RESEARCH PAPER

A Probabilistic Model to Assess Surface Irrigation Water Resources

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Abstract

J.M. Molina, L.A. Gurovich and E. Varas. A probabilistic model to assess surface irrigation water resources. This paper outlines a probabilistic modeling proposal of the components and processes involved in surface water availability and demand of an irrigation system of Chile’s central zone. The objective is aimed to develop a methodology for field water balance studies oriented to optimize available water resources allocation. The model includes relevant variables related to soil, crop, water availability, climatic data and hydraulic infrastructure. Hydrologic modeling tools are used for estimating water availability, describing time and spatial variation of surface water resources. A probability distribution model is applied for estimating flow rates associated to occurrence probabilities. Also, a time and spatial model for water requirements for the irrigation system studied has been developed, calculating different probabilities of excedence based on the Penman-Monteith equation, recently adopted and recommended by the FAO for the calculation of the reference crop evapotranspiration. The simulation model developed, is used both to obtain a better knowledge about the irrigation system actual situation and its water supply confidence, as well as for the evaluation of future situations and alternatives to promote the efficient use of water resources and optimize surface water availability.

Key words: Irrigation water requirements, water balance, water resources.

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INTRODUCTION

The competition for water resources in Chile between the urban sector, electric energy generation and industry consumption, recreational activities and agricultural use, is a growing concern for sustainable economic development Irrigated agriculture is the main water, user most of the time in a rather unefficient way. This has an important environmental, social, and economic impact, specially in drought years (Gurovich, 1999); to minimize this negative impact, tools are needed that enable water user’s associations to administer this resource on the basis of its historical spatial and temporal dynamics of effective supply and demand (ECLAC, 1999). These tools are indispensable to design and implement comprehensive management measures to optimize water resources.

In this article a probabilistic model to assess surface irrigation water supply and crop water requirements, associated to irrigation system water flow capacities is described; the model is

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used to represent and typify actual and future irrigation situations, calculating the magnitude, frequency, and distribution of water deficits, as related to different supply scenarios.

MATERIALS AND METHODS

The model developed in this study was applied to an irrigation system of the central zone of Chile, including grapevine (*Vitis vinifera* L.) production, both in areas irrigated with conventional surface techniques and with pressurized irrigation systems. The study include quantitative descriptions of water diversion, conduction, flow control, and application through existing irrigation systems, taking into account available and future infrastructure characteristics required to optimize water resource use. The model is based on continuity and mass balance equations, applied to system elements concerning water supply and demand; also, it makes use of a probability distribution model for the analysis of climate and water flow random variables, based on Penman–Monteith's model adopted and recommended by FAO, to calculate the evapotranspiration of the reference crop (Smith *et al.*, 1998; Allen, *et al.*, 1994).

Modeling the supply and water requirements

Modeling water supply is developed with three different approaches: 1. Analysis of Maipo River and its main canals hydrology, 2. Water supply modeling and 3. Analysis of a tertiary water irrigation system at farm level (DGA, 2000; DICTUC, 1999; Shahin, 1993). A two parameter LogNormal model is used, to associate values of occurrence probability with different values of median monthly water flow at the sources. Equation (1) enable calculating values of water flow associated to different probabilities.

$$X_T = \mu + K_T \cdot \sigma \qquad (1)$$

This model distributes a random variable X_T as a function of model parameters (average μ and standard deviation σ for the original variable). The frequency coefficient K_T function for the probability of ocurrence is associated to a normal distribution curve and to the coefficient of variation (Cv) of the to original variable in the respective monthly series (Shahin, 1993). The factor of frequency K_T of (1) was calculated using the following equation:

$$K_T = \frac{1}{Cv}\left(\exp\left[-\frac{1}{2}Ln(1+Cv^2)+z_T\sqrt{Ln(1+Cv^2)}\right]\right) \qquad (2)$$

The availability of surface irrigation water in the tertiary system canals is spatially and time estimated by means of a water supply model, based on available records for average monthly main canal's discharge, internal canals' water rights on main water delivery systems, information on flow control within the irrigation network, water conduction losses and recoveries in lower level canals. The analysis focuses on grapevine seasonal development (August-April), defining 10-day water supply periods by means of a data linear interpolation function. Monthly water flow series are estimated for the internal canals, considering several probabilities of occurrence, in the range of 1 to 95%.

Probable flow estimation in the internal canals with the Lognormal model, is defined considering correlation analysis between the yearly and monthly river flow hydrograms and water flows measured of the main canals; represented a proportion of the flow described by the river hydrograms. Water supply patterns consider nodes and sections. The sections were: 1. The main canal, 2. The secondary canal and 3. The internal or tertiary canal. Nodes corresponded to canal water intakes, water division hydraulic structures (flumes) and canal conducting hydraulic sections (Figure 1).

