Chapter 14
Characterizing Drought Risk in a Sicilian River Basin

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Abstract The chapter summarizes the results of the application of proposed methodologies for drought characterization and risk assessment in 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, the results of the drought identification, carried out by means of several drought indices and methods such as the Standardized Precipitation Index (SPI), the Palmer Hydrological Drought Index (PHDI) and the Run Method, are presented. The application of a methodology developed for the assessment of return periods of drought events identified on historical series of annual precipitation is also reported. Then, the methodology for risk assessment 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 is carried out in order to assess both unconditional (long term) and conditional (short term) drought risk. Also, drought impact assessment on rainfed agriculture is presented. Finally, drought mitigation measures historically adopted within the Simeto River basin in order to reduce drought impacts in urban and agricultural sectors are described.

Introduction

In the last twenty years, Italy has experienced many drought events both in semiarid southern regions (where the greater variability of the hydro-meteorological variables and the reduced availability of water resources versus the increasing demands, lay the basis to more frequent conditions of water deficit), as well as in the northern regions, characterized by humid climate and a large amount of water resources.

Despite the severity of past droughts, in particular the event occurred during the period 1988–1990 and the most recent drought of 2002–2003, apparently very few lessons have been learned at political and institutional levels, since the prevalent

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A. Iglesias et al. (eds.), *Coping with Drought Risk in Agriculture and Water Supply Systems*, Advances in Natural and Technological Hazards Research 26,
DOI 10.1007/978-1-4020-9045-5_14,

approach for coping with drought remains reactive, with a preference to manage emergency situations rather than preventing them through an integrated approach to drought management.

Generally, ad hoc measures have been implemented to face severe droughts, considered as natural disasters. For instance, during the drought event of 1988–90, the Department of Civil Protection, which has been entrusted with the task of coping with natural disasters, has defined and implemented emergency interventions (generally structural measures, such as: deepening of wells or realization of new ones, extraordinary maintenance of the main hydraulic infrastructures, temporary allocation of water resources for irrigation purpose to drinking/municipal use, etc). Moreover, Commissioners for Water Emergency have been generally appointed by the Prime Minister during recent droughts.

Although several innovations have been included in the Italian legislation on water resources during the last decades, water management during drought conditions is not ruled properly. This is mainly due to the fact that (i) the necessity of a proactive approach to face efficiently drought consequences does not seem to be widely shared, (ii) a clear distinction between long term and short term measures for drought impact mitigation is lacking, and (iii) the assignment of competences among institutions in charge of planning, water supply agencies, and institutions in charge of emergency management, as the Department of Civil Protection, is ambiguous.

Other significant elements which limit the implementation of an appropriate drought management policy include: the lack of efficient drought monitoring and forecasting systems, the difficulty in transferring advanced methodologies of drought risk assessment to water managers, and the complexity in defining simple and objective criteria to properly select and implement mitigation measures.

In what follows, methodologies for drought identification and characterization, and for risk assessment in water supply systems are applied to an Italian case study, namely the Simeto River basin in Sicily. In particular, drought identification is carried out by means of the Standardized Precipitation Index (SPI) (McKee et al., 1993), the Palmer Hydrological Drought Index (PHDI) (Palmer, 1965) and the Run Method (Yevjevich, 1967). Drought characterization also includes the application of a new methodology for the assessment of the return periods of drought events (Bonaccorso et al., 2003, Cancelliere et al., 2003) identified on the historical annual precipitation series.

Then, the methodology for drought risk assessment in water supply system described in chapter 6 of this book (Cancelliere et al., 2009) is applied to the Salso-Simeto water supply system, which is a part of the larger system of the Simeto River basin. In particular, a Montecarlo simulation of the system, making use of generated streamflow 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. Also, drought impact assessment on rainfed agriculture is presented. Finally, drought mitigation measures historically adopted during past drought events within the Simeto River basin, in order to reduce drought impacts in urban and agricultural sectors, are described.

The Water Supply System of the Simeto River Basin

The Italian case study of the Medroplan project is the Simeto River basin, located in Eastern Sicily (see Fig. 14.1). 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.

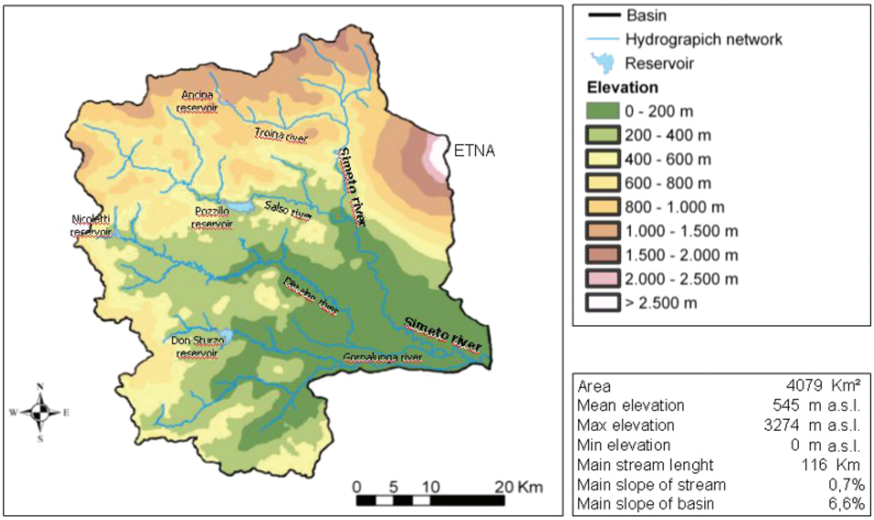


Fig. 14.1 The Simeto River basin

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. 14.2, 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 was built during the 50s. 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 Power 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 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 of Catania (LRC 9). Besides, a small amount of release from Pozzillo is devoted to an irrigation district of the Land Reclamation Consortium no. 6 of Enna (LRC 6).

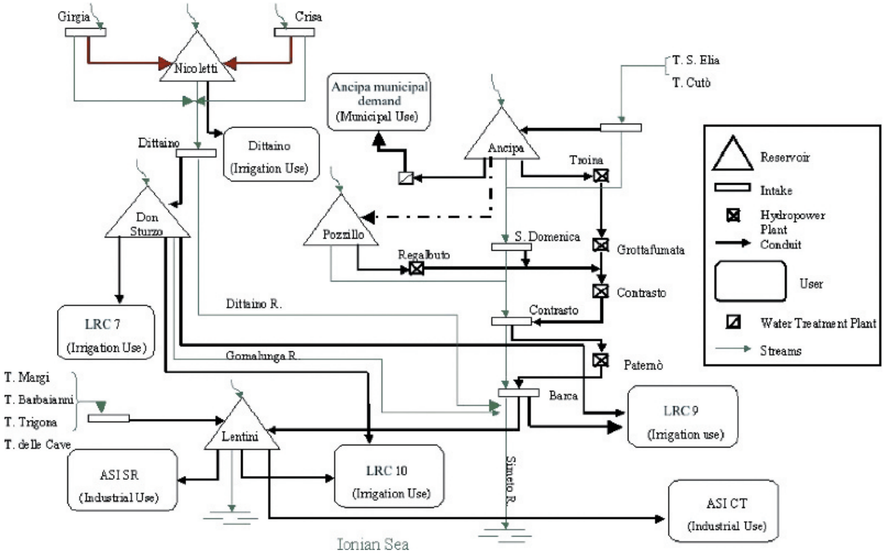


Fig. 14.2 The water supply system of the Simeto River basin

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 to meet the demands of the irrigation districts managed by LRC9 and the Land Reclamation Consortium no. 10 of Siracusa (LRC10), and of the 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, were built during the 70s 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 Consortia no. 6 of Enna (LRC6) and no. 7 of Caltagirone (LRC7).

The main features of the reservoirs of the Simeto water supply system are summarized in Table 14.1.

Available hydrological data include monthly series of precipitation at 22 rain gauges (with at least 80 years of observations starting from 1921), temperature at 4 stations (observations from 1926 to 2003) and streamflow at 10 hydrographic stations (with different sample size).

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 precipitation, average mean temperature and historical series of different drought indices have been computed.

Table 14.1 Basins drainage areas, storage capacities and average annual inflows of reservoirs in Simeto water supply system

Reservoir	Surface area (km^2)		Storage capacity (10^6 m^3)	Annual average inflows (10^6 m^3)
	Direct basin	Tributary basins		
Ancipa	51	58	27.8 (9.3*)	57.54
Pozzillo	577	–	123	92.06
Lentini	16	1086+341	127	96.40
Don Sturzo	171	285	110	31.60
Nicoletti	49.5	13+42	17.4	22.70

* Operational constraint

Moreover, a preliminary stationarity analysis on available precipitation series has been carried out in order to check for trends or jumps in the series, revealing that at least 50% of the considered annual series (computed with respect to the water year) present a significant trend and are not homogeneous in the mean.

Drought Identification and Characterization

SPI

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

According to the commonly adopted classification (see Table 14.2), negative values of the index describe drought conditions, while positive values indicate wet conditions.

