Reclamation Consortium no. 9 (LRC 9).

In addition, the Lentini reservoir is connected to the system via the Ponte Barca intake on Simeto River. It has been recently built in order meet the demands of the irrigation districts managed by LRC9 and LRC10 (Siracusa city) and industrial areas of Siracusa and Catania. It was designed for a net storage capacity of $127 \cdot 10^6$ m^3.

The Nicoletti and Don Sturzo reservoirs, in the Dittaino-Gornalunga system (Fig. 2), have been built during the 70's either for regulating streamflows and for irrigating the Dittaino valley. The Nicoletti reservoir has a storage capacity of $17.4 \cdot 10^6$ m^3, whereas the Don Sturzo reservoir has a storage capacity of $110 \cdot 10^6$ m^3. The Dittaino-Gornalunga water supply system is operated and managed by the Land Reclamation Consortium no. 7 of Caltagirone (LRC 7).

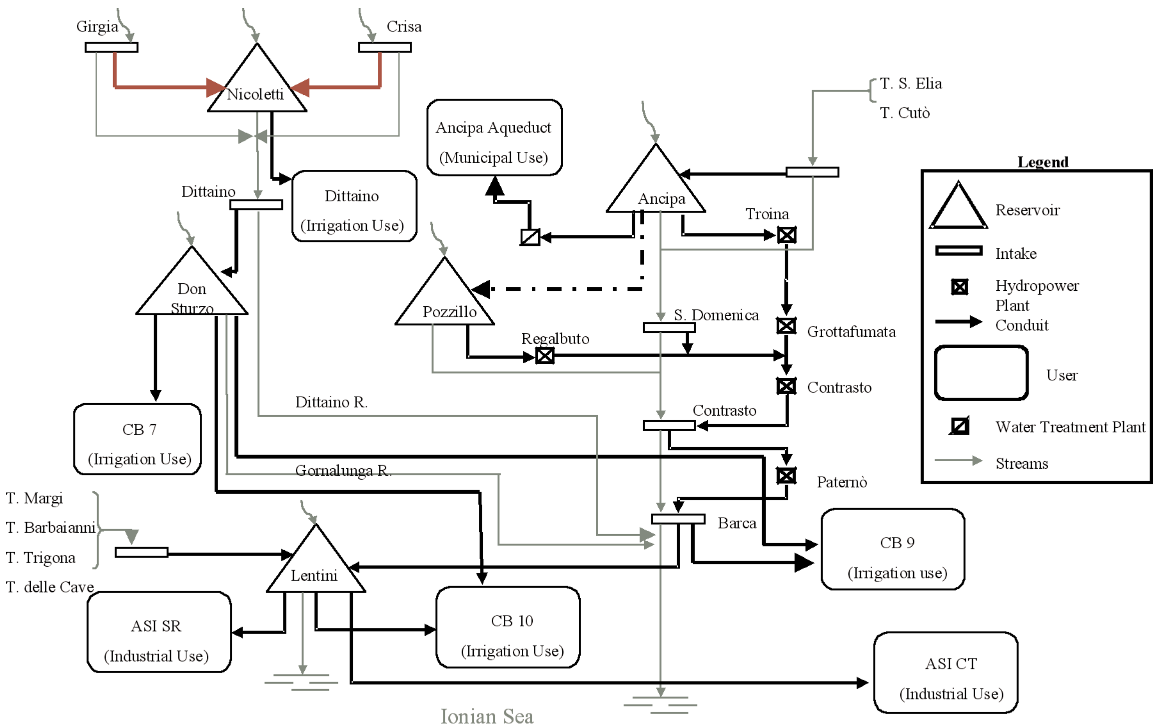


Fig. 2. The water supply system of the Simeto River Basin.

The main features of the reservoirs of the Simeto water supply system are summarized in Table 1.

Table 1. Reservoirs storage capacities, watersheds and annual average inflows of Simeto water supply system reservoirs

Reservoir	Surface (km^2)		Storage capacity (10^6 m^3)	Annual average inflows (10^6 m^3)
	Direct basin	Tributaries basins		
Ancipa	51	58	27.8 (9.3[†])	52.8
Pozzillo	577	–	123	92.3
Lentini	16	1086 + 431	127	96.4
Don Sturzo	171	285	110	31.58
Nicoletti	49.5	13 + 42	17.4	22.73

[†] Operational constraint.

Available hydrological data include monthly series of precipitation at 22 rain gauges (from 1921), of temperature at 4 stations (from 1926) and streamflow at 10 hydrographic stations (from 1923). For the purpose of investigating the hydrological features of the basin, the whole basin has been divided in 9 sub-basins, which roughly coincide with sub-basins upstream of a diversion or of a reservoir or of a merging of two rivers. For each sub-basin, average seasonal precipitations, average mean temperatures and historical series of different drought indices have computed.

In order to promote Medroplan activities, stakeholders operating within the selected case-study have been invited to take part in the Risk Analysis Committee (RAC). In particular, besides the scientific experts in hydrology, hydraulic plants, water resources management, irrigation and agricultural economy from DICA-University of Catania, the RAC includes representatives from the following institutions:

(i) Land Reclamation Consortium no. 9 (Catania)

(ii) Agricultural Provincial Office (Enna, Catania, Siracusa)

(iii) National Electric Agency (ENEL)

(iv) Enna Optimal Territorial Unit (ATO, in charge of municipal supply)

(v) Regional Office for Water Emergency

(vi) Sicily Hydrographic Service

Drought identification and characterization

SPI

The SPI (McKee *et al.*, 1993) is one of the most widely applied tool for drought identification and monitoring. The dimensionless and standardized nature of the index allows to compare droughts among regions with different climates, as well as droughts occurring during different seasons of the year.

According to the commonly adopted classification (see Table 2), negative values of the index describe drought conditions, while positive values indicate wet conditions.

The SPI has been applied on the available monthly precipitation series aggregated at various time scales *k*, corresponding to the time intervals at which the different hydrological components are more sensitive to a significant reduction in precipitation. Also a similar procedure has been applied to the available streamflow series in order to obtain a Standardized Streamflow Index (SSI). SSI is an index, based on the same structure of SPI, by using monthly streamflow data. Figures 3 and 4 represent the time series respectively of the SPI and the SSI at Salso at Pozzillo reservoir. It can be observed that in both cases, the most critical droughts occurred between the end of the ‘80s and the beginning of the ‘90s, and during the last two years. Besides, droughts periods identified by the SSI look much severe and longer than those captured by the SPI.

Table 2. Wet and drought period classification according to the SPI index, provided by National Drought Mitigation Center (NDMC, http://www.ndmc.unl.edu)

Index value	Class
SPI ≥ 2.00	Extremely wet
1.50 ≤ SPI < 2.00	Very wet
1.00 ≤ SPI < 1.50	Moderately wet
-1.00 ≤ SPI < 1.00	Near normal
-1.50≤ SPI < -1.00	Moderate drought
-2.00 ≤ SPI < -1.50	Severe drought
SPI < -2.00	Extreme drought

Another application of the SPI is presented in Fig. 5. In this case, the time series of the SPI at k=12 months are represented for each sub-basins of Simeto reported in vertical axis according to a geographical order, namely from North to South. A general coincidence of dry and wet periods can be observed among the different sites, which confirms that the climatic conditions are rather homogeneous over the whole basin, with a few exceptions.

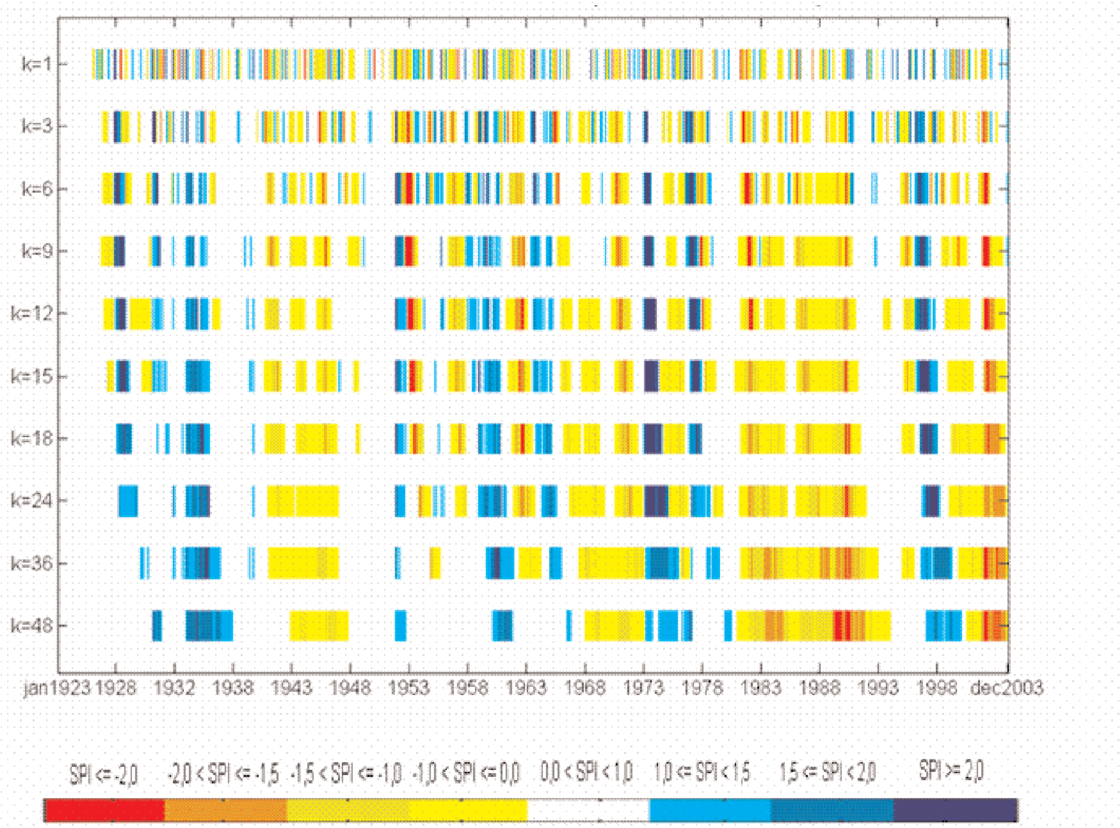


Fig. 3. Time series of the SPI for different time scale k of Salso at Pozzillo reservoir.

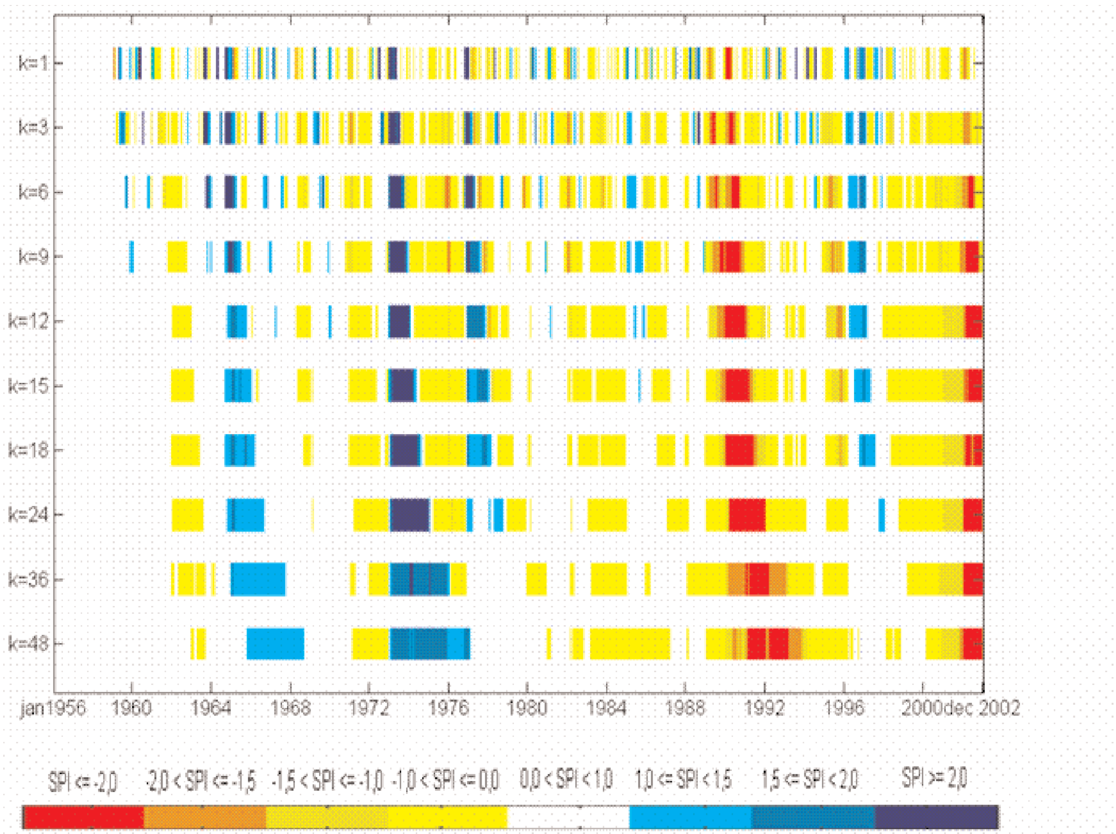


Fig. 4. Time series of the SSI fordifferent time scale k of Salso at Pozzillo reservoir inflows.

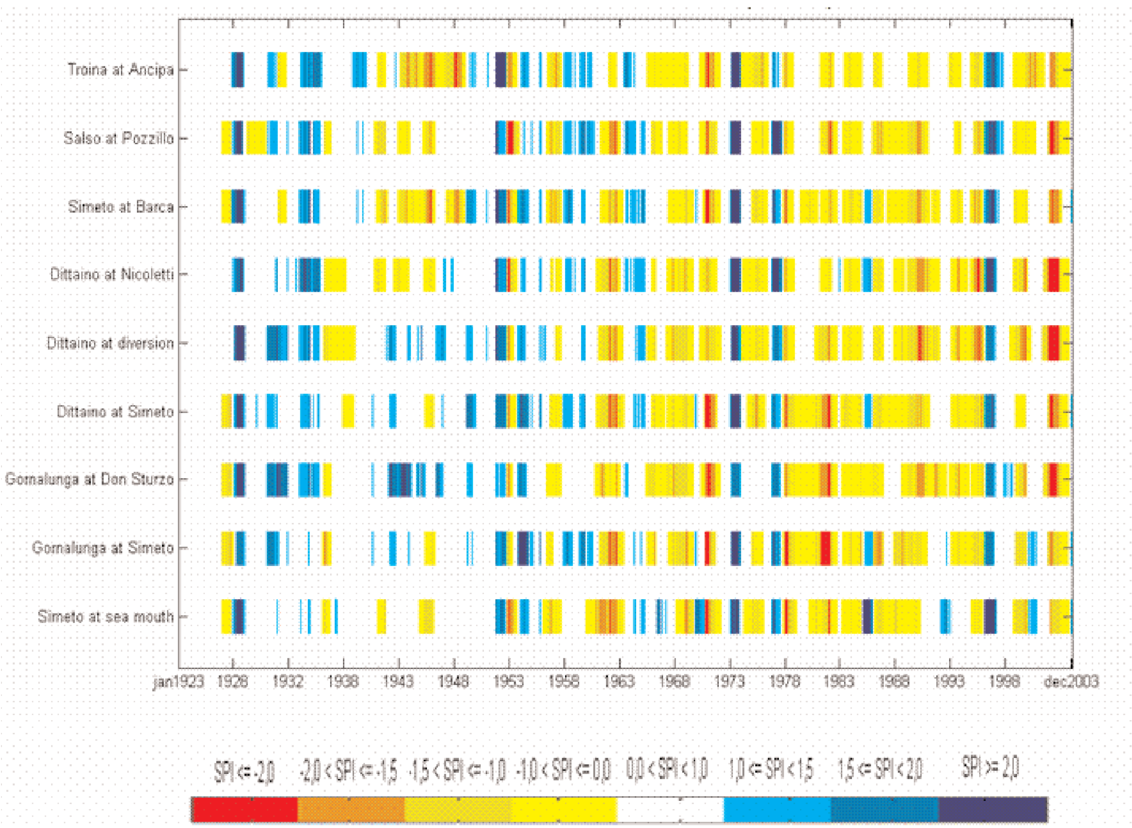


Fig. 5. Time series of the SPI over the sub-basins of Simeto (k=12 months).