The theoretical framework used to quantify the uptake, extraction, losses and recovery of the elements on the irrigation network, consisted in applying the equation of continuity at several nodes and stretches of water, from the water intakes at the main canals up to the internal canals of the tertiary system.

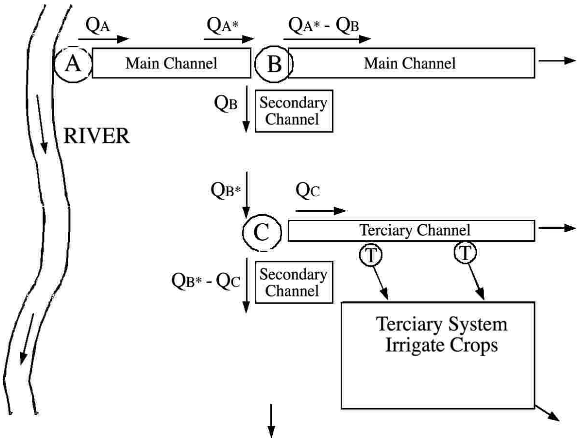


Figure 1: Schematic representation of the hydraulic net. QA is the main channel discharge at water inlet A; QB secondary channel discharge, measured at point B, on the main channel. QC is the tertiary channel discharge measured at point C, QAs is the channel flow measured at point B, considering water losses and recuperations in the main channel, QB* is the flow at point C, considering water losses and recuperations in the secondary channel. Water losses and recuperations in the tertiary channel are included in the outflow model at point C.

Figure 2 represents the model proposed for any section element of the irrigation network, and equation (3) represents the equation of continuity.

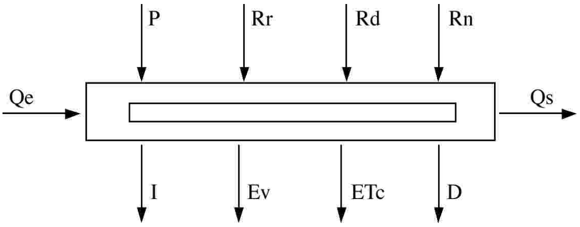


Figure 2: Modeling an hydraulic net component. Qe is the surface flow at the starting point, P is the effective precipitation, Rr represents flow recuperations from rainfall, Rd are recuperations from water spills from unregulated sources, Rn are water recuperations from the water table, Qs is the channel discharge at the final point considered, I are water losses from infiltration and deep percolation, E is direct evaporation from the net component, Etc is canopy evapotranspiration from areas surrounding the net component, D are water losses from spills and ΔV/Δt is the change in water storage in a specific time interval.

$$Qe + P + Rr + Rd + Rn = Qs + I + Ev + ETc + D \pm \frac{\Delta V}{\Delta t} \qquad (3)$$

at each section, determined by:

$$Qe = Qs + Qd \qquad (4)$$

The general variables of the water supply model defined in (3), are affected by the percentages of flow by percolation, spills and recovery of the various canals. Based on the probability and statistical series analysis for water availability in the internal canals, it is possible to establish the contribution and variations of probable flows of each canal in the crop season. The information obtained allow to analyze the behavior of water balance in the different scenarios considered in the simulation, especially in the events of water supply with a high probability of occurrence, that typify the driest hydrological years.

FAO has recommended the use of Penman-Mornteith equation to estimate reference crop evapotranspiration ETo (Smith *et al.*, 1998). Using average or daily monthly weather data, the expression of Penman-Mornteith was simplified according to:

$$ETo = \frac{0,408\,\Delta(R_n - G) + \gamma \frac{900}{T + 273} U_2(e_s - e_a)}{\Delta + \gamma(1 + 0,34U_2)} \qquad (5)$$

where ETo = reference crop evapotranspiration [ETo, (mm^{-1})], Rn = net radiation at the crop surface [Rn, (MJ $m^{-2}\cdot d^{-1}$)], G = fground heat flow [G, (MJ $m^{-2}\cdot d^{-1}$)], T = air temperature average [T, (°C)], U2 = wind speed, measured at 2 m. [U2, ($m\cdot s^{-1}$)] = saturation vapor pressure [ea, (kPa)], ea = actual vapor pressure [ea, kPa], Δ = slope of the vapor pressure curve [Δ, ($kPa\cdot{}^{o}C^{-1}$)], γ = psychometric constant [γ, ($kPa\cdot{}^{o}C^{-1}$)] and 900 = a conversion factor.