Table 14.2 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 $\geq$ 2.00	Extremely wet
1.50 $\leq$ SPI $<$ 2.00	Very wet
1.00 $\leq$ SPI $<$ 1.50	Moderately wet
$-1.00 \leq$ SPI $<$ 1.00	Near normal
$-1.50 \leq$ SPI < -1.00	Moderate drought
$-2.00 \leq$ SPI < -1.50	Severe drought
SPI < -2.00	Extreme drought

The SPI has been applied on the available monthly precipitation series aggregated at various time scale k, corresponding to the time intervals at which the different hydrological components are more sensitive to a significant reduction in precipitation. As an example, Fig. 14.3 represents the time series of SPI at Salso at Pozzillo reservoir. It can be observed that the most critical droughts occurred between the mid 80s and the beginning of the 90s, and the end of the 90s and 2003.

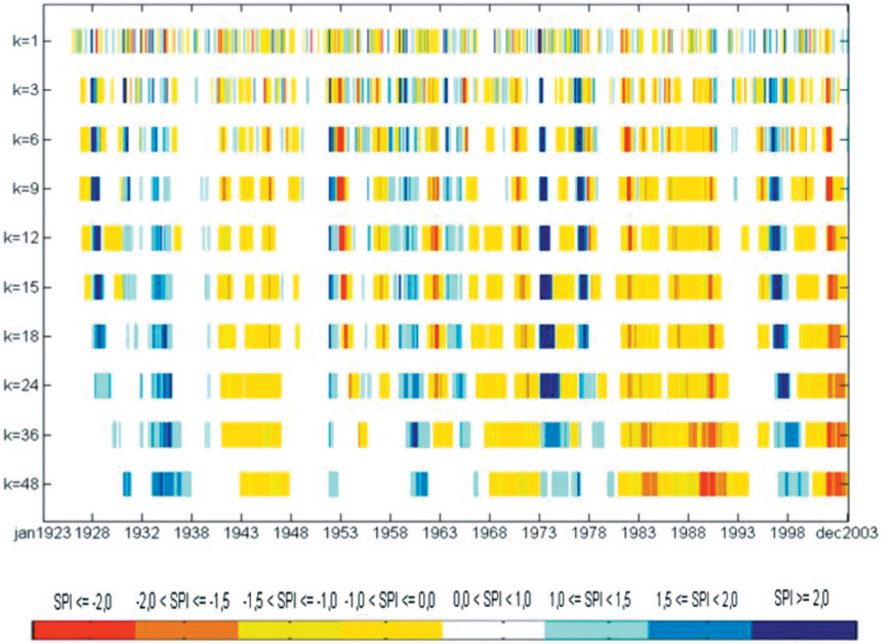


Fig. 14.3 Time series of SPI for different time scales *k* at Salso at Pozzillo reservoir

Another application of the SPI is presented in Fig. 14.4. In this case, the time series of the SPI at $k = 12$ months are represented for each considered sub-basin of the Simeto River basin, reported in the 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.

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 14.3 indicates the classification of dry and wet periods related to the Palmer Index.

In Fig. 14.5 time series of PHDI are represented for each sub-basin of the Simeto river basin. Results reported for PHDI are generally in agreement with those presented in Fig. 14.4, although PHDI seems to identify much longer and more severe drought conditions.

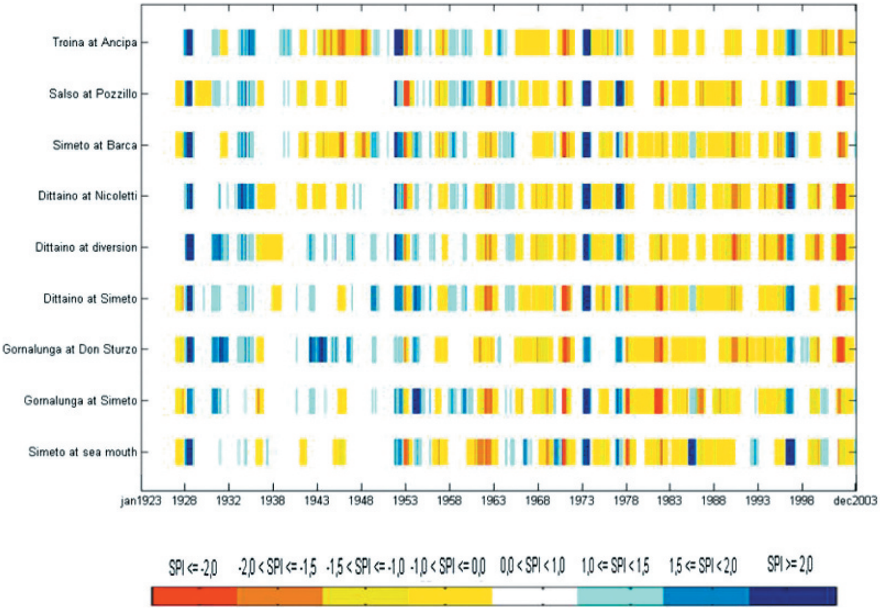


Fig. 14.4 Time series of SPI over the sub-basins of Simeto River ($k = 12$ months)

Table 14.3 Wet and drought period classification according to the Palmer Index (PHDI)

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

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 time intervals where the observed values $h(i)$ $i=1, 2, \ldots n$, of a considered hydrologic variable, remains below a chosen truncation level or threshold h_0. For each drought event, the following characteristics can be derived:

– duration L, defined as the number of consecutive intervals where the variable remains below the threshold;
– accumulated deficit D, defined as the sum of the negative deviations with respect to h_0, extended to the whole drought duration;
– intensity of drought I, defined as the ratio between accumulated deficit and duration.

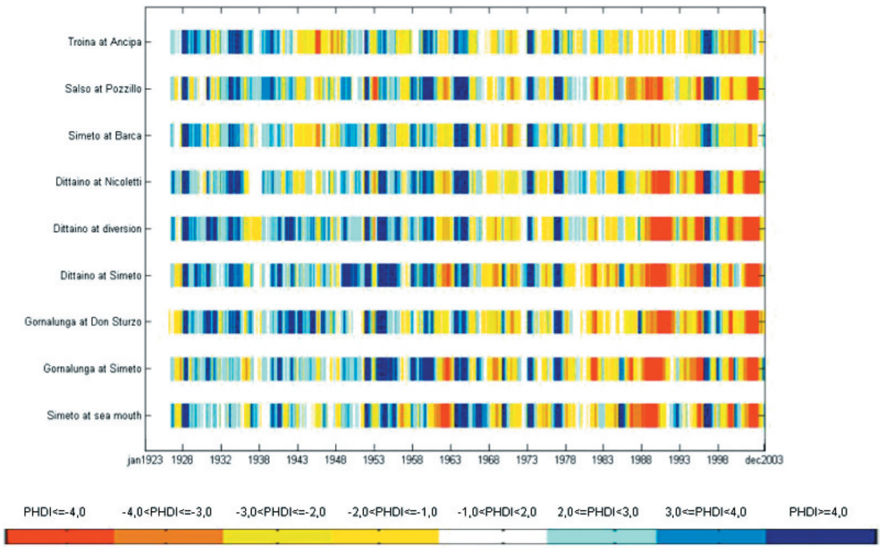


Fig. 14.5 Time series of PHDI over the sub-basins of Simeto River

The run method can also be extended to the case of regional droughts, i.e. droughts which affect large regions, by considering, in addition to the truncation level at each site, another threshold representing the value of the area affected by deficit, above which a regional drought is considered to occur.

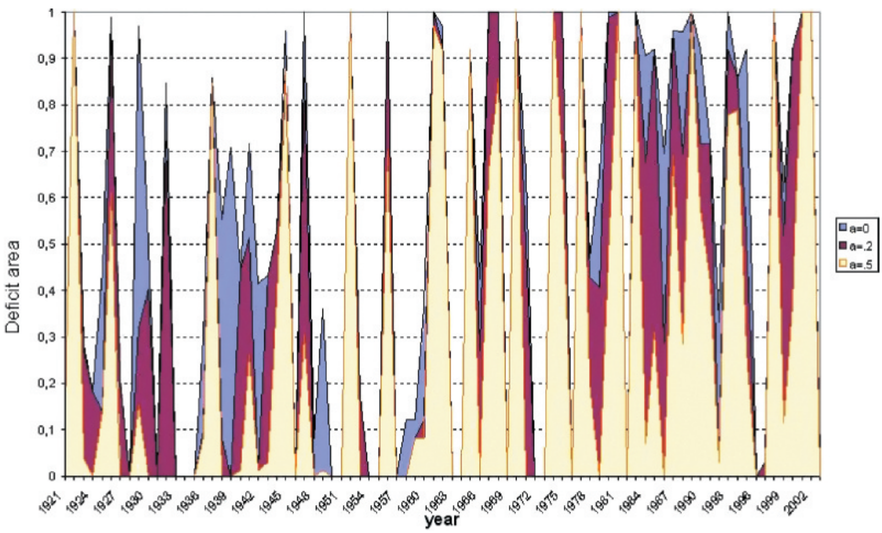


Fig. 14.6 Time series of deficit area over Simeto River basin for different threshold levels

Applications of the run method are illustrated in Figs. 14.6 and 14.7, where respectively the time series of deficit area (with respect to the total area of the basin), and areal deficit (i.e. the weighted average of deficits with respect to the influence areas of the stations where deficits occur) obtained by considering three different threshold levels at each site are shown. In particular, the threshold level is parametrized as $h_0 = h_m - \mathrm{a} \cdot s$, where h_m is the sample mean, s is the sample standard deviation, and a is a dimensionless parameter assumed equal to 0, 0.2 and 0.5. The most critical drought can be recognized by the fact that the whole basin is under drought condition even for the minimum value among the considered threshold levels.