PHDI Index

The Palmer Hydrological Drought Index (Palmer, 1965) is based on a water balance model between soil moisture supply and demand for a two layer soil on a monthly time scale. In order to evaluate such an index, precipitation and temperature series are required. Table 3 indicates the classification of dry and wet periods related to the Palmer Index.

Table 3. Wet and drought period classification according to the Palmer Index (PHDI)

PHDI	Class
<- 4	Most severe drought
- 4 to -3	Severe drought
- 3 to -2	Medium drought
- 2 to –1	Nearly drought
-1 to 1	Normal
1 to 2	Nearly wet
2 to 3	Medium wet
3 to 4	Severe wet
> 4	Most severe wet

In Fig. 6 the time series of the PHDI are represented for each sub-basins of Simeto. The results reported for the PHDI are generally in agreement with those presented in Fig. 7, although the PHDI seems to describe much longer and severe drought conditions.

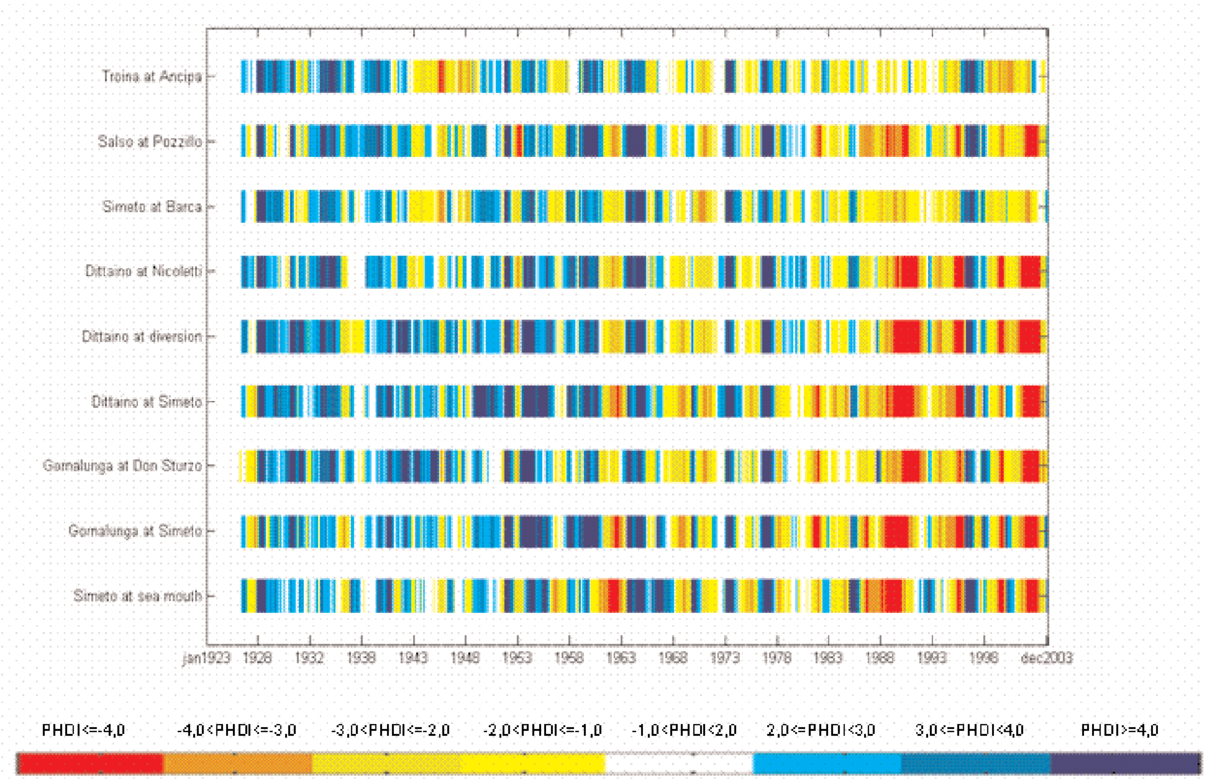


Fig. 6. Time series of the PHDI over the sub-basins of Simeto.

Run method

The run method (Yevjevich, 1967) allows an objective identification of drought periods and it can be applied for evaluating the statistical properties of drought. According to this method a drought period coincides with a "negative run", defined as a consecutive number of intervals where a selected hydrological variable remains below a chosen truncation level or threshold. For each drought event, the following characteristics can be derived:

(i) duration *L*, defined as the number of consecutive intervals where the variable remains below the threshold;

(ii) accumulated deficit *D*, defined as the sum of the negative deviations, extended to the whole drought duration;

(iii) intensity of drought *I*, defined as the ratio between accumulated deficit and duration.

The above analysis can be extended to the case of regional droughts, i.e. droughts which affect large regions, by considering several series of the variable of interest and selecting, besides the truncation level at each site, an additional threshold, which represents the value of the area affected by deficit above which a regional drought is considered to occur.

A possible application of the run method is illustrated in Figs 7 and 8, where respectively the time series of the percentage of deficit area and the areal deficit obtained by considering three different threshold levels $x_0 = x_m\text{-}a{\cdot}s$ at each site are shown. The most critical drought can be recognized by the fact that the whole basin is under drought condition independently of the considered threshold level.

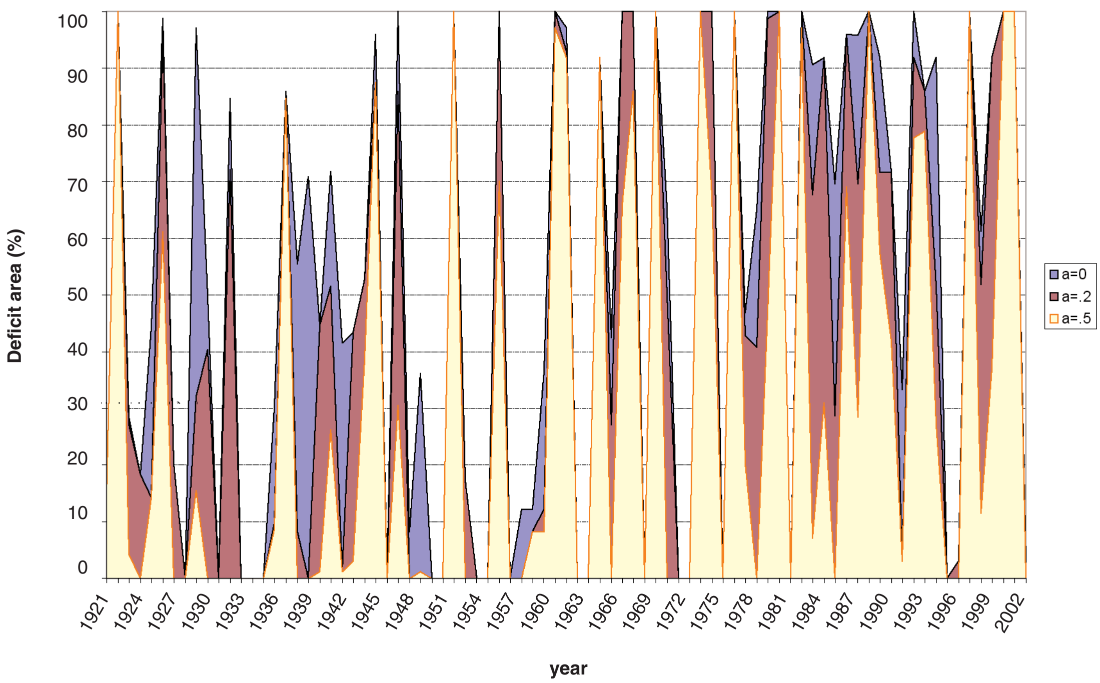


Fig. 7. Time series of the deficit area over Simeto Basin for different threshold levels.

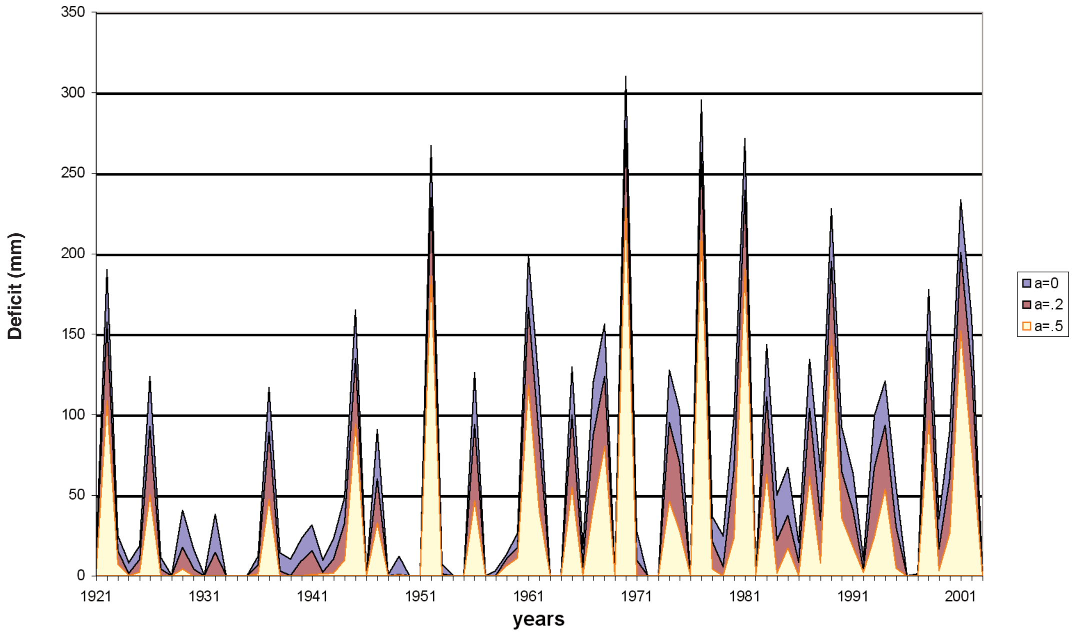


Fig. 8. Time series of the areal deficit over Simeto Basin for different threshold levels.

Assessment of drought return period

The return period of droughts can be defined as the expected value of elapsed time or interarrival time between occurrences of critical events (Shiau and Shen, 2001). With reference to the generic critical drought event identified on stationary (annual) and serially independent series, the return period can be written as:

$$T = \frac{1}{p_1(1-p_1)}\frac{1}{P[\mathrm{A}]}$$

where p_1 is the probability of observing a surplus (i.e. P[$h(i) \leq h_0$]) and P[A] is the occurrence probability of a drought event A.

The following cases have been applied to the case study:

1. Drought event A with duration L equal to l, i.e. A = {$L = l$ (l = 1, 2,...)};

2. Drought event A with duration L greater than or equal to l, i.e. A = {$L \geq l$ (l = 1, 2,...)};

3. Drought event E with cumulated deficit D greater than a specified quantity d, i.e. A = {$D > d$};

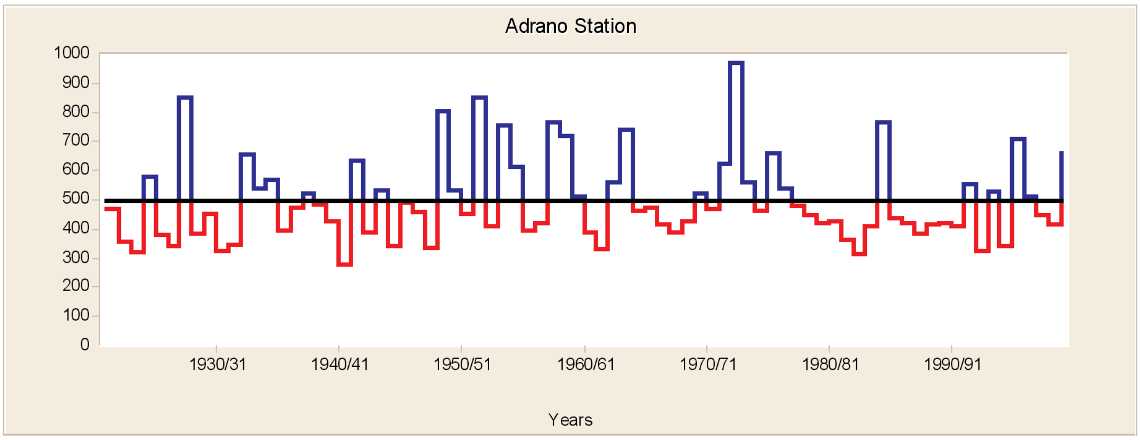
4. Drought event A with cumulated deficit D greater than a specified quantity d and duration L equal to l, i.e. A = {$D > d$ and $L = l$ (l_0 = 1, 2,...)};

5. Drought events A with cumulated deficit D greater than a specified quantity d and duration L greater than or equal to l, i.e. A = {$D > d$ and $L \geq l$ (l_0 = 1, 2,...)}.

The probability distributions of drought characteristics above considered can be derived based on the distribution of the underlying hydrological series and the threshold (Bonaccorso *et al.*, 2003; Cancelliere *et al.*, 2003; Salas *et al.*, 2005). In particular, the gamma distribution has been fitted to the precipitation series of the selected stations.

Such procedure has been implemented in the software for drought analysis REDIM, developed by DICA University of Catania. An example of the application of REDIM for at-site drought analysis at Adrano station is hereafter presented in Fig. 9.

Drought Identification – at site analysis



Station name: Adrano
Hydrological variable: Precipitation
Aggregation time scale: year

Initial month: September
From year: 1921 To: 2000
Threshold (Average 50%): 495,35 mm

Drought Characteristics

Number of drought periods: 19

N	Begin.	End	Durat. *l*	Accum. def *d*	Drought Int. *i*	Tr(L=*l*)	Tr(L≥ *l*)	Tr(D>*d*)	Tr (L=*l*,D>*d*)	Tr (L≥ *l*,D>*d*)
	[year]	[year]	[years]	[mm]	[mm/year]	[years]	[years]	[years]	[years]	[years]
1	1921	1923	3	342.06	114.02	30.05	25.69	18.06	78.40	22.13
2	1925	1926	2	271.71	135.85	16.20	13.85	12.69	65.32	13.89
3	1928	1931	4	469.41	117.35	55.74	47.66	34.82	160.58	44.30
4	1935	1936	2	125.71	62.85	16.20	13.85	6.36	20.12	8.26
5	1938	1940	3	303.06	101.02	30.05	25.69	14.84	59.43	19.36
6	1942	1942	1	105.75	105.75	8.73	7.47	5.83	20.95	5.76
7	1944	1947	4	355.91	88.98	55.74	47.66	19.38	84.31	31.77
8	1950	1950	1	41.75	41.75	8.73	7.47	4.52	10.47	4.37
9	1952	1952	1	88.35	88.35	8.73	7.47	5.41	16.86	5.30
10	1955	1956	2	176.31	88.15	16.20	13.85	8.01	27.39	9.52
11	1960	1961	2	273.11	136.55	16.20	13.85	12.78	66.30	13.97
12	1964	1968	5	312.27	62.45	103.39	88.41	15.54	110.27	49.24
13	1970	1970	1	25.15	25.15	8.73	7.47	4.27	9.37	4.16
14	1974	1974	1	33.15	33.15	8.73	7.47	4.39	9.83	4.25
15	1977	1983	7	604.17	86.31	355.79	304.21	70.89	464.39	190.01
16	1985	1990	6	490.12	81.69	191.80	163.99	38.81	239.56	99.62
17	1992	1992	1	168.55	168.55	8.73	7.47	7.72	51.02	7.86
18	1994	1994	1	156.15	156.15	8.73	7.47	7.29	42.37	7.38
19	1997	1998	2	127.71	63.85	16.20	13.85	6.41	20.31	8.30

General Characteristics of Drought Periods

	Values			Years of max characteristics	
	Mean	Min	Max	Begin.	End
Duration *l* [years]:	2.58	1	7	1977	1983
Cum. Def. *d* [mm]:	235.28	25.15	604.17	1977	1983
Drought Int. *i* [mm/year]:	92.52	25.15	168.55	1992	1992

Fig. 9. Drought identification – at site analysis – and characteristics. Adrano station. Results of the analysis with the REDIM software.