Weather information

Monthly information available at a weather station located at Pirque, Metropolitan Region in Chile, for 1985 to 1999, for average, maximum and minimum temperatures, air relative humidity, wind speed, daily sunshine hours, total evaporation and total rainfall. Using CropWat- software 4W (Clarke *et al.*, 1998; Smith, 1993), mean values of ETo for monthly periods are calculated; ETo probable monthly values are estimated with a Lognormal model and the 10 day moderation adjustment is based on the CropWat-4W software, polynomic using a adjustment tool.

Santa Rita tertiary system

The spatial and temporal modeling of water requirements at the tertiary irrigation system "Santa Rita", include information of cropping areas, soils, and irrigation systems characteristics; water demand evaluation for each decade is calculated, considering different probabilities of occurrence.

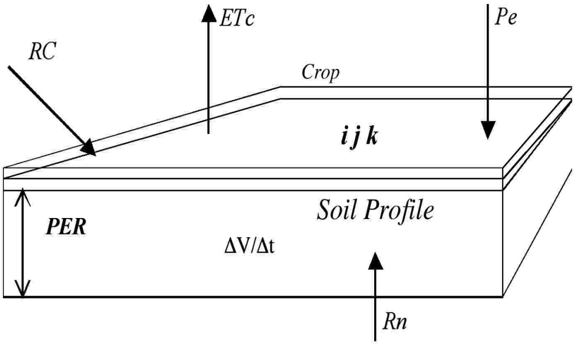


Figure 3. Modeling an homogeneous area (i j k element) in the tertiary irrigation system. I represents each area, according to its geographic location and soil type, j is the specific area, according to the irrigation system, k is the area corresponding to each vine cultivar. ETc is actual crop evapotranspiration at the ijk element, Pe is effective precipitation in the ijk element, RC is the crop water requirement at the ijk element, PER is the root effective depth in the ijk element, Rn are water inputs from the water table and ΔV/Δt are the soil water content differences for a specific time interval.

The existence of different soil types, irrigation methods and grapevine varieties, require different irrigation frequencies and water depths to be considered. Thus, simultaneous modeling of the tertiary irrigation system define a tertiary irrigation spatial subdivision system of relatively homogeneous areas, each one representing an element of the irrigation system where evapotranspiration takes place, generating a specific temporal variation of water requirements. Figure 3 shows the elements (i-j-k) and the variables involved.

The equation of continuity applied to elements i-j-k in Figure 3 is:

$$Pe + Rn + RC \quad = \quad ETc \pm \frac{\Delta V}{\Delta t} \tag{6}$$

Effective rainfall *Pe*, in the equation (6) is defined, according to Dastane, (1978), as the effective portion of the total rainfall *P* in one given period, which was used directly and / or indirectly in the production of crops and in the site where rain fell, with extraction from superficial or subterranean sources.

Kc is defined as the crop evapotranspiration coefficient (Kc = $ET_{real} \cdot ET^{-1}_{potential}$); ETc day $^{-1}$ was estimated according to equation (7) (Dorenbos and Pruitt, 1975; Smith *et al.*, 1998). The temporal variation of the Kc coefficient as a function of the crop vegetative development was proposed by FAO (Dorenbos and Pruitt, 1975).

$$ETc = Kc\, ETo \tag{7}$$

FAO evapotranspiration model, defined by equations (6) and (7), was used to calculate the spatial-temporal and probabilistic functions needed to calculate crop evapotranspiration in elements i-j-k defined in Figure 3. Equation (8), shows grapevine water requirements (RC in equation 6), expressed in mm·(10 days)$^{-1}$, with *Pexc of* occurrence probability and *d* as the order number for the decadal (10-day) period, varying between 1 and 22.7 decades. *Kcd* is the evapotranspiration coefficient for grapevine in the decadal period and *ETo* is expressed in mm per decadal period.

$$RC^{Pexc}_{d}(_{ijk}) = ETc^{Pexc}_{d}(_{ijk}) = Kc_{d}(_{k}) - ETo^{Pexc}_{d} \tag{8}$$

Crop water requirement in equation (8) is affected by the relation between the specific area of homogeneous zone, *AT*(i-j-k) and the total area cultivated in the zone of study (*AT)*. Thus, the partial rate of irrigation *TAR* ($L \cdot s^{-1} \cdot ha^{-1}$), for one decadal period *d* and for a *Pexc* specific probability, can be expressed as:

$$TAR_{d(ijk)}^{Pexc} = 1.1574 \cdot \frac{RC_{d(ijk)}^{Pexc} \cdot A_{(ijk)}}{Ea_{(ij)}} \cdot \frac{A_{(ijk)}}{A_t} \qquad (9)$$

where, Ea (i-j) is the water application efficiency experimentally determined for an irrigation system and a specific soil (Gurovich, 1978, Gurovich, 1980; IAA, 2000). The coefficient 1.1574 is a conversion factor mm·decadal period^{-1} with flow expressed in $L \cdot s^{-1} \cdot has^{-1}$.