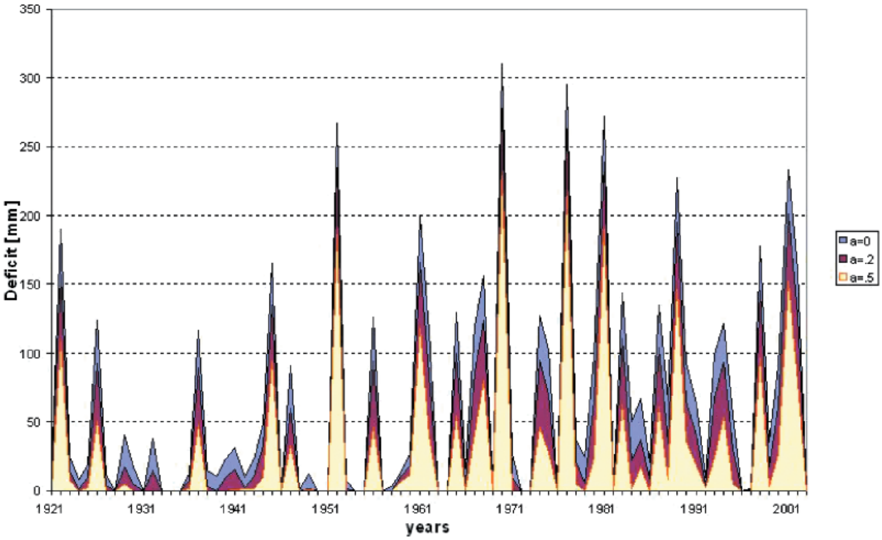


Fig. 14.7 Time series of areal defcit over Simeto River basin for different threshold levels

Assessment of Drought Return Period

The return period of drought events can be defined as the expected value of the 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 and serially independent series, the return period can be written as:

$$T = \frac{1}{p_1 (1 - p_1)} \cdot \frac{1}{P\,[\mathrm{A}]} \tag{14.1}$$

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

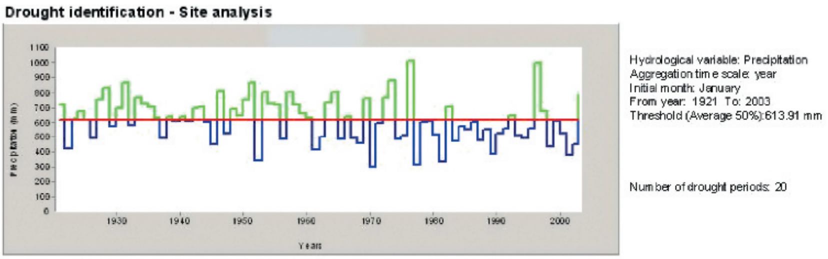
The following cases have been taken into account:

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

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

Such procedure has been implemented in a module of the software REDIM, specifically developed for drought identification and characterization by the Department of Civil and Environmental Engineering of the University of Catania (Rossi and Cancelliere, 2003), also including a routine for SPI computation.

In Fig. 14.8, an example of drought analysis carried out by REDIM, referred to the areal precipitation series over the Simeto River basin, for the period 1921–2003,



N	Begin.	End	Durat. [years]	Cum. Def. [mm]	Drought Int. [mm/year]	Tr(L=l) [years]	Tr(L=>l) [years]	Tr(D>d) [years]	Tr(L=l,D>d) [years]	Tr(L=>l,D>d) [years]
1	1922	1922	1	189.84	189.84	8.58	7.55	8.39	61.67	8.57
2	1926	1926	1	123.43	123.43	8.58	7.55	6.23	24.70	6.20
3	1929	1929	1	39.29	39.29	8.58	7.55	4.46	10.09	4.32
4	1932	1932	1	29.47	29.47	8.58	7.55	4.32	9.45	4.20
5	1937	1937	1	116.38	116.38	8.58	7.55	6.04	22.59	6.00
6	1939	1939	1	6.79	6.79	8.58	7.55	4.06	8.63	4.03
7	1941	1941	1	6.49	6.49	8.58	7.55	4.06	8.63	4.03
8	1944	1945	2	181.81	90.91	16.13	14.19	8.09	27.39	9.70
9	1947	1947	1	90.55	90.55	8.58	7.55	5.42	16.55	5.32
10	1952	1952	1	267.25	267.25	8.58	7.55	12.10	199.17	12.55
11	1956	1956	1	126.17	126.17	8.58	7.55	6.30	25.59	6.29
12	1961	1962	2	312.21	156.11	16.13	14.19	15.05	88.97	16.29
13	1965	1965	1	127.16	127.16	8.58	7.55	6.33	25.92	6.32
14	1967	1968	2	275.60	137.80	16.13	14.19	12.60	61.00	13.88
15	1970	1971	2	329.82	164.91	16.13	14.19	16.42	107.77	17.64
16	1974	1975	2	230.16	115.08	16.13	14.19	10.13	40.00	11.52
17	1977	1981	5	689.83	137.97	107.07	94.14	103.30	539.97	121.36
18	1983	1991	9	823.28	91.48	1335.45	1174.21	208.38	1744.18	730.45
19	1993	1995	3	268.62	89.54	30.32	26.66	12.18	46.82	17.64
20	1998	2002	5	662.11	132.42	107.07	94.14	89.38	445.58	109.45

Fig. 14.8 Example of drought analysis carried out on the areal precipitation series over the Simeto River basin by using REDIM software

is presented. For each drought, identified by the run method using a truncation level equal to the long term mean, the beginning and termination years, together with related characteristics (duration, accumulated deficit, intensity) and return periods for all the cases previously mentioned are determined.

Also, the spatial distributions of drought characteristics and return period of historical drought events have been investigated. An example of such application is presented in Fig. 14.9, where spatial distributions of return periods $T[L \geq l, D > d]$ corresponding to the most severe historical droughts occurred in the Simeto river basin are illustrated.

It is worth underlining that the differences in drought durations between Figs. 14.8 and 14.9 are clearly due to the fact that the first application is carried out on areal precipitation series, while the latter has been performed by interpolating local values of return periods computed on the basis of precipitation series observed in the considered 22 stations within the Simeto River basin.

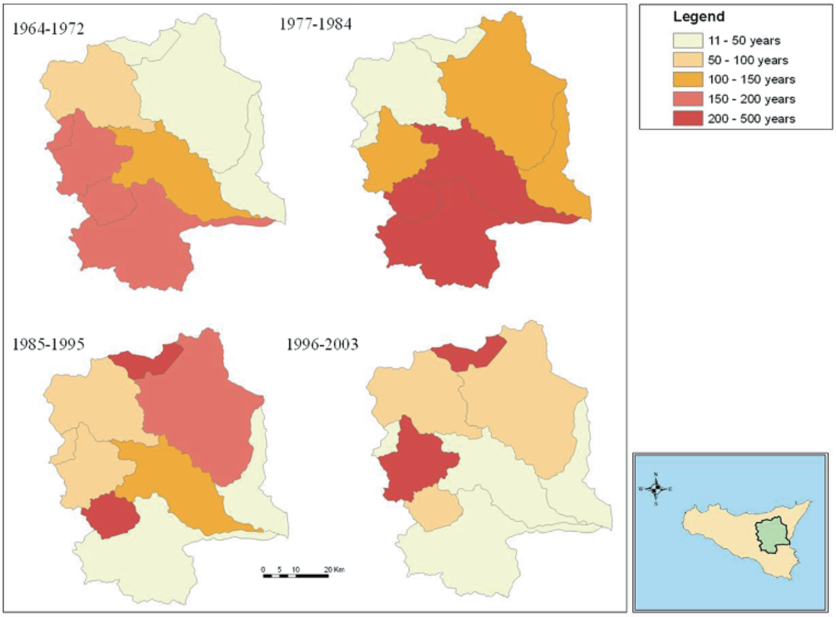


Fig. 14.9 Spatial distributions of return period T_r $[L \geq l, D > d]$ of historical droughts occurred in the Simeto River basin

Risk Assessment for Salso-Simeto Water Supply System

The methodology for the unconditional and conditional risk assessment of water shortages due to drought has been applied to the Salso-Simeto water supply system depicted in Fig. 14.10.