The first application concerns the run analysis with the derivation of drought return period. In particular, the figure illustrates drought events identified on the annual precipitation series, by fixing a threshold equal to the long term mean. It is worth observing that the considered time interval is the hydrological year, defined as the period during which the hydrological cycle takes place (conventionally starting in September for Sicily region). Thus, the period of observation is September 1921 – August 2000 (79 years).

Drought mitigation measures for the Simeto River Basin

The measures to be implemented to mitigate drought impacts can be classified in several ways (Rossi, 2000; Rossi, 2003). A first classification (Yevjevich *et al.*,1978) refers to three main categories: (i) water demand oriented measures, (ii) water supply oriented measures, and (iii) drought impacts oriented measures. In particular, the role of the three mentioned categories of drought mitigation measures is highlighted. It is apparent that the first two categories of measures, by increasing water supply or by reducing water demand, aim to reduce the risk of water shortage due to a drought event, while the third category is oriented to minimise the environmental, economic and social impacts of drought.

A second classification focuses on the type of response to drought problems, distinguishing between a *reactive* and a *proactive* approach. The *reactive* approach consists of measures adopted once a drought occurs and its impacts are perceived. It includes measures implemented during and after a drought period finalized to minimise the impacts of the drought itself. It can be indicated as the "crisis management" approach because it is not based on plans prepared in advance. The *proactive* approach consists of measures conceived and prepared according to a planning strategy (Yevjevich *et al.*, 1983), which are implemented before, during and after a drought event. In particular, measures undertaken before a drought event aim to reduce the vulnerability of the system to droughts and/or to improve drought preparedness.

Within the proactive approach, a further classification can be made according to the time horizon of the measures, namely:

(i) Long-term actions, oriented to reduce the vulnerability of water supply systems to droughts, i.e. to improve the reliability of each system to meet future demands under drought conditions by a set of appropriate structural and institutional measures.

(ii) Short-term actions, which try to face an incoming particular drought event within the existing framework of infrastructures and management policies.

Finally, for a more specific analysis of the various measures, the identification of the affected water use sector is necessary. Therefore, measures regarding at least 4 main categories, urban, agricultural, industrial, recreational and environmental, should also be distinguished. Thus, a specific drought mitigation measure can be classified according to a three-dimensional plot, as shown in Fig. 10.

Among the main actions undertaken at regional level, it is worth mentioning the activities carried out by the Regional Hydrographic Service of Sicily (UIR). In particular, a real time hydro-meteorological network, which also includes 40 gauges to measure the water level in the aquifers and 23 gauges to monitor the storage volumes in the most important Sicilian water supply reservoirs, has been developed in 2000.

Besides, an web-based monthly bulletin for drought monitoring has been developed by the Department of Civil and Environmental Engineering of Catania University for the Regional Hydrographic Service of Sicily, with the aim to provide the agencies in charge of water management in Sicily, with the information necessary in order to adopt appropriate drought mitigation measures and to improve the preparedness to drought of water supply systems. In Fig. 11, the home page of the drought bulletin for Sicily is shown.

Finally, campaigns for increasing population awareness to water saving, either at municipal level and regional level (see Fig. 12), have been promoted by the Sicilian Regional Government.

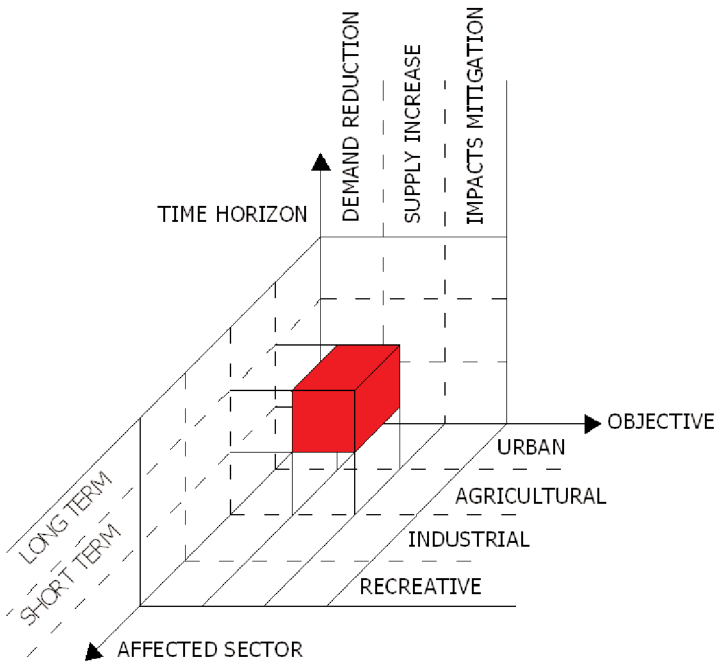


Fig. 10. 3D representation of drought mitigation measures.

Fig. 11. Home Page of the Drought Bulletin for Sicily.

Fig. 12. Water saving campaign sponsored by Sicily Region.

About past actions to mitigate drought impacts in urban sector, during the last drought events, the Sicilian Aqueduct Agency, who manages reservoirs and main aqueducts in Sicily, and the Municipal Water Supply Departments have implemented water supply increase measures, such as:

(i) diversion and reallocation of surface water resources (stored in Ancipa reservoir) normally devoted to irrigation use;

(ii) increase of groundwater withdrawal by wells for municipal use;

(iii) use of groundwater withdrawal by private wells (normally devoted to irrigation use).

With reference to the actions adopted to mitigate drought impacts in agriculture, it is possible to distinguish between actions undertaken by Land Reclamation Consortia and by private farmers.

The main actions undertaken for the Simeto River Basin by Land Reclamation Consortia of Catania, Caltagirone, Siracusa and Enna, have been:

(i) Priority allocation of available resources for agricultural use in Ancipa and Pozzillo reservoirs to perennial crops (i.e. citrus trees) and restriction of water supply to annual crops.

(ii) Maintenance of canal networks for reducing water losses.

(iii) Projects to transform the canal network (conveyance and distribution) in pipelines.

(iv) Projects of emergency pumping plants of surface water stored in Lentini reservoir (currently not operational).

(v) Projects of public ponds to improve operation of irrigation system.

The mitigation of damages in agriculture (rainfed) is principally linked to the dry-farming practices applied at farm level:

(i) Collecting and saving rainfall (deep labour in summer, minimum tillage and weeding during the crop cycle, optimal planting and sowing, etc.).

(ii) Using water efficiently (low water consuming crop species, fertilization adapted to the water availability, selection of varieties able to accomplish their cycle within the length of the climate growing period, etc.).

Private farmers have implemented two different types of mitigation measure to cope with drought in irrigated agriculture:

(i) Measures to increase preparedness to water scarcity

– Introduction of more efficient irrigation techniques (micro-irrigation);

– Construction of farm ponds (to be filled by water delivered by consortium before the irrigation season start and/or by private wells);

– Reduction of irrigated areas for annual crops.

(ii) Measures for coping with drought
- Deepening of existing wells;
- Construction of new wells;
- Water transfer by trucks (in extreme cases and for small farms).

Also financial benefits for the farmers related to the "*natural disaster declaration*" by the national or regional government are to be mentioned. It should be mentioned however that such benefits have been insufficient to cover the actual damages during the past drought periods (see Table 4).

Table 4. Past actions to mitigate impacts in agriculture at State/Regional level (financial measures to the farmers)

Province	Grant			Lan with 40% of grant			Five years Loan		
	Amount requested (Million €)	Amount provided (Million €)	%	Amount requested (Million €)	Amount provided (Million €)	%	Amount requested (Million €)	Amount provided (Million €)	%
Catania	50.378	0.743	1.47	No data					
Siracusa	34	4.282	12.6	14.818	3.611	24.3	9.915	2.512	25.3
Enna	31.169	6.475	21.8	14.20	5.364	37.6	12.640	2.163	17.19

Risk analysis for Salso-Simeto water supply system

System identification

The methodology for the unconditional and conditional risk assessment has been applied to the Salso-Simeto water supply system depicted in Fig. 13. In Fig. 14, the scheme of the system is shown from which it can be inferred that the system includes two dams, Pozzillo on Salso River and Ancipa on Troina River, and one intake located on the Simeto River. In addition, the Lentini reservoir is connected to the system via the Ponte Barca intake on Simeto River.

Fig. 13. Simeto River Basin at Barca diversion.

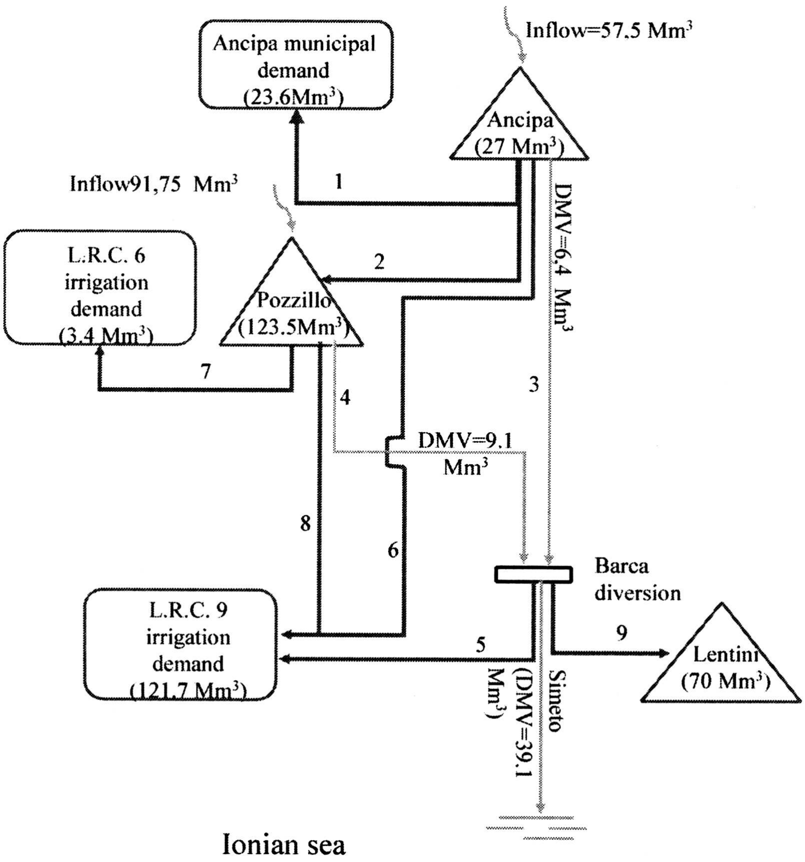


Fig. 14. Salso-Simeto water supply system.

Streamflow data include more than 40 years of reconstructed streamflows at Ancipa and Pozzillo reservoirs and Barca diversion (see Figs 15, 16 and 17). The annual demands have been estimated as follows: municipal demand from Ancipa reservoir 23.5 10^6 m^3/year (see Fig. 18), irrigation demands 121.4 10^6 m^3/year and 3.4 10^6 m^3/year for Catania Plain (LRC9) and Enna (LRC6) (see Fig. 19). Furthermore, instream flow requirements (indicated by DMV in Fig. 4) equal to 9.1, 6.4 and 39.1 10^6 m^3/year downstream of Pozzillo and Ancipa dams and Barca diversion respectively have also been considered.

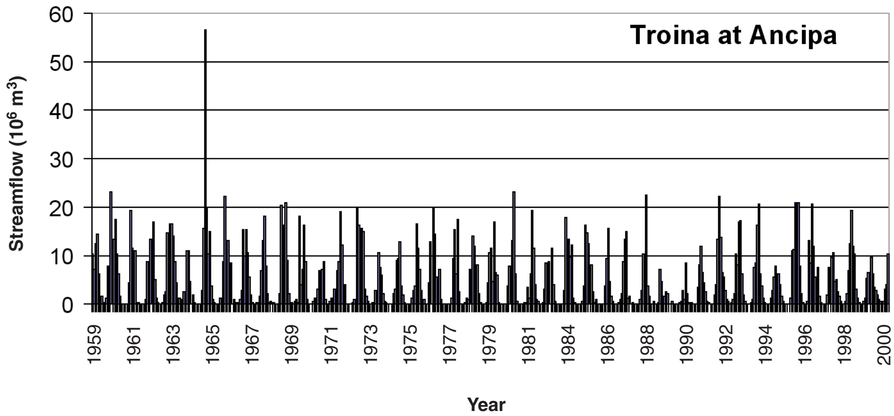


Fig. 15. Streamflows of Troina River at Ancipa.

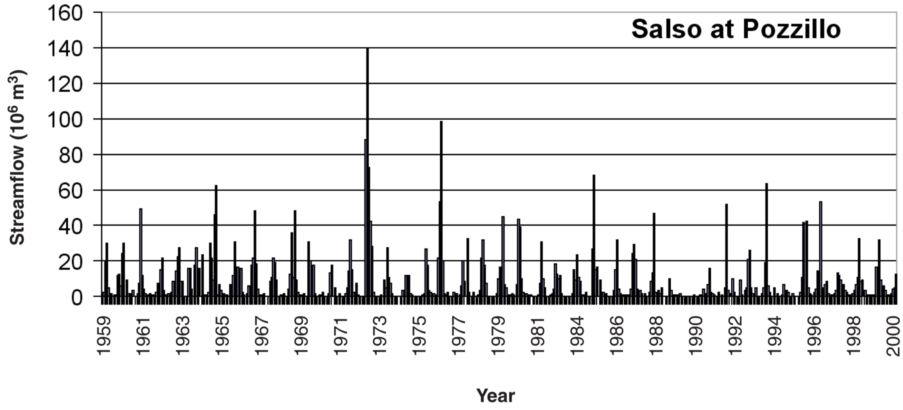


Fig. 16. Streamflows of Salso River at Pozzillo.

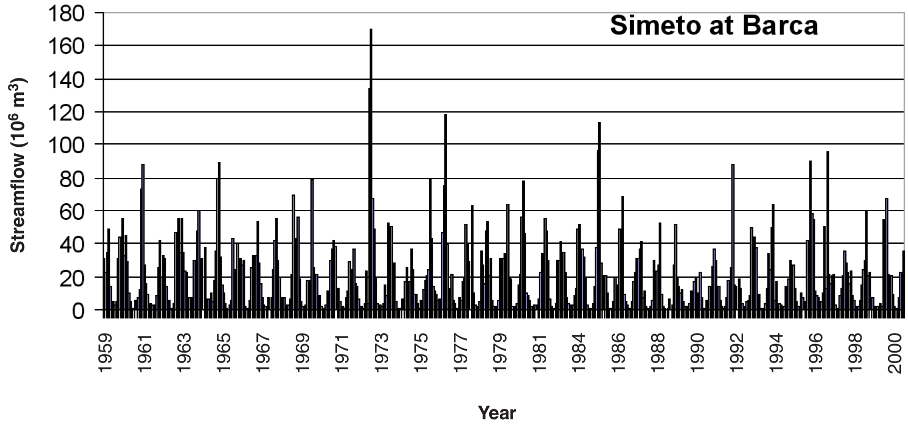


Fig. 17. Streamflows of Simeto River at Barca.

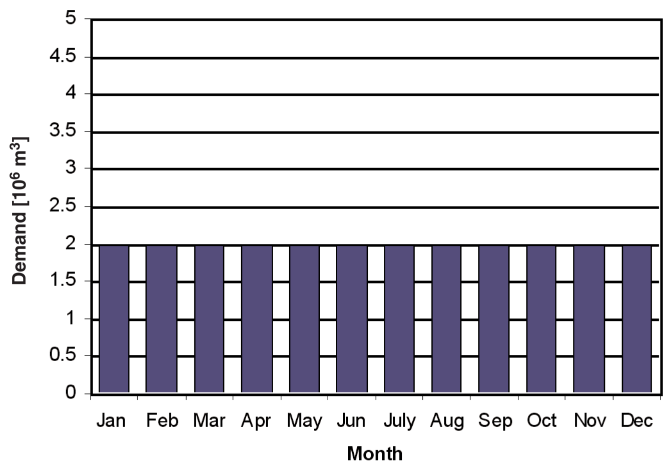


Fig. 18. Municipal demand (Ancipa Aqueduct).

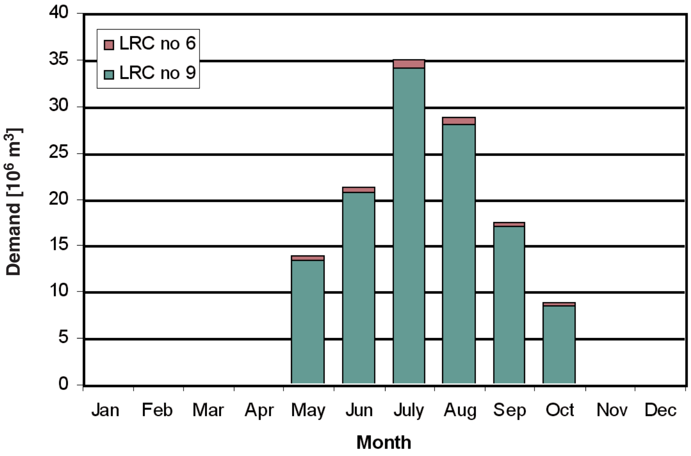


Fig. 19. Agricultural demand (LRC no. 6 and no. 9).

Stochastic generation of streamflow series

Generation of synthetic streamflow data has been performed by means of the sofware SAMS (Sveinsson *et al.*, 2003). In Fig. 20, the lag 0 monthly cross correlations between the three streamflow series (Pozzillo inflow, Ancipa inflow and Barca streamflows) are shown. From the figure, where the confidence limits under the no correlation hypothesis according to Anderson are shown by dashed lines (Salas, 1993), it can be inferred that in several months the series exhibit a significant cross correlation, while in other such cross correlation is negligible. Thus, the stochastic modeling of the three series must be carried out by means of a seasonal multivariate model, able to take into account the cross correlations, as well as their seasonal variability from month to month.

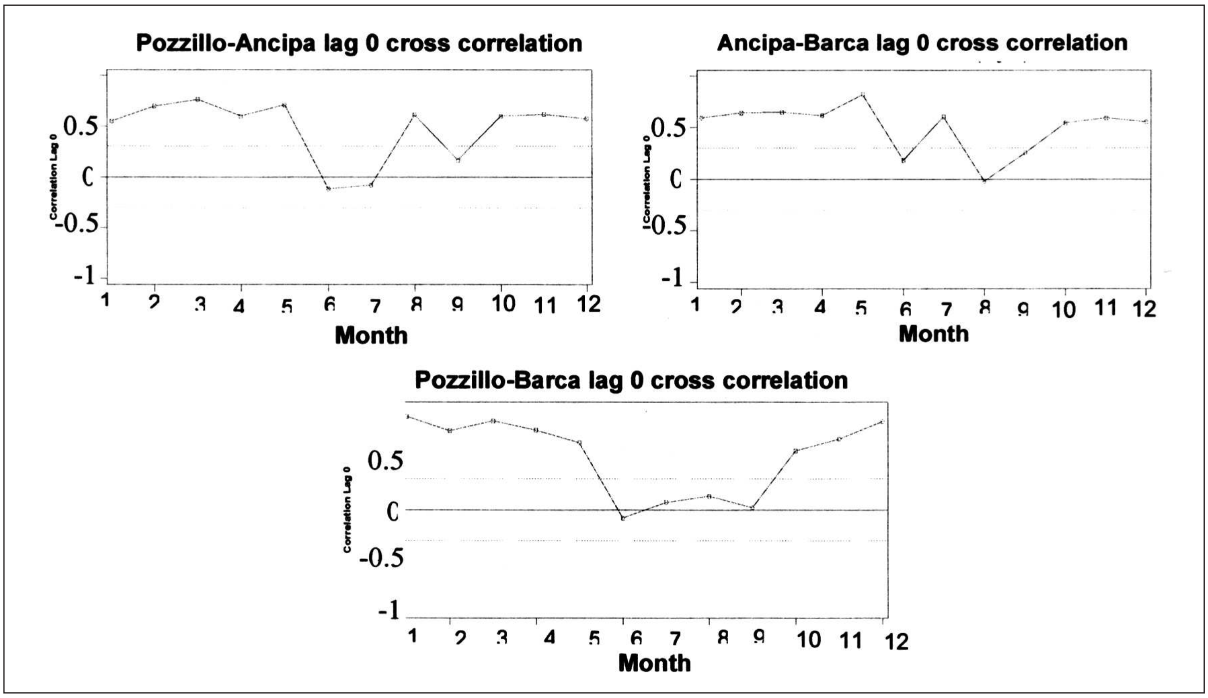


Fig. 20. Lag 0 monthly cross correlations between the three investigated series.

Then, the proposed generation scheme is as follows:

(i) First, annual and monthly data have been transformed, in order to reduce skewness, by means of the relation:

$$X_v = (X^*_\upsilon + a)^b$$

where X^*_υ is the original (untransformed) data at year *n*, X_υ is the transformed data, approximately normally distributed, and *a* and *b* are parameters, obtained by imposing the minimization of the skewness of the transformed data.

(ii) Then, annual data are generated by means of multivariate autoregressive model:

$$\underline{X}_v = \underline{GX}^*_{v-1} + \underline{L}\varepsilon_v$$

where $\underline{X}_\upsilon$ is the vector of the values at year υ at the three sites, *G* and *L* are square matrices (in our case 3x3), and ε_v is a vector of white noise;

(iii) Finally, monthly data are generated by means of a disaggregation scheme (Salas,1993):

$$\underline{Y}_v = \underline{AX}_v + \underline{B}\zeta_v + \underline{C}\,\underline{Y}_{v-1}$$

where $\underline{Y}_\upsilon$ is the vector of the monthly values at year υ at the three sites, $\underline{Y}_{v-1}$ is a vector of values from the previous year, ζ_v is a white noise vector and *A*, *B* and *C* are matrices of parameters.

In Table 5, the comparison between historical and generated annual statistics at the three sites is shown. It can be inferred that the model is able to preserve the main statistics of the observed series and therefore it is suitable for data generation.

Table 5. Comparison between statistics of historical and generated annual streamflow series at the three sites

	Pozzillo		Ancipa		Barca	
	Historical	Generated	Historical	Generated	Historical	Generated
Mean (10^6 m^3)	92.06	91.83	57.54	57.50	231.50	231.30
StDev (10^6 m^3)	56.57	53.78	18.99	18.91	68.59	66.98
CV	0.61	0.59	0.33	0.33	0.30	0.29
Skew	1.57	1.06	0.52	0.21	1.01	0.79
Min (10^6 m^3)	8.50	0.00	13.30	0.00	109.20	61.12
Max (10^6 m^3)	295.10	540.40	116.20	155.90	438.50	728.90
Acf(1)	-0.03	0.06	0.13	0.15	-0.08	0.01
Acf(2)	-0.16	-0.08	0.02	-0.06	-0.04	-0.05

Simulation of the system

Simulation of the system has been carried out by means of the software SIMDRO, specifically developed to simulate the implementation of drought mitigation measures according to a specified plan.

SIMDRO simulates the system through a node-link network. Sources and demands are represented by numbered nodes whereas system connections are represented by links characterized by origin node (source) and final node (source or demand).

System configuration is defined specifying in a input ASCII file number of sources (reservoirs, diversions, wells), number of demands, number and type of links (source to source or source to demand connection). Each node representing a reservoir has to be defined also in terms of maximum storage capacity, dead storage and initial stored volume. Coefficients of storage-area relationships (assumed well represented by a law of the type y = $a + b$x + cx^2 with y = area and x = storage) and monthly evaporations has to be defined as well.

Hydrological inputs to the system are managed by means of inflow-nodes (not coincident with source nodes and characterized by a different numeration) associated with hydrological series through an inflow name linked to an external file containing the data. These files can be supplied both in a free text format or in a tabular form. Each source node has to be associated with its inflow node otherwise the source will present a null input.

In order to take into account diversion to dams, for each inflow node it is possible to define a minimum volume Q_{min} and a utilization coefficient c_{ut}. Under the minimum volume Q_{min} input to the source node is considered null whereas c_{ut} is used to take into account the effective water that can be diverted at the source node related to its technical features.

Demands have to be defined in terms of their yearly amount and monthly pattern.

Simulation of the system is carried out in a monthly timescale respecting for each reservoir node the following mass-balance equation:

$$V_{t+1} = V_t + I_t - E_t - R_t - Sf_t \pm Tr_t$$

Where:

– t is the current step defined as [$t = \tau + 12 * (\upsilon - 1)$ with $1 \leq \tau \leq 12$ month of the υ year;

– V_t is the stored volume at the beginning of the month t;

– I_t is the net streamflow to the reservoir at month t;

– E_t is the evaporation at month t;

– R_t is the release at month t;

– Sf_t is the spill at month t occurring when volume V_{t+1} is greater than the maximum capacity of reservoir;

– Tr_t is the transfer between two sources at month t;

In addition the constraints, such as minimum and maximum storages, are implemented.

Net streamflow to reservoirs is computed as the difference between the total inflow from direct basin and from linked basins (expressed as a function of utilization coefficient c_{ut} and minimum volume Q_{min}) and an in-stream ecological releases. In normal conditions, if total inflows to a given reservoir for a particular month is less or equal than in-stream ecological requirements no net runoff will be available at that particular reservoir.

Monthly evaporation losses are computed considering monthly evaporation heights times an average area function of the areas obtained by the storage-area relationship for the beginning and the end of the current timestep. Due to the fact that stored volume at the end of the timestep is unknown an iterative procedure till convergence is carried out.

One of the most important features of SIMDRO is that it is specifically oriented at the implementation of drought mitigation measures. In particular the software is able to simulate the system behaving differently in dependence of different hydrological states to which correspond different possible drought mitigation measures defined by the user.

Three different hydrological states namely normal, alert and alarm can be defined by the user as a function of the available storage in reservoirs as well as of the expected flows.

Drought mitigation measures for each hydrological state are triggered when the total volume stored in the system is not enough to meet the total demand of the next dry season computed as a weighted (c_c, c_{ir} and c_{in}) sum of different demands (municipal *Dc,* irrigational *Dir,* industrial *Din*). Such total demand Dr_t is computed for each month of the dry season as sum of a percentage of demands of the next *k* months. Water demand reduction levels change in correspondence of municipal, irrigation and industrial demands and *k* is a function of the current month of the dry season in a way that makes easy to take into account demands for the months that come before the beginning of water year (i.e. October):

$$Dr_t = \sum_{m=t+1}^{t+k(\tau)} \left(c_c Dc_m + c_{ir} Dir_m + c_{in} Din_m \right)$$

Water availability in the system ($Disp_t$) is assumed equal to the sum of the volumes stored on reservoirs plus net runoffs for current time step *t* at reservoirs and runoffs with a fixed non-exceedence probability for the *k* following months.

$$Disp_t = \sum_{f=1}^{z} \left(I_{tf} + V_{tf} \right) + \sum_{t=t+1}^{t+k(\tau)} \sum_{f=1}^{z} I_{tf}(P)$$

If in a given month water availability is less than the trigger defined for the hydrological state characterized by normal conditions the system will switch from normal condition to alert conditions behaving as defined previously by the user making effective the implemented drought mitigation measures. The measures can consist in demand rationing, release reduction to the water demand according to different reduction levels for each type of demand, fulfilment of municipal demand before other uses, etc. The aim is to impose small deficits in the present in order to reduce the risk of larger deficits in the future.

If in a given month water availability is less than the trigger defined for the hydrological state characterized by alert conditions the system will switch from alert condition to alarm conditions again behaving as defined previously by the user for this particular condition implementing stricter drought mitigation measures consisting for example in breaking the constraints related to the minimum storage on reservoirs and/or relaxing instream flow requirements.

The system will remain in alert or alarm conditions performing in accordance with the drought mitigation measures specified for the particular condition (alert or alarm) for a period of time defined formerly by the user. At the end of this pre-defined period SIMDRO will compare the water availability in the system with the predefined thresholds for the hydrological states. If water availability is more than the threshold defined for normal condition it will switch automatically to this condition otherwise it will continue to perform in alert or alarm conditions until water availability is above the threshold defined for normal conditions.

The drought mitigation measures to be set by the user varying from normal to alert and alarm conditions are listed below:

(i) priority of demands;

(ii) priority of sources to meet a specified demand;

(iii) maximum release in a given month;

(iv) maximum in-stream ecological release for a given month;

(v) minimum stored volume on reservoirs under which not consider low priority demands; and

(vi) demands and their monthly distribution.

In the italian case study the simulation of the system in normal conditions has been performed according to the following operating rules:

(i) Target storages are imposed at Pozzillo and Ancipa reservoir, such that no water is released if the stored volume is below the target, with some exceptions. In Fig. 21, the monthly target storages at Pozzillo and Ancipa are shown.

(ii) Municipal demand has the highest priority over the other demands and up to a percentage equal to 90% is not affected by target storages (i.e., 90% of the demand will be released regardless of the target storages).

(iii) A water transfer of up to 8 10^6 m^3/month from Ancipa to Pozzillo is activated during the winter months if the volume stored in Ancipa is greater than 85% of net storage (24 10^6 m^3).

(iv) Instream flow requirements are released from the reservoirs and the diversion, unless the upstream inflow is less. In this case, the whole streamflow is released.

(v) During the winter months, a water transfer from Barca to Lentini is activated up to 11.7 10^6 m^3.

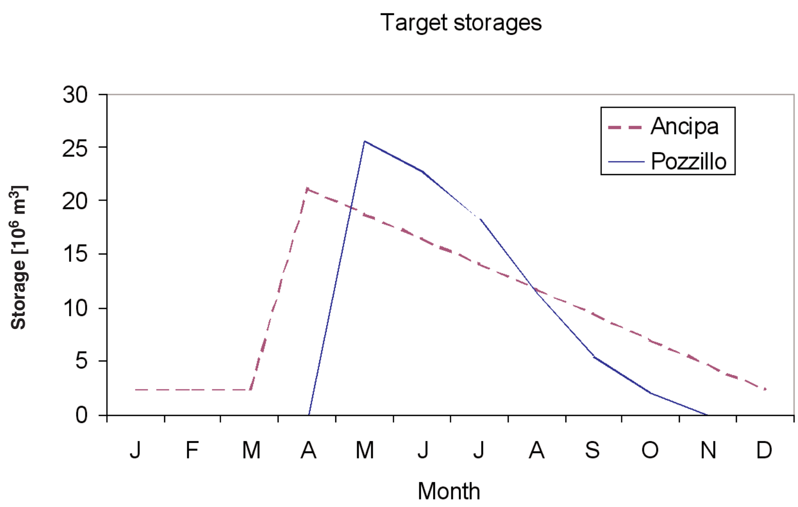


Fig. 21. Target storages at Pozzillo and Ancipa reservoirs.

Alert and alarm conditions are activated by comparing the total storage in Pozzillo and Ancipa with triggering levels, shown in Fig. 22. In particular the following measures are adopted, according to the conditions:

Alert conditions

– Relax target storage requirement for municipal
– Restrictions on irrigation
– No irrigation release from Ancipa

Alarm conditions

– As Alert + relax instream flow requirement

Fig. 22. Triggering levels for normal, alert and alarm conditions.

Unconditional risk analysis

Unconditional risk assessment of the Salso-Simeto water supply system has been carried out through two sets of simulations. In the first case, no mitigation measures have been considered, i.e. the system has been assumed to be always in normal conditions. In the second case mitigation measures have been activated as mentioned previously. Simulations have been carried out with reference to 500 generated series with the same length of the historical one (42 years).

In Table 6 and Table 7, the performance indices obtained by simulating the system using the generated series are shown, with reference to the two main water uses of the system, Enna municipalities and LRC 9 irrigation respectively. From each table, the comparison between the system performances with or without mitigation measures can be inferred.