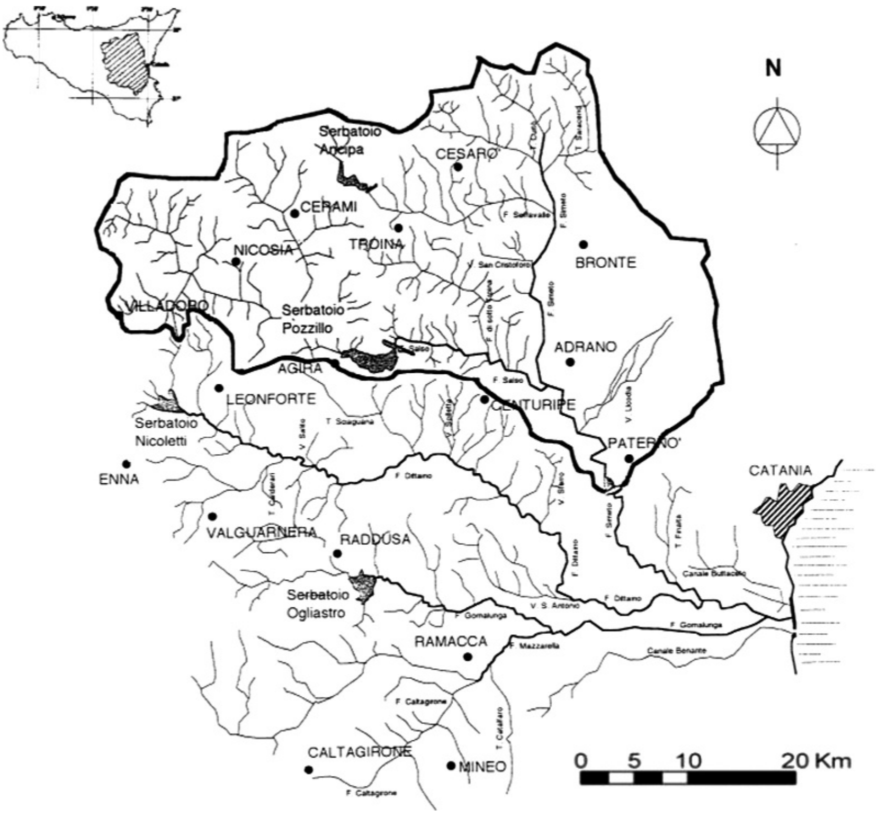


Fig. 14.10 Simeto River basin at Barca diversion

As shown in Fig. 14.11, the system under study includes two dams, Pozzillo on Salso River and Ancipa on Troina River, and one diversion located on the Simeto River. In addition, the Lentini reservoir is connected to the system via the Ponte Barca diversion on Simeto River.

Streamflow data include 42 years of reconstructed streamflows at Ancipa and Pozzillo reservoirs and Barca diversion, whereas the annual demands have been estimated as follows: demand for municipal use from Ancipa reservoir $23.5 \cdot 10^6\ m^3$/year with a constant distribution through the year, demand for irrigation uses $121.4 \cdot 10^6\ m^3$/year and $3.4 \cdot 10^6\ m^3$/year for Catania Plain (LRC9) and Enna (LRC6), unevenly distributed during the irrigation season from May to October. Furthermore, instream flow requirements (IFR) equal to 9.1, 6.4 and $39.1 \cdot 10^6\ m^3$/year downstream of Pozzillo and Ancipa dams and Barca diversion respectively have been also considered.

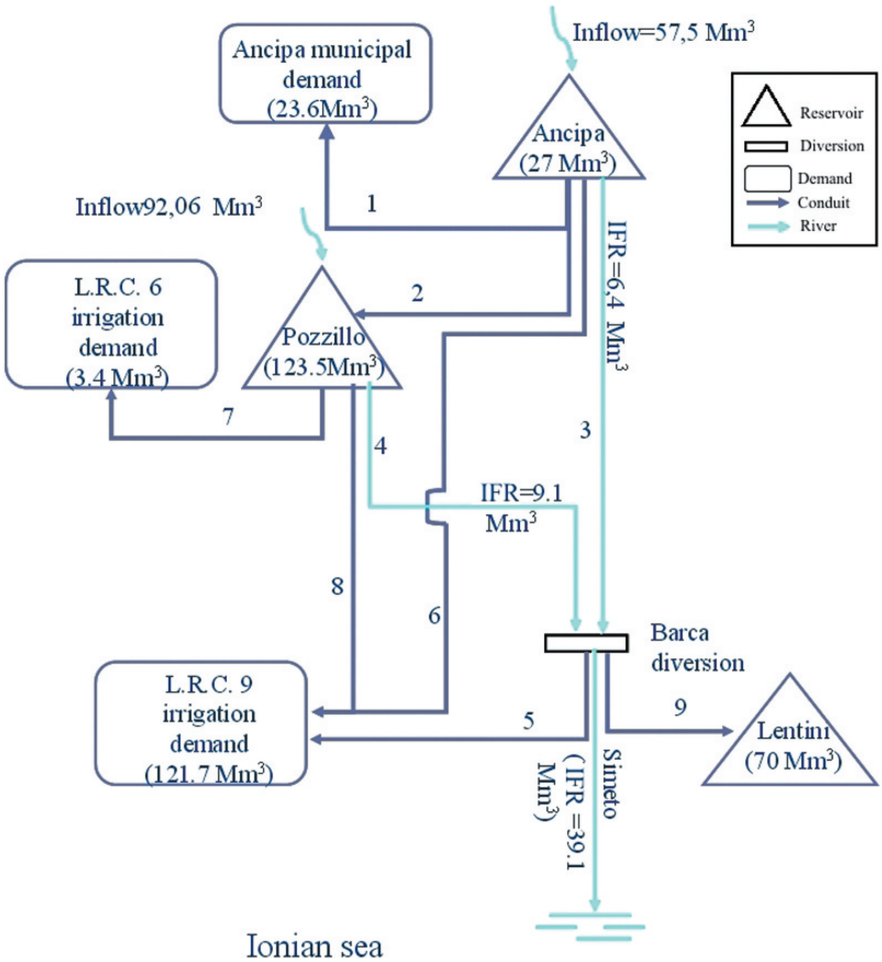


Fig. 14.11 Salso-Simeto water supply system

Stochastic Generation of Streamflow Series for the Salso-Simeto Water Supply System

In Fig. 14.12, the lag 0 monthly cross correlations between the three streamflow series (Pozzillo inflows, Ancipa inflows and Barca streamflows) are shown. From the figure, where the confidence limits under the no correlation hypothesis are shown by dashed lines, it can be inferred that in several months the series exhibit a significant cross correlation, while in others 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. Generation of synthetic streamflow data has been performed by means of the software SAMS (Sveinsson et al., 2003).

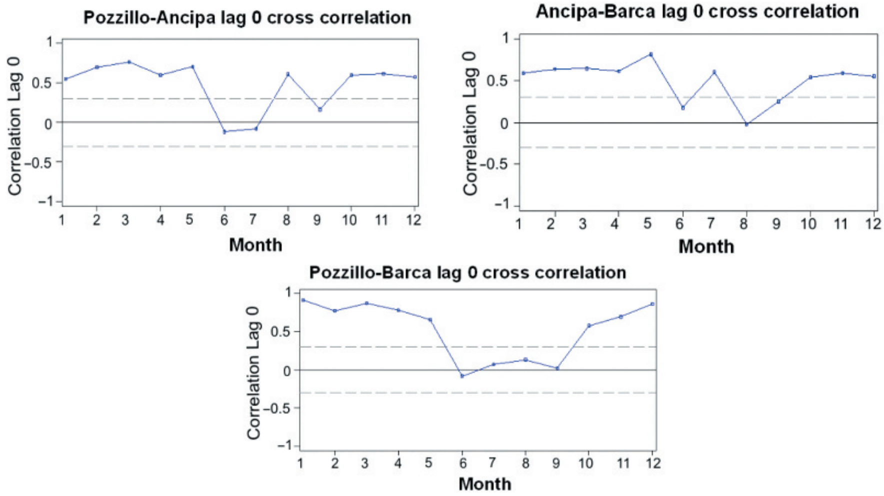


Fig. 14.12 Lag 0 monthly cross correlations between the three investigated series

Then, the proposed generation scheme is as follows:

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

$$X_\nu = (X_\nu^* + a)^b$$

where X_ν^* is the original (untransformed) data at year ν, X_ν 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.

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

$$\underline{X}_\nu = \underline{GX}_{\nu-1} - \underline{L}\varepsilon_\nu$$

where $\underline{X}_\nu$ is the vector of the values at year ν at the three sites, G and L are square matrices (in our case 3x3), and e_ν is a vector of white noise.