Table 6. Performance indices for municipal use. Simulation on generated series, Enna Municipalities

	Temporal reliability (% month)	Volumetric reliability (%)	Average shortage period length (months)	Max monthly shortage (10^6 m^3)	Max annual shortage (10^6 m^3)	Sum of squared shortage (10^6 m^3)
No mitigation measures	96.8	97.4	4.0	2.0	12.9	47.7
Mitigation measures	88.1	96.9	3.2	1.0	9.5	21.1

Table 7. Performance indices for irrigation use. Simulation on generated series, LRC9 irrigation

	Temporal reliability (% month)	Volumetric reliability (%)	Average shortage period length (months)	Max monthly shortage (10^6 m^3)	Max annual shortage (10^6 m^3)	Sum of squared shortage (10^6 m^3)
No mitigation measures	71.4	81.9	3.1	34.1	104.0	7264
Mitigation measures	73.0	82.9	3.0	33.2	98.6	5920

In particular, with reference to the municipal supply, both temporal and volumetric reliability show a reduction due to the mitigation measures of about 9% for temporal reliability and less than 1% for volumetric reliability. The reduction in the just mentioned indices is fully balanced by the gain of about 20% for the average shortage period length index (from 4.0 to 3.2 months), 50% for the maximum monthly shortage index (from 2.0 to 1.0 10^6 m^3), 26% for the maximum annual shortage index (from 12.9 to 9.5 10^6 m^3) and about 56% for the sum of squared shortage index (from 47.7 to 21.1 10^6 m^3). Better values of the latter performance indices have to be ascribed to the implementation of mitigation measures such as restrictions on irrigation and no irrigation release from Ancipa.

Table 7 shows that basically average shortage period length and maximum monthly shortage indices are not affected by the implementation of the drought mitigation measures while temporal and volumetric reliability show very slight increase, on the contrary maximum annual shortage and sum of squared shortage indices show increases (5% for the first and about 18% for the latter) likely due to the relaxation of the target storage requirements for municipal implemented as mitigation measure both in alert and alarm conditions that makes more water available for irrigation use.

Figure 23 shows monthly frequencies of shortages for Enna municipalities as results of the simulation on generated series without mitigation measures. In this case shortages of more than 75% of the municipal demands appear for the whole period within March to August with probability of about 0.05 with a peak for April of about 0.1 but there are almost no shortages for the period within September to February.

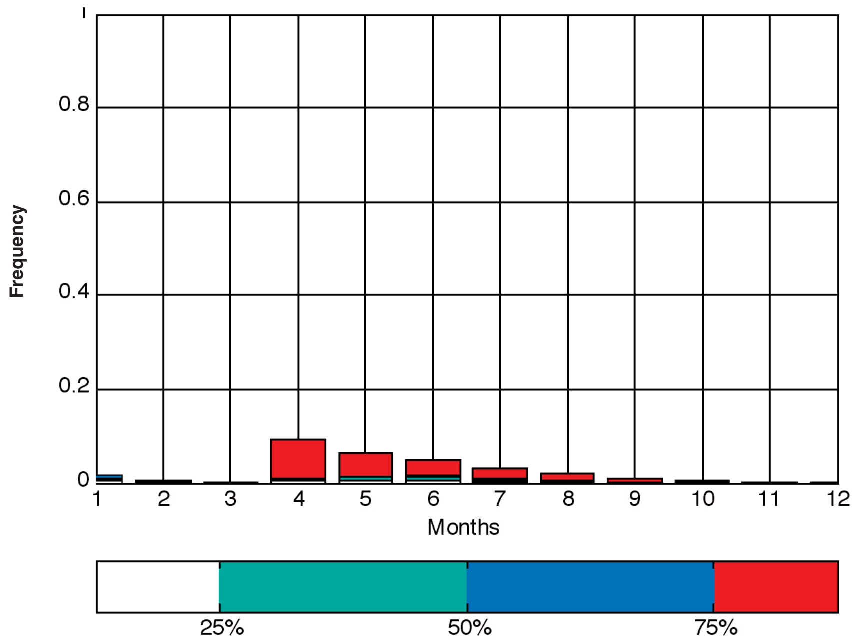


Fig. 23. Monthly frequencies of shortages for Enna municipalities (simulation without mitigation measures).

Figure 24. shows the same type of results of Fig. 23 but for the simulation implementing drought mitigation measures triggered by the defined hydrological states. The occurrence probabilities of shortages in the period within March to August is increased in comparison with the simulation without mitigation measures (on average 0.1 with a peak for August of about 0.3) but the entity of the shortages is reduced to the class of shortages less or equal than 50% of the municipal demand. The period within September to February shows shortages belonging to the class of less than 25% and only occasionally less than 50% of the municipal demand while almost no shortages in the simulation without mitigation measures appeared.

As expected the implementation of mitigation measures produces more frequent but slighter shortages making a given drought event more tolerable for the particular demand.

Figure 25 and Fig. 26 show the frequencies of shortages for LRC9 irrigation demand, presenting the same kind of behavior obtained for the municipal demand. Implementation of mitigation measures produces almost the same monthly occurrence probabilities of shortages of the simulation without mitigation measures but decreasing the class of shortage. For almost the entire irrigation season, indeed, Fig. 25 shows shortages also belonging to the class of shortages greater than 75% of irrigation demand while Fig. 26 shows less occurrence probability of shortages belonging to this class. Globally implementing mitigation measures helps to reduce the amount of shortages during the irrigation season.

Figures 27 and 28 show sample frequencies of monthly shortages for the municipal demand as result of simulations using generated series with and without mitigation measures. As depicted in Fig. 27 simulations without mitigation measures produce almost the same probability for shortages of large or small entity whereas Fig. 28 shows that, implementing mitigation measures, monthly shortages of more than 50% of municipal demand are very unlikely even if shortages of smaller entity are more frequent than the case without mitigation measures.

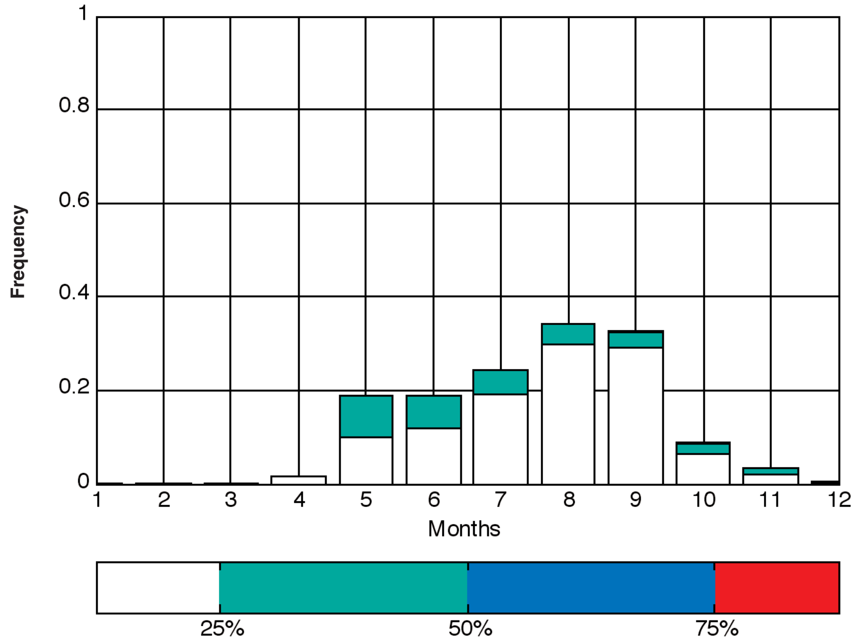


Fig. 24. Monthly frequencies of shortages for Enna municipalities (simulation with mitigation measures).

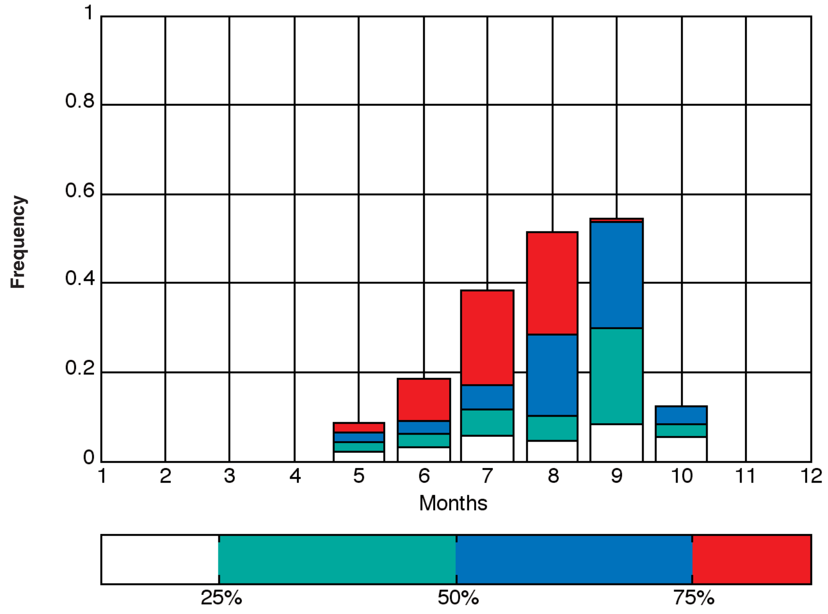


Fig. 25. Monthly frequencies of shortages for LRC9 irrigation demand (simulation without mitigation measures).

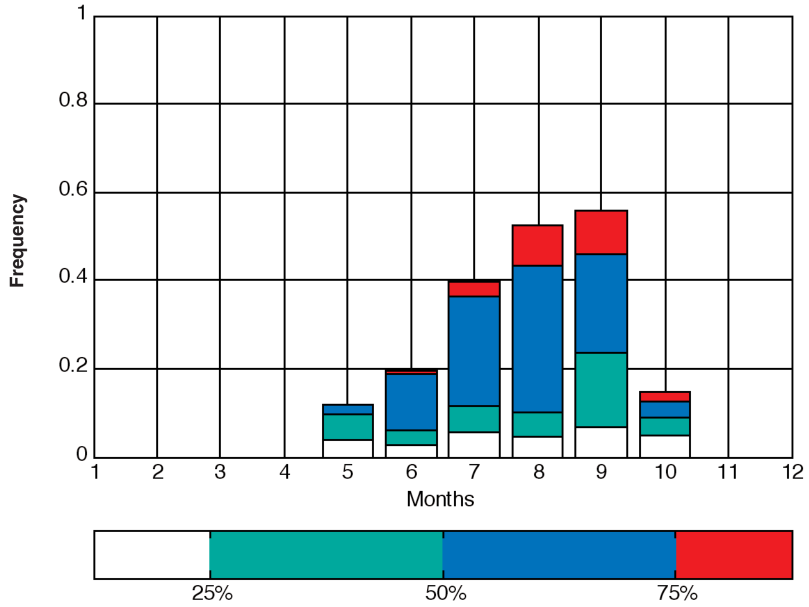


Fig. 26. Monthly frequencies of shortages for LRC9 irrigation demand (simulation with mitigation measures).

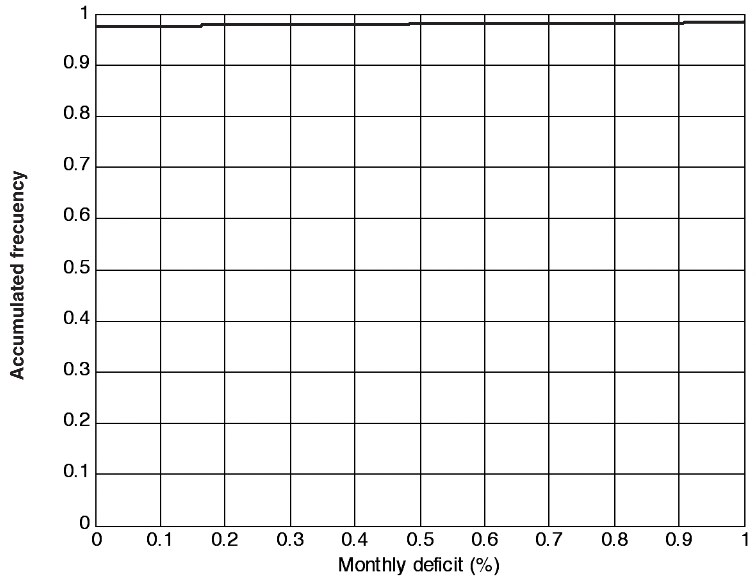


Fig. 27. Sample frequencies of monthly shortages for municipal use (simulation without mitigation measures).

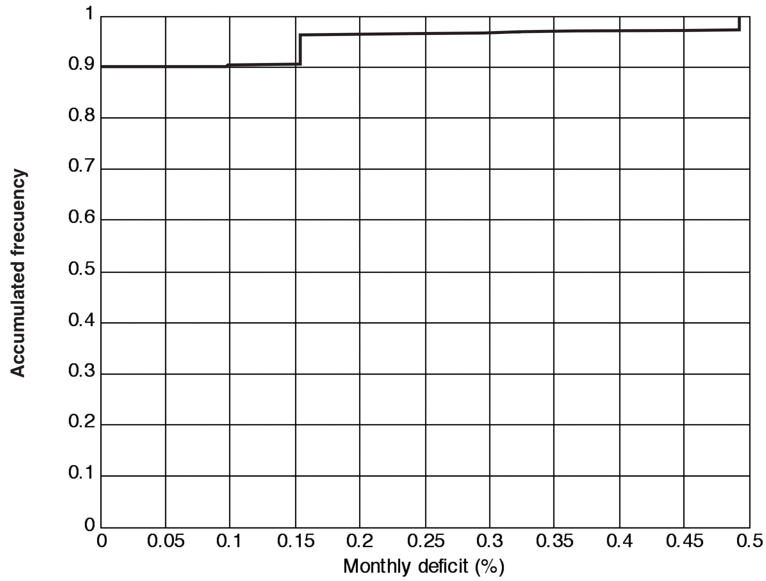


Fig. 28. Sample frequencies of monthly shortages for municipal use (simulation with mitigation measures).

Sample frequencies of monthly shortages for irrigation demand (LR9) reported in Fig. 29 and Fig. 30 respectively for simulations without and with mitigation measures show almost the same pattern except for a step for shortages of about 67% of irrigation demand that goes from a non exceedence probability of about 0.91 to 0.97 for the case with mitigation measures. Again implementation of mitigation measures has reduced the occurrence of large shortages leaving substantially unchanged non exceedence probabilities of smaller shortages.

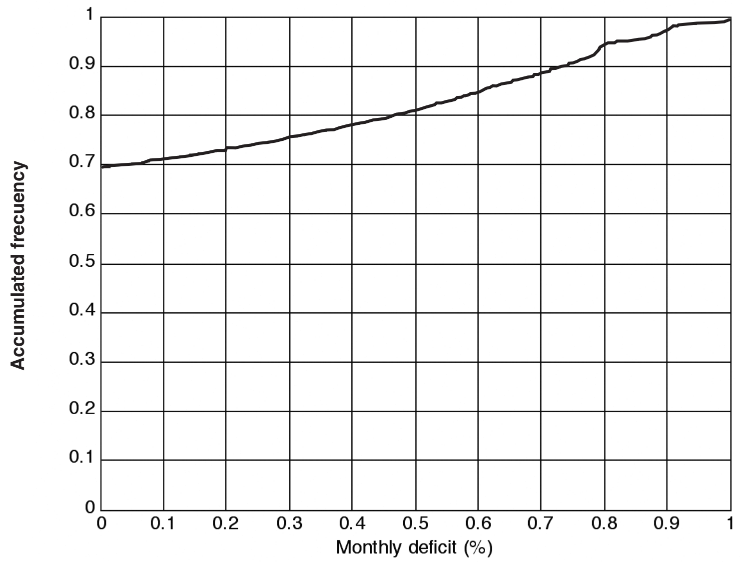


Fig. 29. Sample frequencies of monthly shortages for irrigation demand (simulation without mitigation measures).

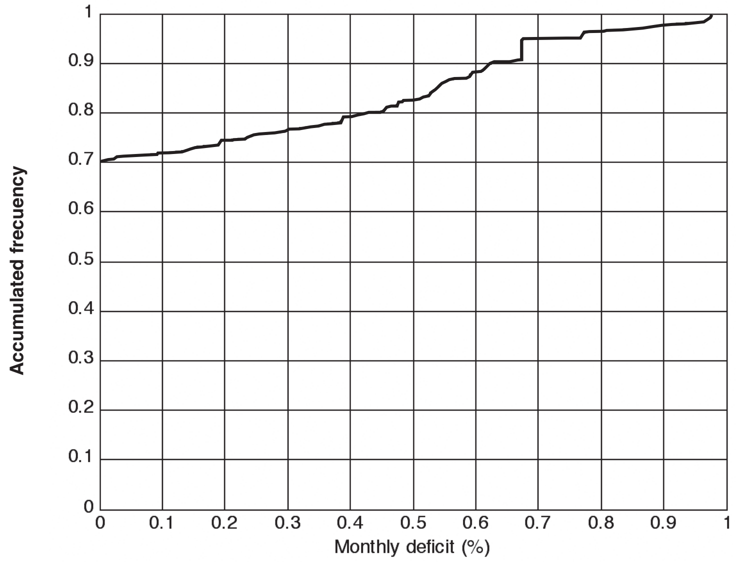


Fig. 30. Sample frequencies of monthly shortages for irrigation demand (simulation with mitigation measures).

The two curves of Fig. 31 show return period of annual shortages in municipal demand for simulations performed with and without mitigation measures. The curves are very close to each other for shortages less than 30% of municipal annual demand then start to depart from the same pattern showing, for example, differences of about 33% (from about 140 to about 210 return period years) for shortages of 50% of the municipal demand. The curves show a more than linear direct relationship between percentage of shortage and return period that becomes more relevant for the simulations with mitigation measures.

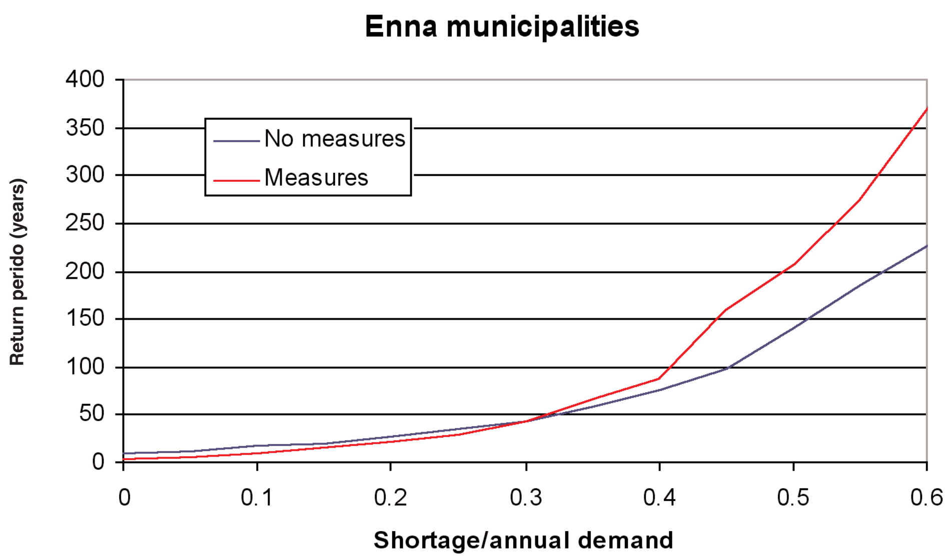


Fig. 31. Comparison between return period of annual shortages for municipal use simulating without or with mitigation measures.

Conditional risk analysis

Conditional risk assessment of the Salso-Simeto water supply system has been carried out by means of 500 synthetically generated series of 36 months starting from the initial condition that the system presented in correspondence of March 1989.

This particular condition has been chosen as consequence of the analysis performed over the whole available historic period. The historic simulation, indeed, shows that a significant period of drought on LR9, LR6 and Enna municipalities demands started in 1989 as depicted in Fig. 32.

In order to perform the conditional risk assessment and to verify the goodness of the proposed mitigation measures, four different management criteria have been used. The first criterion considers the system managed as it was in *normal condition*, i.e. no activation of mitigation measures is implemented regardless the actual state of the system. The second and the third management criteria consider always the system managed respectively in *alert* and in *alarm* condition. The forth simulate the system following a possible drought mitigation plan providing triggers based on the actual volumes stored on the reservoirs of the system to activate the different state condition and the relative mitigation measures (see Fig. 22).

Shows the probability of shortage in municipal use for 36 months ahead starting by the condition of the system of March 1989 for the four above mentioned management criteria. From the figure can be inferred that if the system is managed following the policy typical of *normal* condition greater and more frequent shortage appear respect to those obtained in the case of management criteria for *alert* and *alarm* conditions.

Figure 34 shows the probability of shortage on irrigation demand for 36 months ahead starting by the condition of the system of March 1989. Better results obtained for municipal demand respect to those obtained on irrigational varying management conditions are due to the fact that mitigation measures are particularly devoted to the satisfaction of municipal demand as required by the law. In particular, during alert conditions, the absence of irrigation releases from Ancipa reservoir to the Land Reclamation Consortium 9 makes more water available for municipal demand. Similar considerations can be drawn for the alarm conditions case. On the contrary mitigation measures activation gives results not as good for irrigation demand as shown by Fig. 34.

Goodness of chosen mitigation measures is confirmed by the general reduction of the probability to have deficits during the 36 months of the future under investigation and from the fact that in general the probability to have large deficits is decreased.

The analysis done "forcing" the system in a particular operational condition (normal, alert or alarm) is useful to confirm correctness of the chosen mitigation measures. However a real management of the system should consider the possibility to switch between the different operational conditions.

To simulate the real behavior of water managers it’s necessary to consider the simulation with triggers to activate the different operational conditions.

Results obtained by operating with triggering levels are better than those obtained by the simulation of the system always in normal condition representing a good trade-off between a management that doesn’t consider any mitigation measure and a continuous management in alert or alarm conditions. Indeed, the overall probability of deficits and their amount is less for both demands if the system is operated with triggering levels activating mitigation measures based on the provide thresholds.

The following Tables 8, 9, 10 and 11 report performance indices of the system calculated for the simulations in the three operational conditions and for simulations with triggering levels. All indices, calculated as mean of indices obtained for each one of the 500 simulation done, are better switching from normal conditions to alert and alarm for municipal demand and for irrigation demand at LR9. Satisfaction of irrigation demand at LR6 is penalized by the mitigation measures in comparison to the larger LR9 irrigation demand because it can rely on alternative sources that are insufficient for LR9.

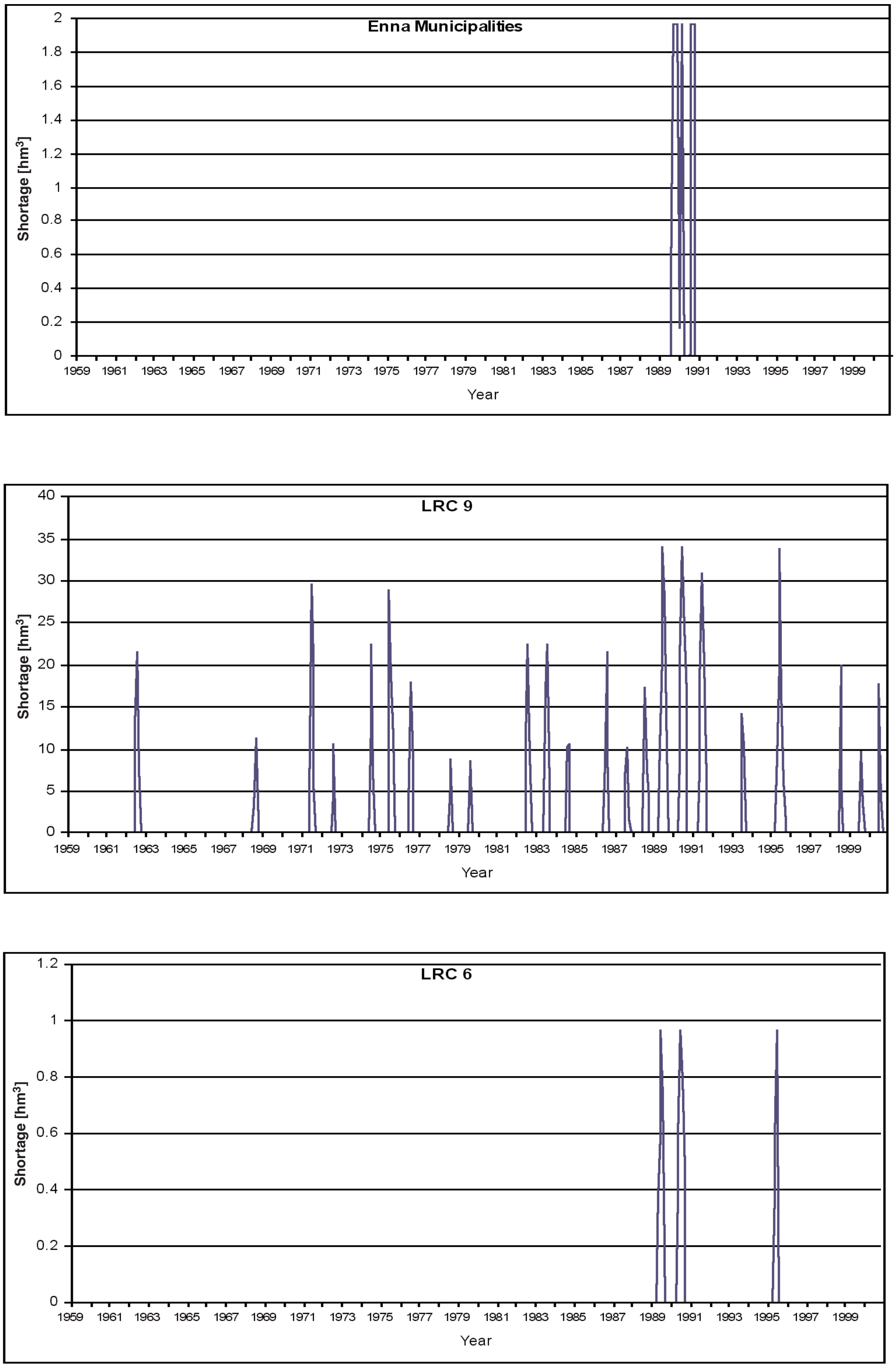


Fig. 32. Water shortage obtained by historical simulation (1959-2000) using normal condition operating policies.

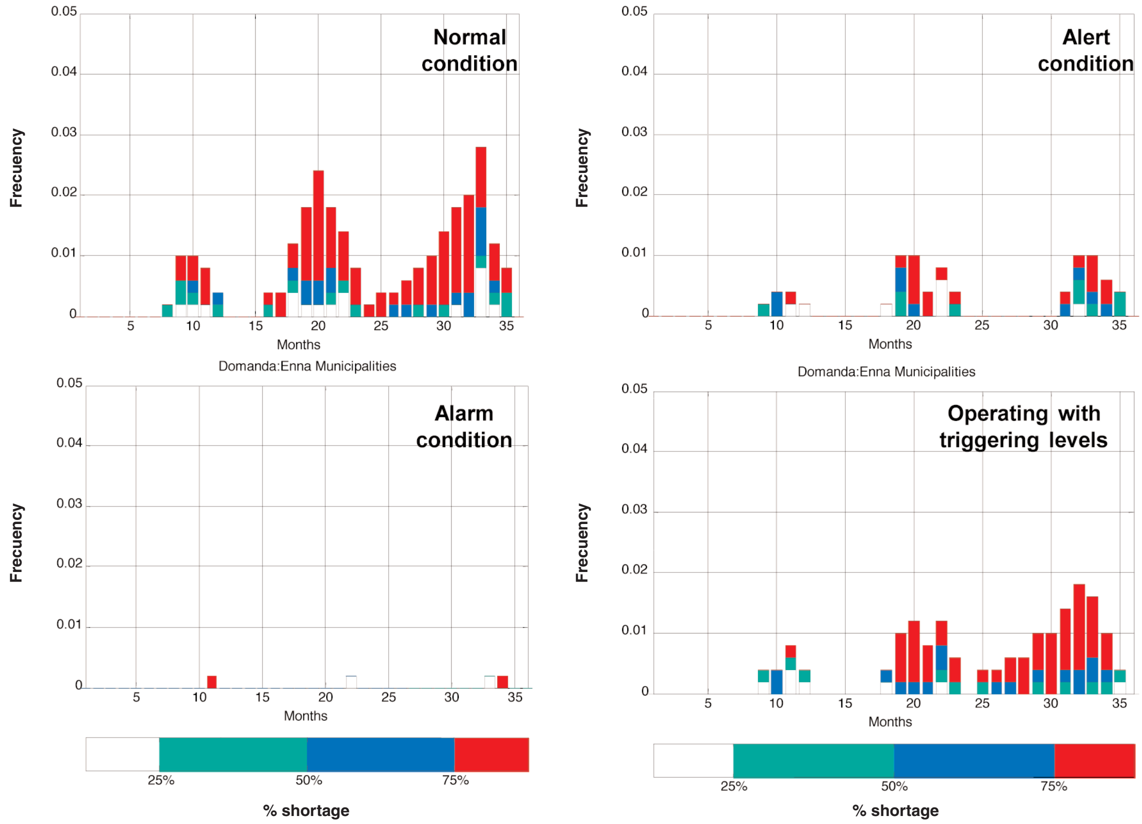


Fig. 33. Frequency of shortage in municipal use in the 36 months following March 1989.

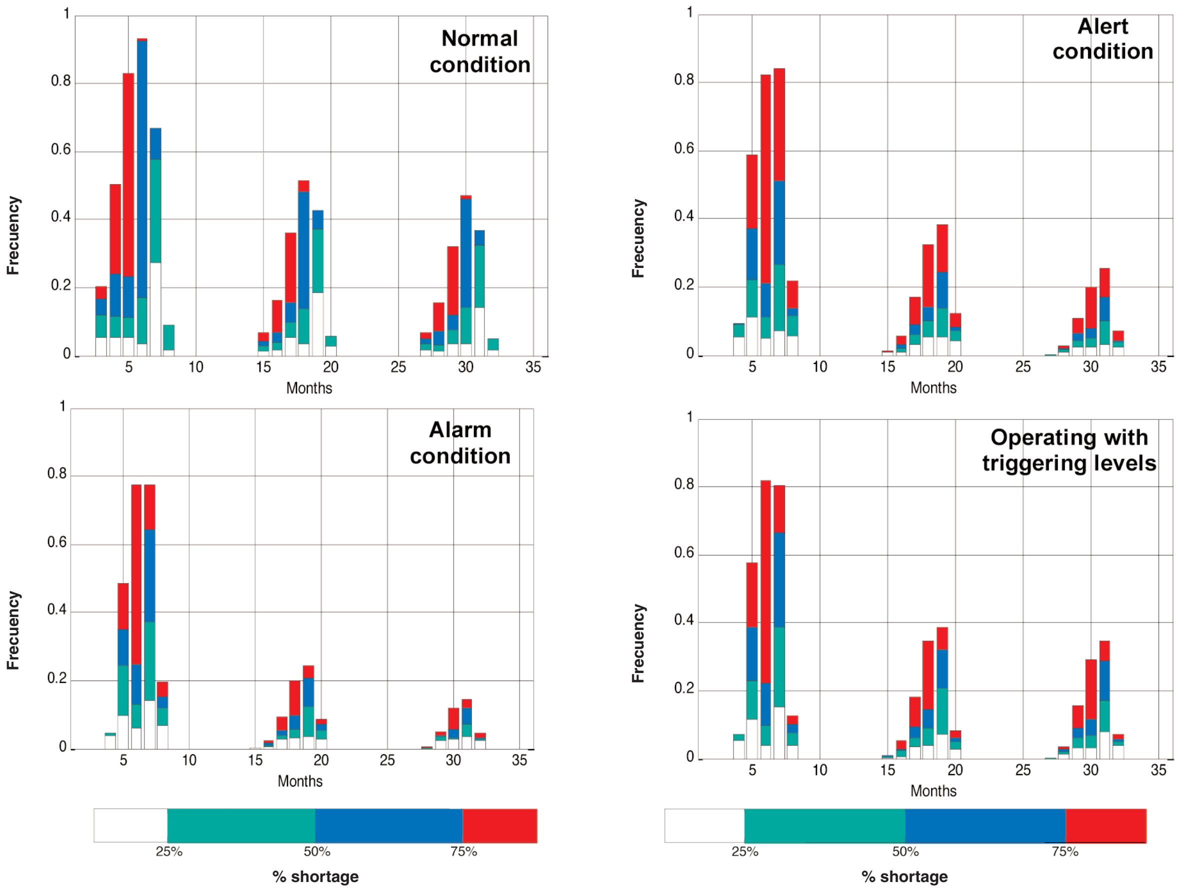


Fig. 34. Frequency of shortage in irrigation use (LRC9) in the 36 months following March 1989.