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

$$\underline{Y}_\nu = \underline{AX}_\nu + \underline{B\zeta}_\nu + \underline{CY}_{\nu-1}$$

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

In Table 14.4, 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 14.4 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
$\rho(1)$	−0.03	0.06	0.13	0.15	−0.08	0.01
$\rho(2)$	−0.16	−0.08	0.02	−0.06	−0.04	−0.05

Simulation of the Salso-Simeto Water Supply System

Simulation of the system has been carried out by means of the software SIMDRO (Cancelliere et al., 2006), 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 uses are represented by numbered nodes whereas system connections are represented by links characterized by origin node (source) and final node (source or use).

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 different possible drought mitigation measures defined by the user correspond.

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

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 (or from alert to alarm), behaving as previously defined by the user, namely making effective the planned drought mitigation measures.

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

- priority of demands;
- priority of sources to meet a specified demand;
- maximum release in a given month;
- maximum in-stream ecological release for a given month;
- minimum stored volume on reservoirs under which not consider low priority demands;

- demands and their monthly distribution;
- level of rationing for each demand.

The general aim of the planned mitigation measures could be to impose small deficits in the present in order to reduce the risk of larger deficits in the future.

For the Salso-Simeto water supply system the simulation in normal conditions has been performed according to the following operating rules:

- Target storages are imposed at Pozzillo and Ancipa reservoirs, such that no water is released if the stored volume is below the target, with some exceptions. In Fig. 14.13, the monthly target storages at Pozzillo and Ancipa are shown.
- 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).
- A water transfer up to $8 \cdot 10^6$ 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 ($24 \cdot 10^6$ m^3).
- Instream flow requirements are released from the reservoirs and the diversion, unless the upstream inflow in the time interval is less. In this case, the whole available streamflow is released.
- During the winter months, a water transfer from Barca to Lentini is activated up to $11.7 \cdot 10^6$ m^3/month.

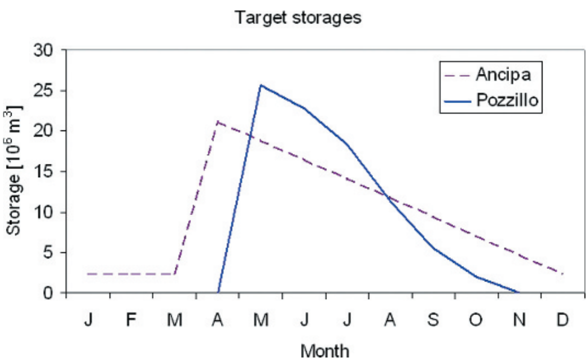


Fig. 14.13 Target storages at Pozzillo and Ancipa reservoirs

Alert and alarm conditions are activated by comparing the total storage in Pozzillo and Ancipa with triggering levels, shown in Fig. 14.14. In particular the following measures are adopted in case of:

Alert conditions:

- Relax target storage requirement for municipal
- Restrictions on irrigation use;
- No irrigation release from Ancipa;

Alarm conditions:

- As Alert + relax instream flow requirement.

Fig. 14.14 Triggering levels for normal, alert and alarm conditions

Unconditional Risk Assessment of Water Shortages Due to Drought

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 measure has 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 previously mentioned. Simulations have been carried out with reference to 500 generated series with the same length of the historical one (42 years).

In Tables 14.5 and 14.6, 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: municipal use (Ancipa aqueduct) and irrigation use (LRC9) respectively. From each table, the comparison between the system performances with or without mitigation measures can be inferred.

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 indices just mentioned 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 14.5 Performance indices for municipal use (Ancipa aqueduct). Simulation on generated series

Ancipa aqueduct						
	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 14.6 Performance indices for irrigation use (LRC9). Simulation on generated series

LRC9						
	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

Table 14.6 shows that basically average shortage period length and maximum monthly shortage indices are slightly affected by the implementation of the drought mitigation measures, while temporal and volumetric reliability show very slight increases; on the contrary maximum annual shortage and sum of squared shortage indices are likely to decrease (5% for the first and about 18% for the latter) due to the relaxation of the target storage requirements for municipal use, implemented as mitigation measure both in alert and alarm conditions in order to make more water available for irrigation use.

Figure 14.15 shows monthly frequencies of shortages for municipal use 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 an occurrence probability, expressed in terms of frequency of shortage, of about 0.05 with a peak for April of about 0.1, while almost no shortages appear from September to February.

Figure 14.16 shows the same type of results of Fig. 14.15 for the simulation implementing drought mitigation measures triggered by the defined hydrological states. The occurrence probabilities in the period from 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 from September to February shows shortage belonging to the class of less than 25% and

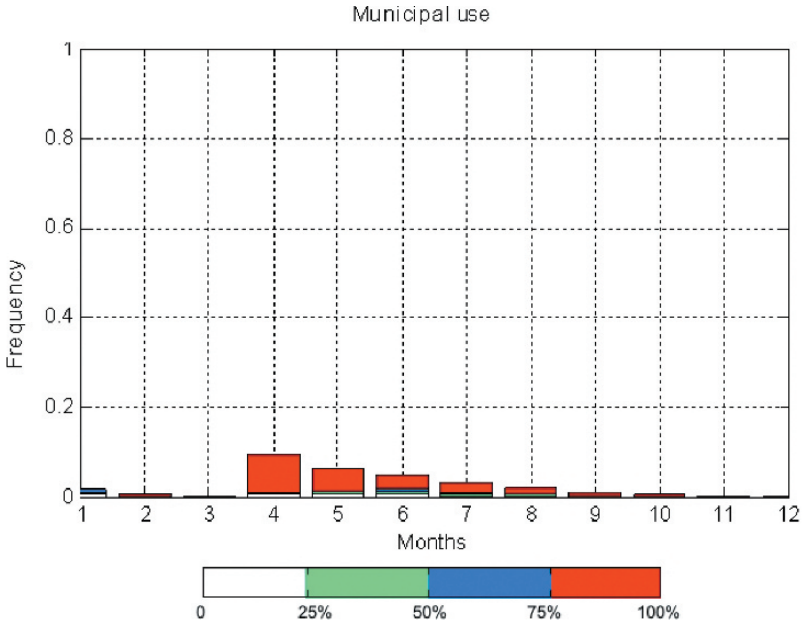


Fig. 14.15 Monthly frequencies of shortages for Enna municipalities (simulation without mitigation measures)

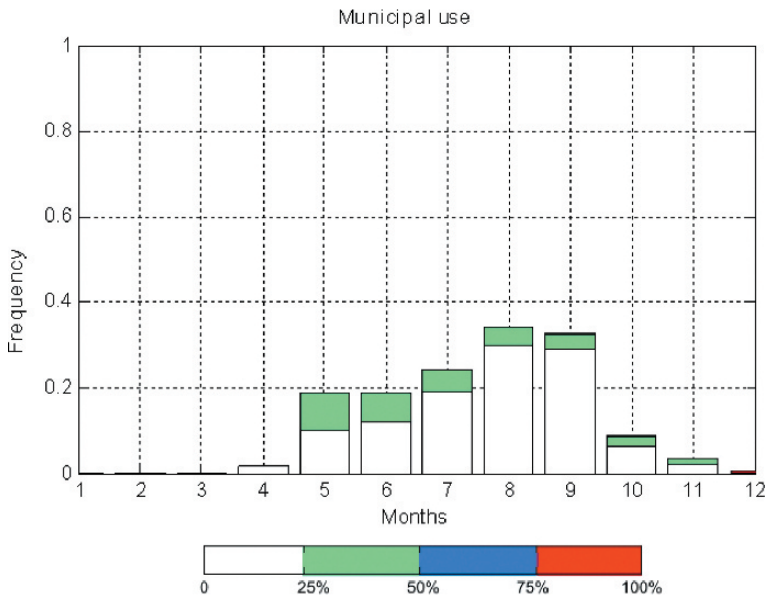


Fig. 14.16 Monthly frequencies of shortages for Enna municipalities (simulation with mitigation measures)

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.

Figures 14.17 and 14.18 show for the irrigation demand the same kind of behavior obtained for the municipal one. 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. 14.17 shows shortages greater than 75% of the irrigation demand, while Fig. 14.18 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.

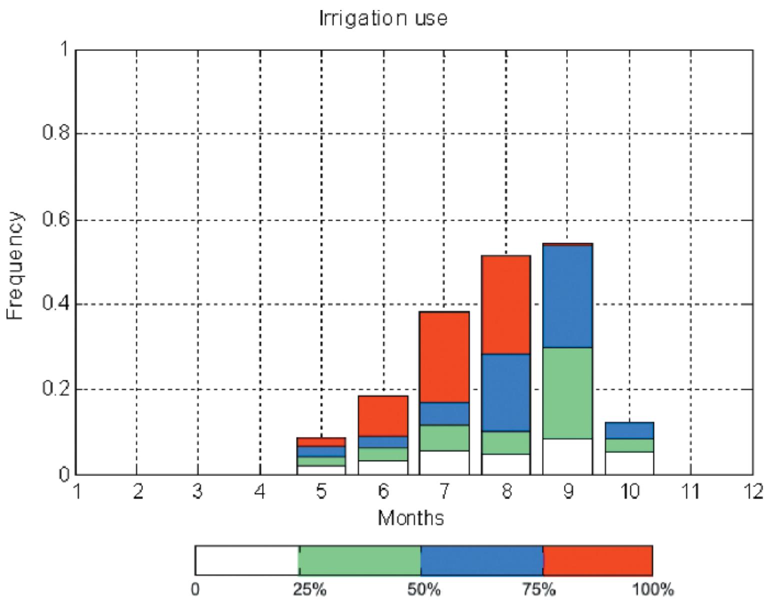


Fig. 14.17 Monthly frequencies of shortages for LRC9 irrigation use (simulation without mitigation measures)

Figure 14.19 shows sample frequencies of monthly shortages for the municipal demand as a result of simulations using generated series with and without mitigation measures. As depicted in Fig. 14.19(a) simulations without mitigation measures produce almost the same probability for shortages of large or small entity whereas Fig. 14.19(b) shows that, implementing mitigation measures, monthly shortages of more than 50% of municipal demand are very unlikely, even if shortages of minor importance are more frequent than in the case without mitigation measures.