Table 8. Performance indices of the system operated in normal conditions

	Temporal reliability (% month)	Volumetric reliability (%)	Average shortage period length (months)	Max monthly shortage (10^6 m^3)	Max annual shortage (10^6 m^3)	Sum of squared shortage (10^6 m^3)
Enna municipalities	99.2	99.4	0.21	0.09	0.33	0.5609
LR9	65.3	75.5	2.90	16.97	36.33	756.22
LR6	96.3	96.5	0.55	0.11	0.21	0.0970

Table 9. Performance indices of the system operated in alert conditions

	Temporal reliability (% month)	Volumetric reliability (%)	Average shortage period length (months)	Max monthly shortage (10^6 m^3)	Max annual shortage (10^6 m^3)	Sum of squared shortage (10^6 m^3)
Enna municipalities	99.7	99.8	0.07	0.04	0.09	0.1294
LR9	76.1	81.9	2.51	14.99	30.7	597.73
LR6	88.4	91.5	1.27	0.28	0.43	0.2030

Table 10. Performance indices of the system operated in alarm conditions

	Temporal reliability (% month)	Volumetric reliability (%)	Average shortage period length (months)	Max monthly shortage (10^6 m^3)	Max annual shortage (10^6 m^3)	Sum of squared shortage (10^6 m^3)
Enna municipalities	99.9	99.9	0.008	0.006	0.006	0.0101
LR9	81.8	87.6	2.245	12.724	23.432	383.21
LR6	91.7	94.6	1.068	0.213	0.2986	0.1185

Table 11. Performance indices of the system operated with triggering levels

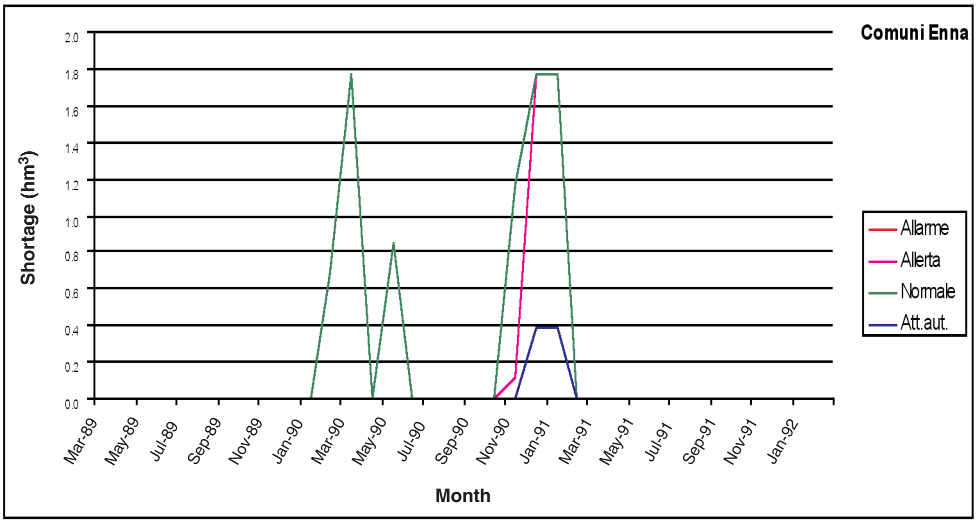
	Temporal reliability (% month)	Volumetric reliability (%)	Average shortage period length (months)	Max monthly shortage (10^6 m^3)	Max annual shortage (10^6 m^3)	Sum of squared shortage (10^6 m^3)
Enna municipalities	99.5	99.6	0.136	0.06	0.21	0.33
LR9	75.8	82.4	2.42	14.8	29.0	570.25
LR6	86.8	91.5	1.36	0.28	0.42	0.18

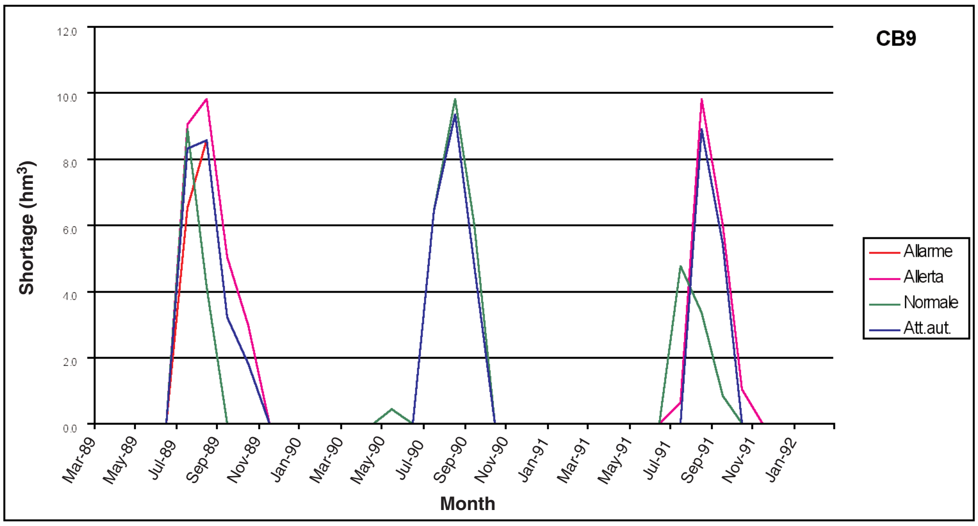
Indices calculated in correspondence of the system operated with triggering levels are always between those calculated for simulation with no mitigation measures and those obtained operating the system as it was always in alarm condition. Indices obtained operating the system with triggering levels have to be considered as the most meaningful because represent the performance obtainable following the behavior of the water managers that tend to adapt the managing to real conditions of the system and not follow pre-constituted operating rules.

The methodology aids water managers to choose management criteria in order to contain the risk of shortage over the immediate future constituted by the 36 months successive to the time in which the decision about the right management criterion has to be done.

In order to evaluate actual effects of the proposed management criteria a new simulation was performed considering to operate the system with triggering levels starting on march 1989 till February 1992 using the historic 36 streamflow to the system (Fig. 35).

Operating with triggering levels contributes to reduce risk of deficit both for municipal and irrigational demands resulting in worst results only for irrigational demand during the third year fully compensated by the gains obtained on municipal demands during the previous two years.





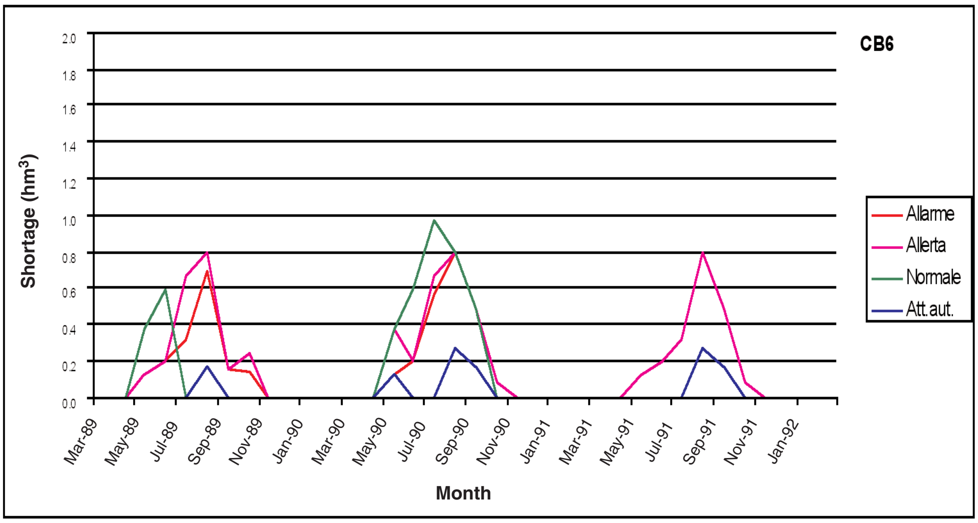


Fig. 35. Simulation using 36 months historic records starting from March 1989.

Drought damage in rainfed agriculture

Drought impacts in the agricultural sector strictly depends on the type of agriculture practiced in a specific area: rainfed or irrigated. Indeed, in rainfed agriculture drought impacts are usually very serious and often all or part of the crop production is lost. Sometimes farmers are unable to produce spring and summer crops and they have few defense tools.

Irrigation, of course, is the best way to cope with the climatic variability, although in the farms or districts supplied by surface water the impacts of severe droughts can be also very serious. In the farms supplied by groundwater, the impacts of droughts are almost non-existing, if the short term is considered. For long drought periods, the impacts are related to the decreasing of water tables level. In this case the farmer is forced to change the operating rules of the wells and/or of the irrigation system. In the farms supplied by an irrigation district or a land reclamation consortium, the impacts are related to water resources availability existing during the drought period both at farm and district level. When water resources are limited, the district/consortium gives priority to the fruit orchards and change the irrigation scheduling with a longer turn of water delivery.

In order to evaluate the risk associated to drought events in agriculture, an analysis of the expected social and economic impacts has to be carried out. The main difficulty related to this issue is to collect all the possible data about drought damages and express such data in economic terms. Among these data, damages caused by drought either to rainfed and irrigated agriculture, expressed as production losses, are generally assessed by specific institutions that control agriculture activity. For instance, in Italy, the damages consequent to drought events, are assessed by the Provincial Agricultural Offices, on their own initiative or solicited by farmers or by social and categories organizations. In particular, for each crop cultivated in the target area, the percentage of Gross Sale Production (GSP) corresponding to the economic loss is evaluated, then the whole damage is computed as a weighted average. Only when the damage reaches a given percentage (30% according to the L. Decree 102/2004, 35% according to the previous law) of GSP of the whole crops production of the target area, it is possible to request the "natural disaster declaration". In Fig. 36 the institutional framework to cope with drought emergency in agriculture is illustrated. The declaration of natural calamity is requested by the Regional Government, through the Regional Agricultural Department, to the Ministry of Agricultural Affairs. Once that the extreme nature of the occurred drought event, in terms of impacts on agricultural production, is ascertained, the status of natural calamity is declared and funding to cover income losses or to stipulate insurance is supplied to the Regional Government and then to Provincial Agricultural Offices, which are in charge to build new infrastructures and/or to allocate funding to the farmers for insurance.

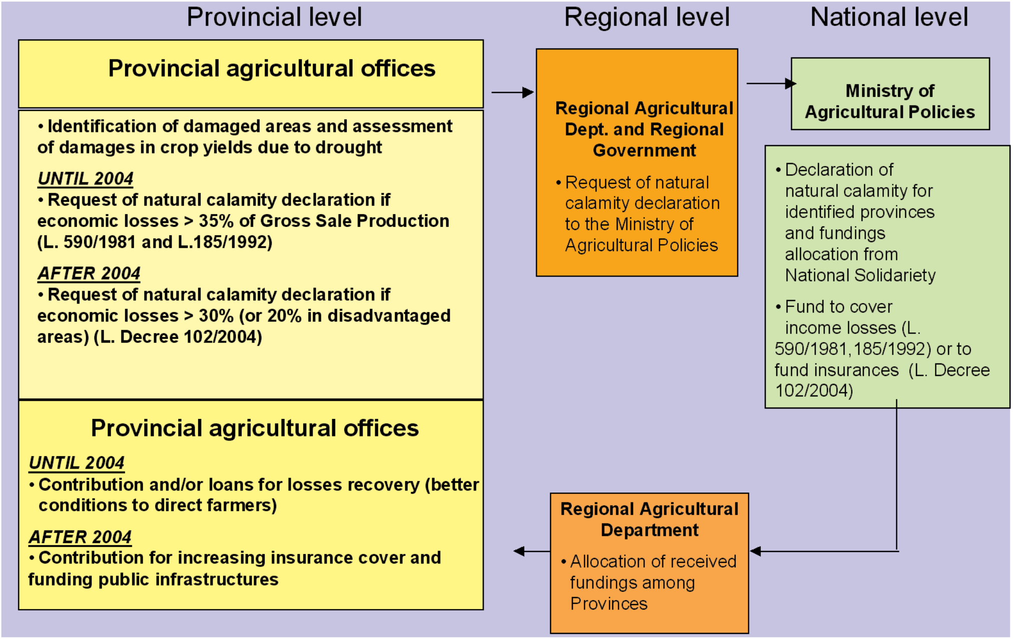


Fig. 36. Institutional framework in Italy to cope with drought emergency in agriculture.

With regard to the examined case-study, data related to losses in crop production during the recent drought events, as estimated by the Provincial Agricultural Offices, have been collected in the Offices of Catania, Siracusa and Enna. For these provinces the soil use, together with the location of the considered rain gauges, is reported in Fig. 37.

The sample series of the areal rainfall with respect to the cultivate areas in each province has been computed, based on monthly precipitation data observed in the selected rain gauges during the period 1921-2000, by using the Thiessen polygons methods. Rainfall values for each kind of soil use has been determined by considering a weighted average among the intersections between cultivate areas and relative polygons (see Fig. 38). Finally, fixing the time scale, the corresponding SPI series have been calulated.

In Fig 39 and Fig. 40, as an example, a preliminary comparison between the values of SPI and the contemporary percentage of damages on cereals and fodders for Catania and Siracusa is presented. The SPI has been calculated by considering an aggregation time scale *k* equal to the crop cycle (from seeding to harvesting) and/or to the critical phenological phases of the different crops. For instance, if cereal is the kind of the crop, the rain during the months October, November and December is essential for the sowing, as well as the rain on the period March to May, during which the plants are not able to complete the crop cycle. Therefore, for this case, it can be useful considering SPI values on May with time scales of 7 or 8 months, or on January with 3 or 4 months. It is easy to observe that, even if there is a certain agreement, however there is no direct proportionality between percentages of damages and SPI values. This can be partially due to the fact that drought impacts on agriculture are roughly assessed, and in some cases they might be artificially increased in order to overcome the threshold for getting refunds according to current legislation. Further investigations are still in progress regarding this issue.

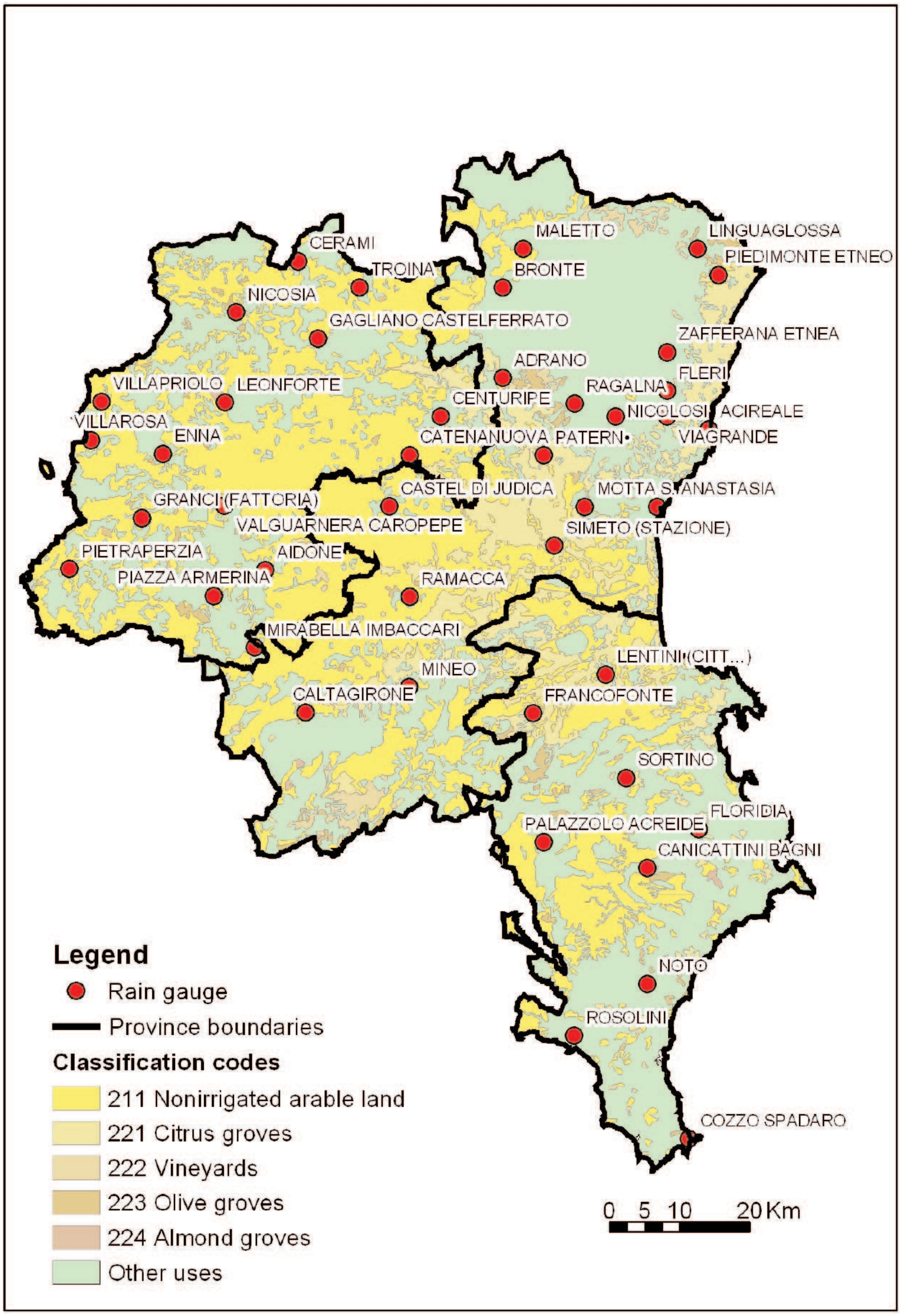


Fig. 37. Rain gauges and soil use for the 3 provinces of Catania, Siracusa and Enna.