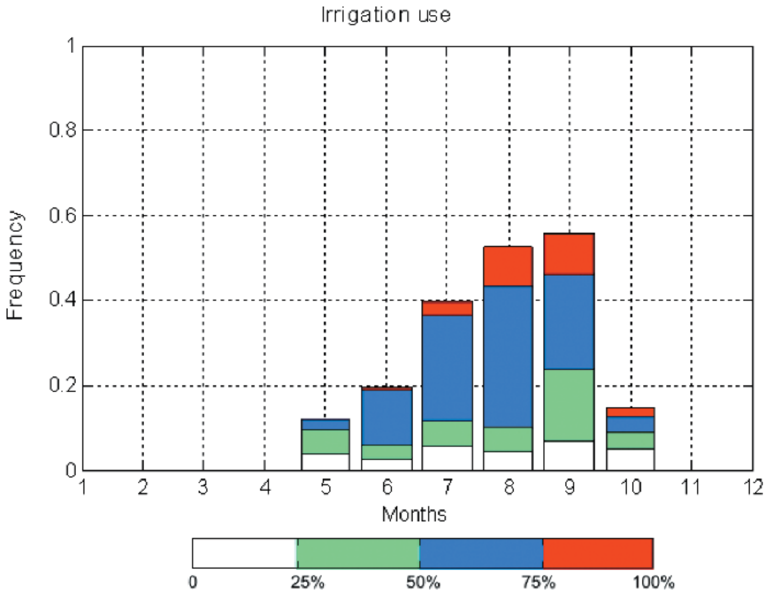


Fig. 14.18 Monthly frequencies of shortages for LRC9 irrigation use (simulation with mitigation measures)

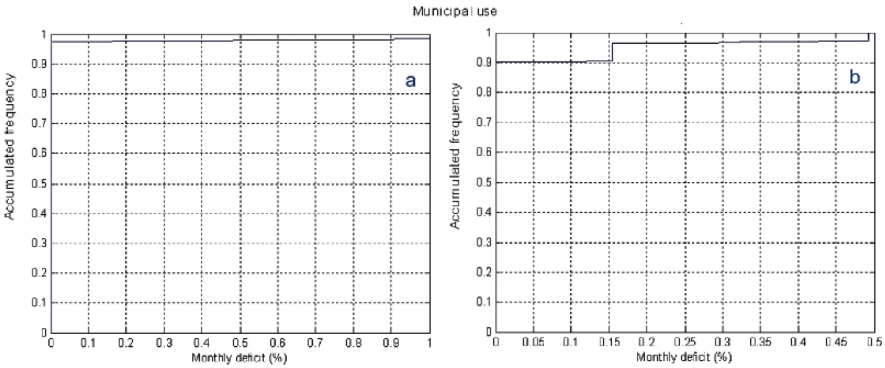


Fig. 14.19 Sample frequencies of monthly shortages for municipal use (simulation (a) without and (b) with mitigation measures)

Sample frequencies of monthly shortages for irrigation demand (LRC9) reported in Fig. 14.20, respectively for simulations without and with mitigation measures, show almost the same pattern except for a step with shortages of about 67% of the irrigation demand, that goes from an accumulated frequency of about 0.91 to 0.97 for the case with mitigation measures. Again, implementation of mitigation

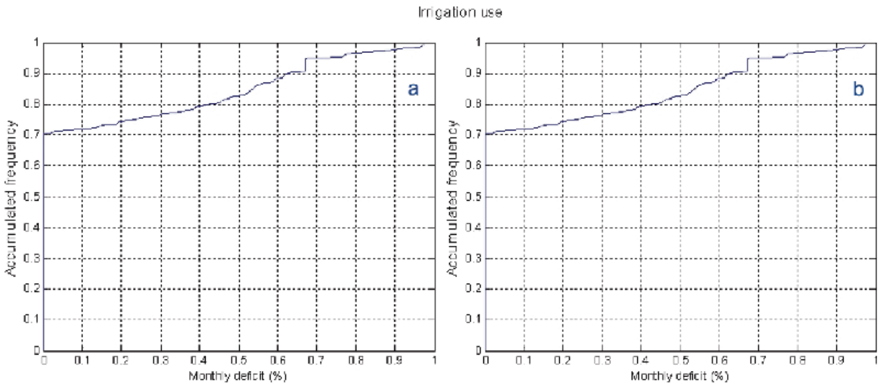


Fig. 14.20 Sample frequencies of monthly shortages for irrigation use (simulation (a) without and (b) with mitigation measures)

measures has reduced the occurrence of large shortages, leaving substantially unchanged non-exceedence probabilities of smaller shortages.

The two curves of Fig. 14.21 show return periods 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.

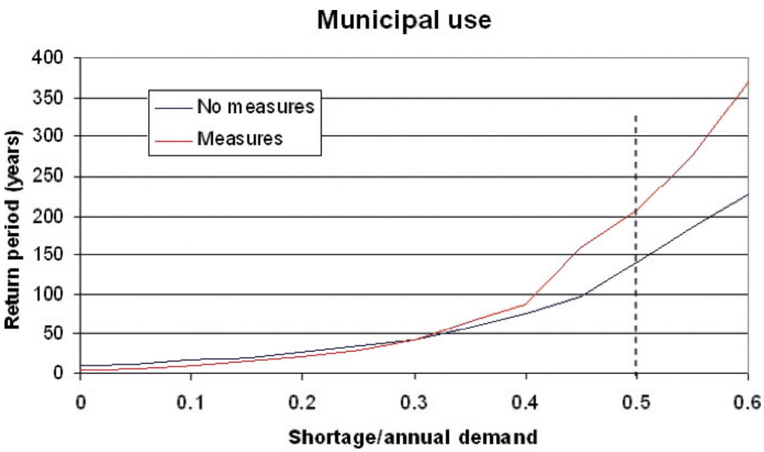


Fig. 14.21 Comparison between return period of annual shortages for municipal use simulating without or with mitigation measures

Conditional Risk Assessment of Water Shortages Due to Drought

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 shortages in irrigation and municipal demands started in 1989.

In order to perform the conditional risk assessment and to verify the goodness of the proposed mitigation measures, two 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 of the actual state of the system. The second simulates 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 conditions and the relative mitigation measures (see Fig. 14.14).

Figure 14.22 shows the frequencies of shortage in municipal use for 36 months ahead, starting by the condition of the system of March 1989 for the two above mentioned management criteria.

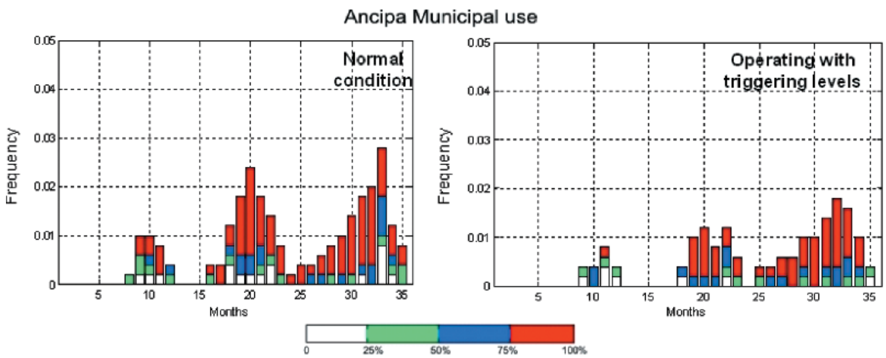


Fig. 14.22 Frequency of shortage in municipal use in the 36 months following March 1989

From the figure it can be inferred that, if the system is managed following the policy typical of normal condition, greater and more frequent shortages appear with respect to those obtained in the case of operating the system with triggering levels.

Figure 14.23 shows the frequencies of shortage on irrigation use 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 use as required by law.

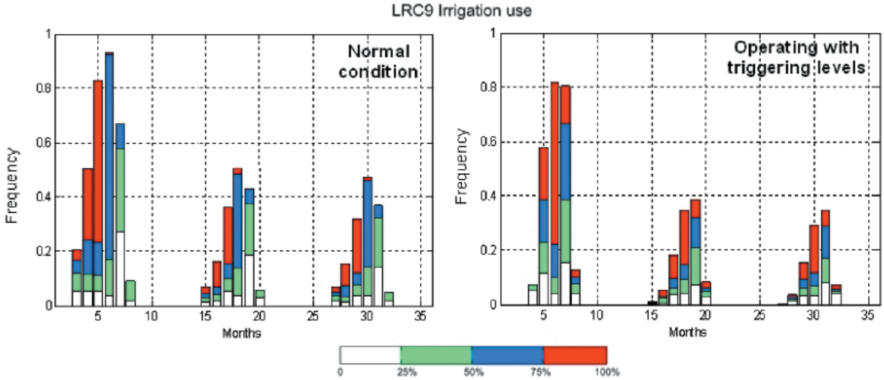


Fig. 14.23 Frequency of shortage in irrigation use in the 36 months following March 1989

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 use. Similar considerations can be drawn for the alarm conditions case.

On the contrary activation of migration measures does not gives good results for irrigation use as shown by Fig. 14.23. However, goodness of chosen mitigation measures is confirmed by the general reduction of the probability to have deficits during the future 36 months under investigation, and from the fact that in general the probability to have large deficits is decreased.

Results obtained by operating with triggering levels are better than those obtained by the simulation of the system always in normal condition. Indeed, the overall probability of deficits and their amount is less for both uses if the system is operated with triggering levels activating mitigation measures based on the provided thresholds.

The following Tables 14.7 and 14.8 report performance indices of the system calculated for the simulations in the two operational conditions considered. All indices, calculated as mean of indices obtained for each of the 500 simulations done,

Table 14.7 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)
Ancipa aqueduct (municipal use)	99.2	99.4	0.21	0.09	0.33	0.56
Irrigation use (LRC9)	65.3	75.5	2.90	16.97	36.33	756.22
Irrigation use (LRC6)	96.3	96.5	0.55	0.11	0.21	0.097

Table 14.8 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)
Ancipa aqueduct (municipal use)	99.5	99.6	0.14	0.06	0.21	0.33
Irrigation use (LRC9)	75.8	82.4	2.42	14.8	29.0	570.25
Irrigation use (LRC6)	86.8	91.5	1.36	0.28	0.42	0.18

provide a better performance when the system is managed by triggering levels either for municipal use and irrigation use (LRC9).

Satisfaction of irrigation use at LRC6 is penalized by the mitigation measures in comparison to the larger LRC9 irrigation use, because it can rely on alternative sources that are insufficient for LRC9.

Indices obtained operating the system with triggering levels 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 to follow pre-constituted operating rules.

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

Drought Damages 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 severe and often all or part of the crop production is lost.

Irrigation is, clearly, the best way to cope with the climatic variability, although in the farms or districts supplied by surface water the impacts of droughts can also be very severe. In the farms supplied by groundwater, drought impacts are almost negligible for events lasting a short amount of time. For long drought periods, the impacts are related to the decreasing of the water tables levels. 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 by a land reclamation consortium, the impacts are related to water resources available during the drought period. 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 requested by farmers. 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 assessed damage reaches a given percentage (30% according to the Legislative 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". 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 insurance is supplied to the Regional Government and then to Provincial Agricultural Offices, which are in charge of building new infrastructures and/or allocating funding to the farmers for insurance.

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. 14.24.

The sample series of the areal rainfall with respect to the cultivated 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 has been determined by considering a weighted average among the intersections between cultivated areas and relative polygons. Finally, the corresponding SPI series have been calculated for fixed aggregation time scales k.

In particular, 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, for cereal, precipitation occurring from October to December is essential for the sowing, as well as precipitation from March to May, after which plants are not able to complete the crop cycle. Therefore, for this case, it can be useful considering SPI values in May with an aggregation time scale of 7 or 8 months, or in January with an aggregation time scale of 3 or 4 months.

As an example, in Fig. 14.25 a preliminary comparison between SPI values and the contemporary percentage of damages on cereals for Catania province is presented. It is easy to observe that, even if there is a good agreement for $k = 3$ months, however there is no direct proportionality between percentages of damages and SPI values for $k = 7$ months. This can be partially due to the fact that drought impacts

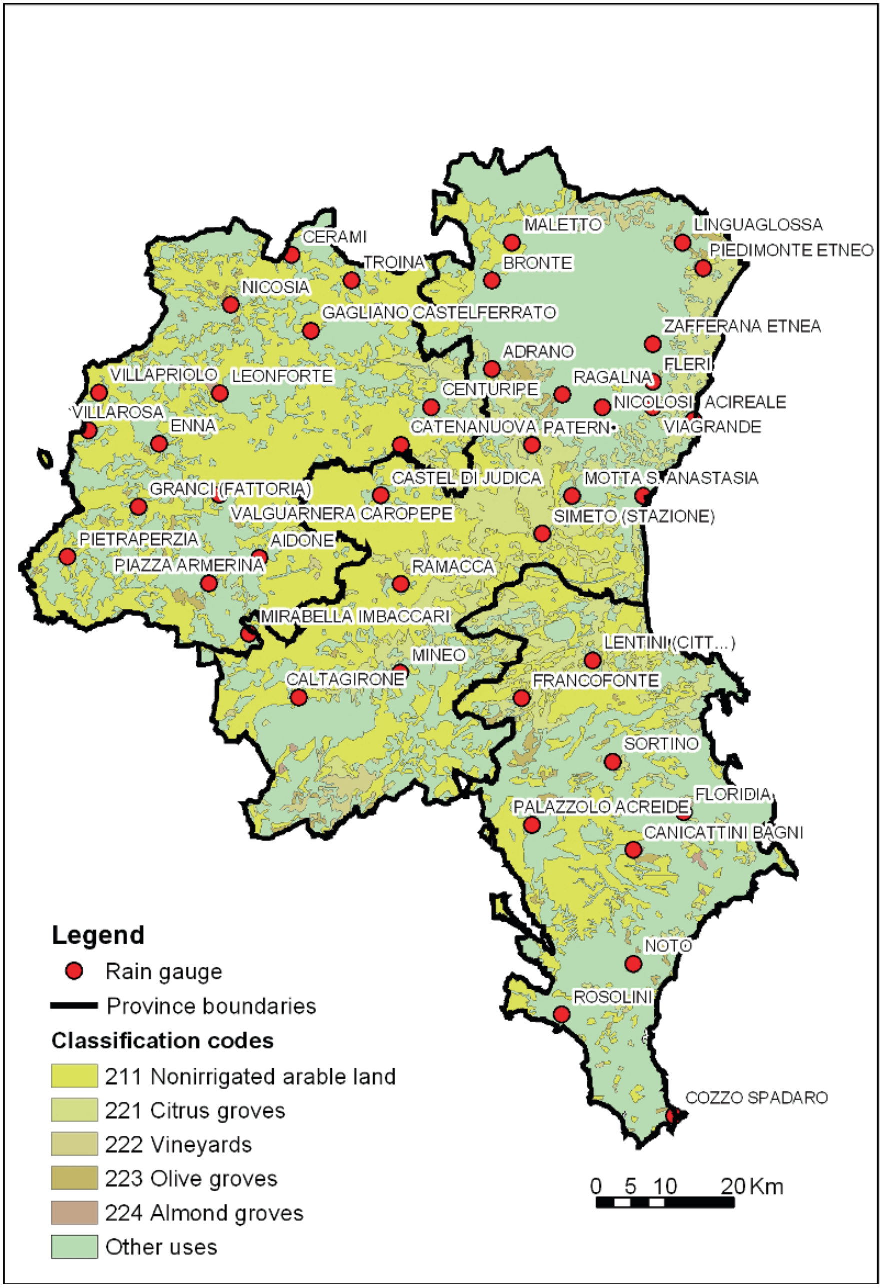


Fig. 14.24 Rain gauges and soil use for the provinces of Catania, Siracusa and Enna

on agriculture are roughly assessed, and in some cases they might be artificially increased in order to overcome the threshold for obtaining refunds according to current legislation.