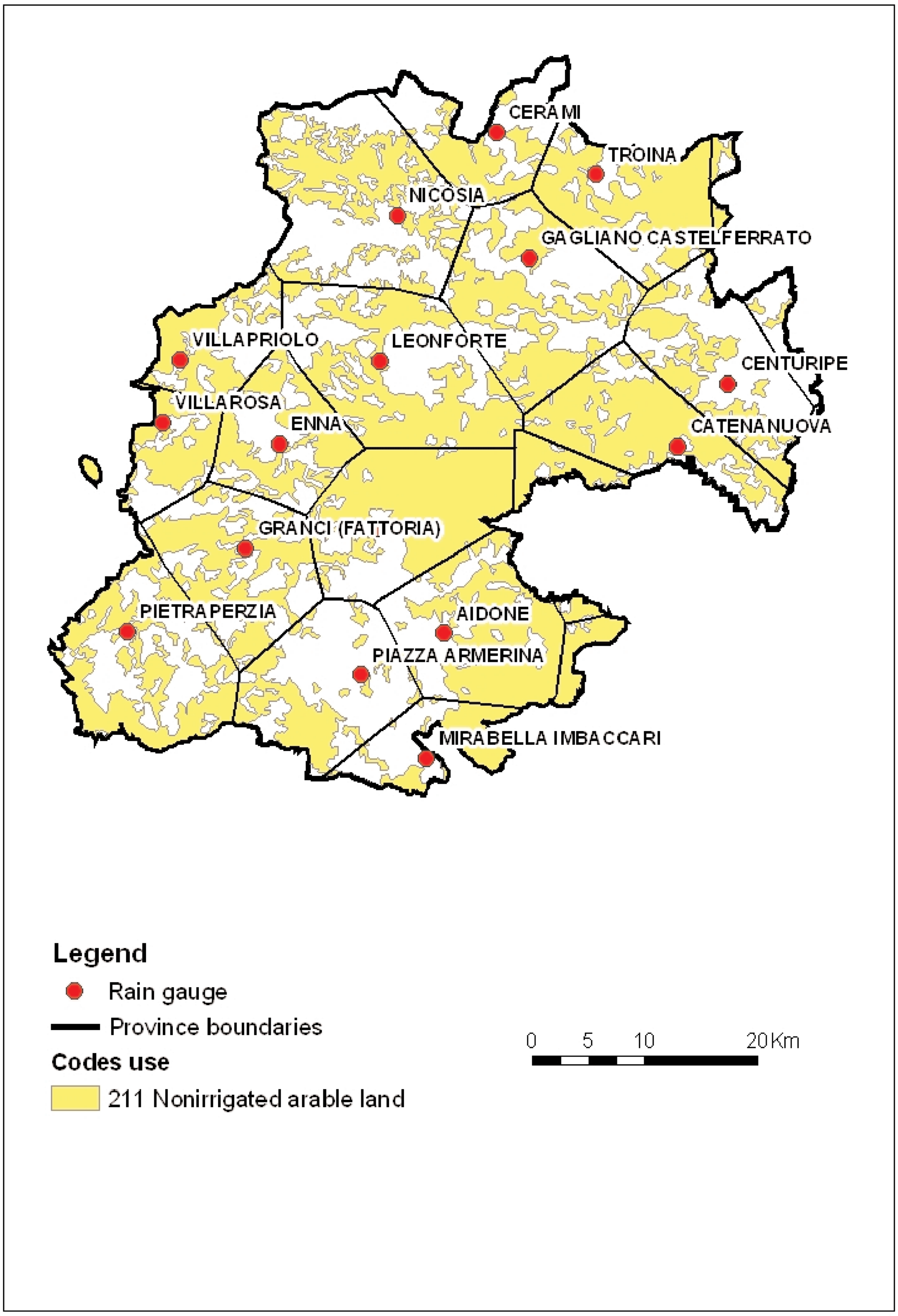


Fig. 38. Thiessen polygons and soil use for the province of Enna.

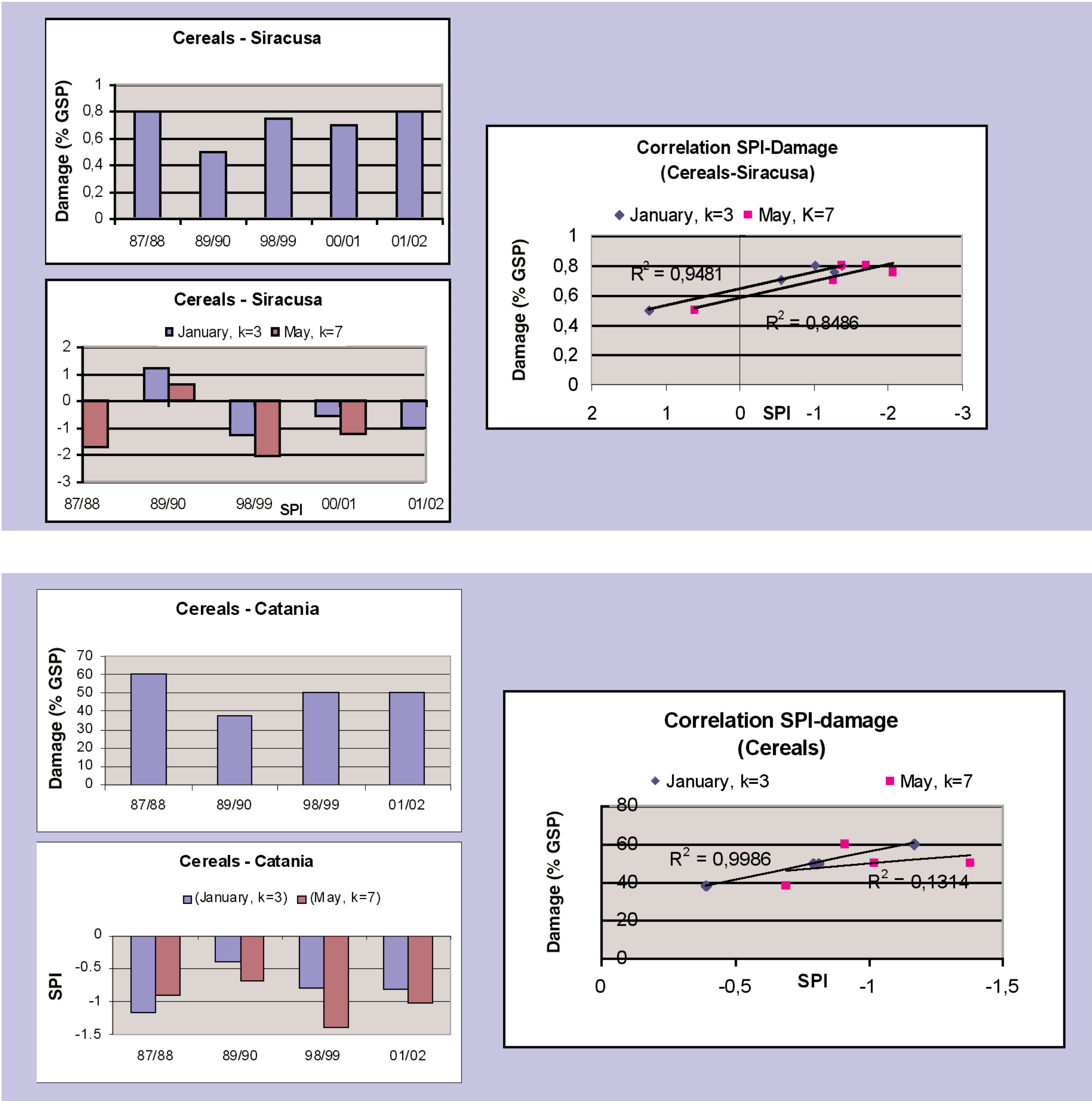


Fig. 39. Comparison between SPI and drought impacts on cereals for the provinces of Catania and Siracusa.

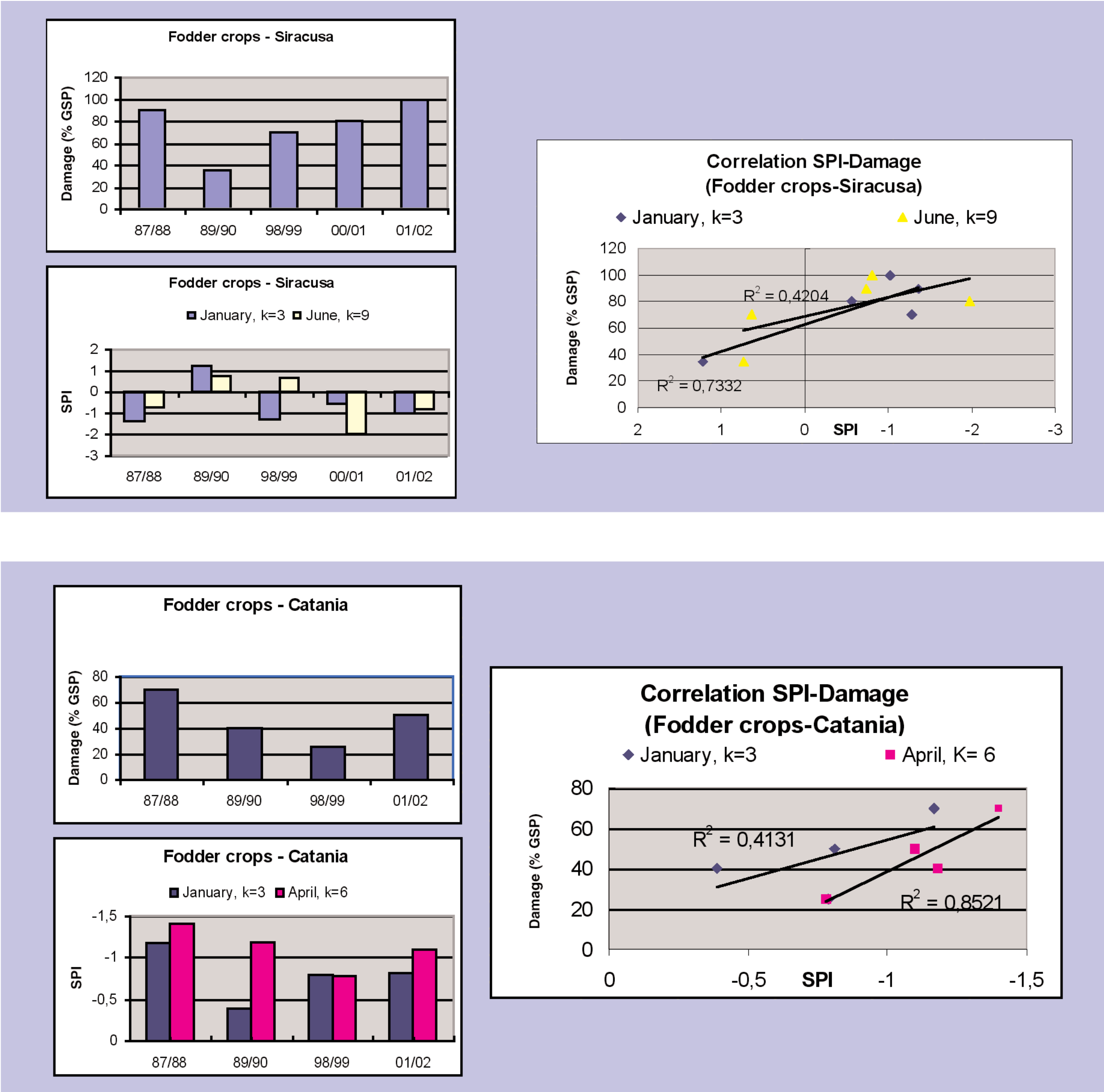


Fig. 40. Comparison between SPI and drought impacts on fodder crops for the provinces of Catania and Siracusa.

References

Bonaccorso, B., Cancelliere, A. and Rossi, G. (2003). An analytical formulation of return period of drought severity, *Stochastic Environmental Research and Risk Assessment,* 17: 157-174.

Cancelliere A., Bonaccorso, B., Rossi, G. and Salas, J.D. (2003). On the probabilistic characterization of drought events, *AGU 23rd Hydrology Days*, Colorado State University, Fort Collins, Co.

McKee, T.B., Doesken, N.J. and Kleist, J. (1993). The relationship of drought frequency and duration to time scales. In: *8th Conference on Applied Climatology*, Anaheim, California, 17-22 January 1993, pp.179-184.

Palmer, W. C. (1965). *Meteorological drought*. U.S. Weather Bureau Research Paper 45, Washington, D.C.

Rossi, G. (2000). Drought mitigation measures: A comprehensive framework. In *Drought and drought mitigation in Europe*, J. V. Vogt and F. Somma (eds). Kluwer Academic Publishers, The Netherlands, pp. 233-246.

Rossi G. (2003). An integrated approach to drought mitigation in Mediterranean regions. In: Rossi, G., Cancelliere, A., Pereira, L., Oweis, T. and Shatanawi, M. (eds), *Tools for Drought Mitigation in Mediterranean Regions,* Kluwer Academic Publishers, Dordrecht, pp. 3-18.

Salas, J.D. (1993). Analysis and modeling of hydrologic time series. In: D. Maidment (ed), *Handbook of Hydrology,* chap. 19, McGraw-Hill, New York.

Salas, J. D., Fu, C., Cancelliere, A., Dustin, D., Bode, D., Pineda, A., and Vincent, E. (2005). Characterizing the Severity and Risk of Droughts of the Poudre River. *Journal of Water Resources Planning and Management (ASCE)*, 131(5): 337-408.

Shiau, J., and Shen, H. W. (2001). Recurrence analysis of hydrologic droughts of differing severity. *Journal of Water Resources Planning and Management*, 127(1): 30-40.

Sveinsson, O., Salas, J.D., Lane, W.L., Frevert, D.K., (2003). Progress in stochastic analysis modelling and simulation: SAMS-2003. In: *23rd Annual American Geophysical Union Hydrology Days*, March 31-April 2 2003, Fort Collins, Co, USA, Colorado State University

Yevjevich, V. (1967). An objective approach to definitions and investigations of continental hydrologic droughts. *Hydrology Paper* no. 23, Colorado State University, Fort Collins, CO.

Yevjevich, V., Da Cunha, L. and Vlachos, E. (1983). *Coping with Droughts*. Water Resources Publications, Littleton, Colorado, 417 p.

Yevjevich, V., Hall, W.A. and Salas, J.D. (1978). *Proc. Conference on Drought Research Needs*, Water Resources Publications, Fort Collins, 276 p.