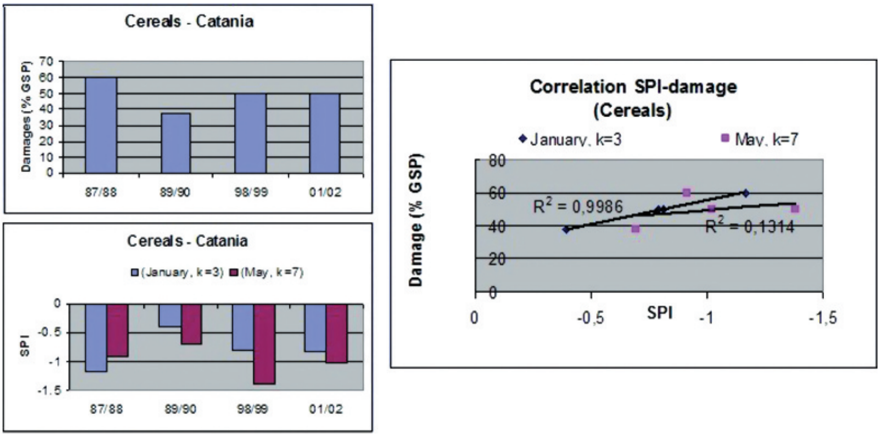


Fig. 14.25 Comparison between SPI and drought impacts on cereals for the province of Catania

Drought Mitigation Measures for the Simeto River Basin

The measures to mitigate drought impacts can be classified in several ways (Rossi, 2000). A first classification (Yevjevich et al., 1978) refers to three main categories: i) water demand oriented measures, ii) water supply oriented measures, iii) drought impacts oriented measures. The first two categories of measures aim to reduce the risk of water shortage due to a drought event, while the third category is oriented to minimize 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 that a drought occurs and its impacts are perceived, which aim to minimize drought impacts. 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:

- 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;

– short-term actions, which try to face an incoming 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, namely urban, agricultural, industrial, recreational and environmental, should also be distinguished.

Among the main actions undertaken at regional level, it is worth mentioning the activities carried out by the Water Observatory of the Sicilian Regional Agency for Waste and Water, formerly the Regional Technical Hydrographic Service of Sicily (STIR). 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, a web-based monthly bulletin for drought monitoring has been developed by the Department of Civil and Environmental Engineering of Catania University for STIR, 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 drought preparedness. In Fig. 14.26, the home page of the drought bulletin for Sicily is shown.

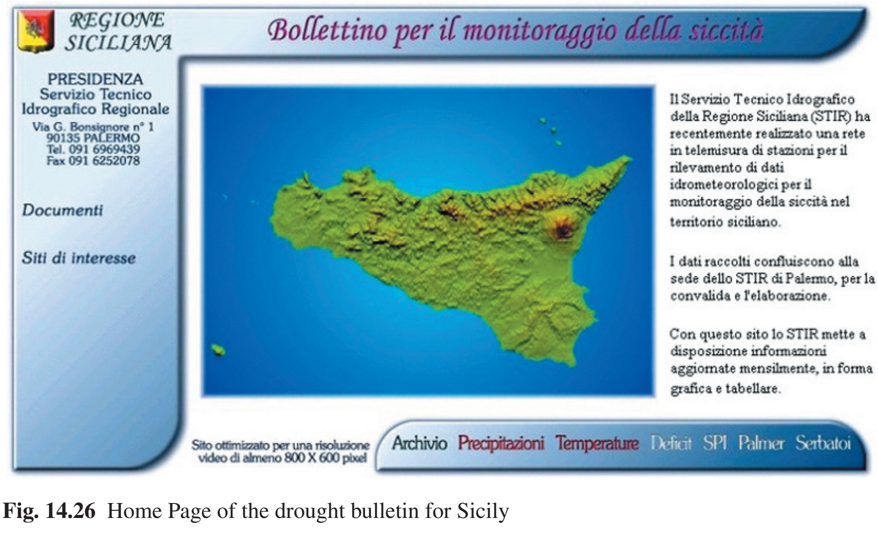


Fig. 14.26 Home Page of the drought bulletin for Sicily

Moreover, campaigns for increasing population awareness to water saving, either at municipal and regional level, have been promoted by the Sicilian Regional Government.

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:

- diversion and reallocation of surface water resources (stored in Ancipa reservoir) normally devoted to irrigation use;
- increase of groundwater withdrawal from wells for municipal use;
- use of groundwater withdrawal from 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:

- 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;
- maintenance of canal networks for reducing water losses;
- projects to transform the canal network (conveyance and distribution) in pipelines;
- projects of emergency pumping plants of surface water stored in Lentini reservoir (currently not operational);
- projects of public ponds to improve the operation of irrigation systems.

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

- collecting and saving rainfall (deep labour in summer, minimum tillage and weeding during the crop cycle, optimal planting and sowing, etc.);
- 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 growing period, etc.).

In irrigated agriculture private farmers have implemented two different types of mitigation measure to cope with drought consequences:

- 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 the consortium before the irrigation season starts and/or from private wells);
- reduction of irrigated areas for annual crops.
- measures for coping with water shortage
- 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. However, it should be underlined that such benefits have been insufficient to cover the actual damages during the past drought periods (see Table 14.9).

Table 14.9 Past actions to mitigate impacts in agriculture at state/regional level (financial measures to the farmers)

Province	Grant			Loan with 40% of grant			Five years loan		
	Amount requested (10^6€)	Amount provided (10^6€)	%	Amount requested (10^6€)	Amount provided (10^6€)	%	Amount requested (10^6€)	Amount provided (10^6€)	%
Catania	50.378	0.743	1.5	–	–	–	–	–	–
Siracusa	34.000	4.282	12.6	14.818	3.611	24.3	9.915	2.512	25.3
Enna	31.169	6.475	21.8	14.269	5.364	37.6	12.640	2.163	17.2

Conclusions

The key issue for implementing an efficient drought management strategy should consist of the following steps: planning, monitoring and forecasting, implementation of mitigation measures planned in advance, management of emergency situations not foreseen during the planning process and recovery of drought damages.

In particular, drought monitoring and forecasting systems, able to promptly warn of the onset of a drought and to follow its evolution in space and time, as well as risk assessment procedures based on Montecarlo simulation of water supply systems under different scenarios, can help decision makers to timely select and implement appropriate measures to mitigate drought impacts on the water supply systems, the productive sectors and the environment.

In this chapter, applications of proposed methodologies for drought identification and characterization, risk assessment and risk management for water supply systems of the Simeto River basin in Sicily have been presented. More specifically, a detailed analysis of drought periods occurred in the Simeto River basin and related characteristics has been carried out by making use of SPI, PHDI and Run Method. Results show that the most critical droughts have been observed between mid ‘80s and the beginning of the ‘90s, and the end of the ’90s and 2003.

Also, return periods of historical droughts occurred in the Simeto River basin, have been computed based on the probability distribution of the underlying hydrologic series and the truncation level adopted for drought identification through the Run Method. Results have highlighted that drought occurred between the mid 80s and the beginning of the 90s has been the most adverse event observed in the period 1921–2003. Moreover, spatial distribution of return periods of some of the most severe historical droughts occurred in the Simeto River basin has enabled drought prone areas to be identified within the basin.

With reference to the methodology for the unconditional risk assessment, aiming at comparing and selecting preferable mitigation alternatives through the Montecarlo simulation of water supply systems over a long time horizon (30–40 years), application to the Salso-Simeto system has shown that it is possible to globally reduce higher monthly shortages by implementing mitigation measures. In addition, the methodology for the conditional risk assessment, performed through Montecarlo simulation with respect to a shorter time horizon (2–3 years) by taking into account the initial state of the system, represents a valuable tool which enables water managers to adapt managing rules to the real conditions of the water supply system by using appropriate triggering levels activating mitigation measures planned for worsening conditions of the system with regard to drought (Normal, Alert and Alarm).

Besides, an attempt to evaluate the risk associated to drought events in rainfed agriculture has been carried out, in terms of a preliminary comparison between SPI values and the contemporary percentage of damages on cereals for Catania province. Unfortunately, no direct proportionality between percentages of damages and SPI values can be inferred because drought impacts on agriculture are roughly assessed, and in some cases artificially increased in order to overcome the threshold for obtaining refunds according to current legislation.

Finally, the analysis of past actions to mitigate drought impacts both in the urban and agricultural sectors shows a prevailing recourse to emergency measures, some of which of structural type, with the purpose of increasing water supply, even though several projects have already been proposed aiming to reduce drought vulnerability of current systems, mainly in irrigated agriculture.

References

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

Cancelliere A, Rossi G, Nicolosi V M (2006) Valutazione del rischio di deficienza idrica dovuta a siccità in sistemi di approvvigionamento, Proceedings of the XXX Convegno di Idraulica e Costruzioni Idrauliche IDRA 2006, Rome, 10–15 September 2006.

Cancelliere A, Nicolosi V M, Rossi G (2009) Assessment of drought risk in water supply systems, *in this book*.

McKee T B, Doesken N J, Kleist J (1993) The relationship of drought frequency and duration to time scales, 8th Conference on Applied Climatology, Anaheim, California, 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, Vogt, J V, Somma F (eds.), Kluwer Academic Publishers, The Netherlands, pp. 233–246.

Rossi G, Cancelliere A (2003) At site and regional drought identification by REDIM model, in Rossi G, Cancelliere A, Pereira L, Oweis T, Shatanawi M (eds.), Tools for Drought Mitigation in Mediterranean Regions, Kluwer Academic Publishers, Dordrecht, pp. 37–54.

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

Salas J D, Fu C, Cancelliere A, Dustin D, Bode D, Pineda A, 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, 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, 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, Hall W A, Salas J D (1978) Proceedings of the Conference on Drought Research Needs, Water Resources Publications, Fort Collins, 276p.

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