Irrigation requirements for a homogeneous zone *RRdPexc(i-j-k)* [$l \cdot s^{-1}$], is calculated considering *TAR d Pexc(i-j-k)* from equation (9) and the specific area *AT(*i-j-k) of the element considered. The integration of partial requirements *RRdPexc*(*i-j-k*) for each one of the elements is the total irrigation requirement *RRTdPexc* [$L \cdot s^{-1}$], for one decadal period *d* and a specific probability of occurrence P*exc*:

$$RRT_{d}^{Pexc} = \sum_{i} \sum_{j} \sum_{k} RR_{d}^{Pexc}(ijk) \qquad (10)$$

The “Santa Rita” irrigation system is fairly representative of Chile agricultural central zone (33º 41` 9`` to 33º 43` 9`` southern latitude, and 70º 37`30`` to 70º 41`0`` western longitude), at 520 m over sea level, corresponded to a tertiary irrigation system of 570.3 ha of grapevine plantations destined for vinification. Current water sources are based on surface and underground aquifers at the Maipo River basin. Maipo River is originated at the Andes mountains, showing an average monthly flow (1912-1999) of 100.7 $m^3 \cdot s^{-1}$, measured at the fluviometric station La Obra, Metropolitan Region of Chile. The maximum contribution of Maipo River basin is between the December and January months, due to snow melting.

The area under study is a semi-arid Mediterranean climate (Santibañez and Uribe, 1990), with 7 to 8 dry months. Eighty percent of the yearly rainfall falls in autumn and winter (largets rainfall amounts normally occur in August), with a yearly average of 420 mm and a 50% of probability of occurrence.

In this study, the analysis consider only the surface water resources, which actually irrigate over 90% of the total cultivated area, being diverted from the Maipo River by two main canals: Huidobro and Unidos de Buin, Metropolitan Region, Chile, with two independent water intake points.

The Huidobro system also receives water surpluses from the Clarillo River. Water flow distribution between farmers is carried out according to a proportion of total river water right shares (8113) without taking into account crop water needs or the effective conduction capability of the current irrigation infrastructure (DICTUC, 1999).

The secondary canals Huidobro and Santa Rita stem from main Huidobro and Unidos de Buin canals, respectively, and reach the entry of the tertiary irrigation at the northwest point of Santa Rita vineyard plantation, dividing its flows into tertiary canals that feed the irrigation system. The conduction system is based on earth canals throughout the network, except in the areas with hydraulic distribution structures and flow control flumes, constructed in reinforced concrete. The “Santa Rita” system irrigates 320.64 has (56.2%) by furrows, and 249.66 has (43.8%) by drip/trickle systems. The period without irrigation during the winter recess goes from the twentieth of April to the beginning of September for red grape varieties , and from the beginning of April to mid August for the white ones (Gurovich, 1991). The cultivated area is composed by 47 different irrigation sectors with 11 red varieties (Cabernet Sauvignon, Cabernet Franc, Merlot and Carménère) and 3 white ones (Chardonnay, Sauvignon Blanc and Sauvignonasse).

According to the edaphological information available, the cultivated area is divided into three different areas. The soil profile shows 2 to 3 strata in the first meter, with a texture range between loam to clayey loam at the surface and loam to clay in the second stratum. In some sectors, it shows a stony surface (less than 20% by volume).

Simulation model methodology consist on the application of the balance of masses equation between water availability and demand. In the deterministic approach, results obtained with the proposed model stemmed from several simulations, with variations in the values of some main parameters of water supply and demand, like: water application efficiency (Ea) in the furrow and dripping irrigation systems, grapevine evapotranspiration coefficient (Kc) in the developmental phase, percentage of water percolation losses at the main and secondary canals (*Pcm*), (*TPci*), and water spills (*Pd*) respectively. In the deterministic approach, the situation of an average year was considered having a probability of occurrence of 50%, both in the supply as well as in the water demand.

In the probabilistic approach, parameters considered include the LogNormal probability model used to adjust weather and flow data. Here, the representative event of water requirements is considered with a probability of occurrence of 50%, but including different years of water supply hydrograms, with especial emphasis in those years that typify the periods of drought. From the point of view of water supply, the safety of irrigation is analyzed for probabilities of high occurrence, equal to 80, 90, and 95%, respectively. The frequency analysis defined with the probabilistic approach, allow establishing the reliance of the “Santa Rita” irrigation system.

RESULTS

The seasonal variation of the probable monthly average flow in the two internal canals, show significant differences (Figure 4), in spite of the fact that its water intake points are located close to one another, at the same river.

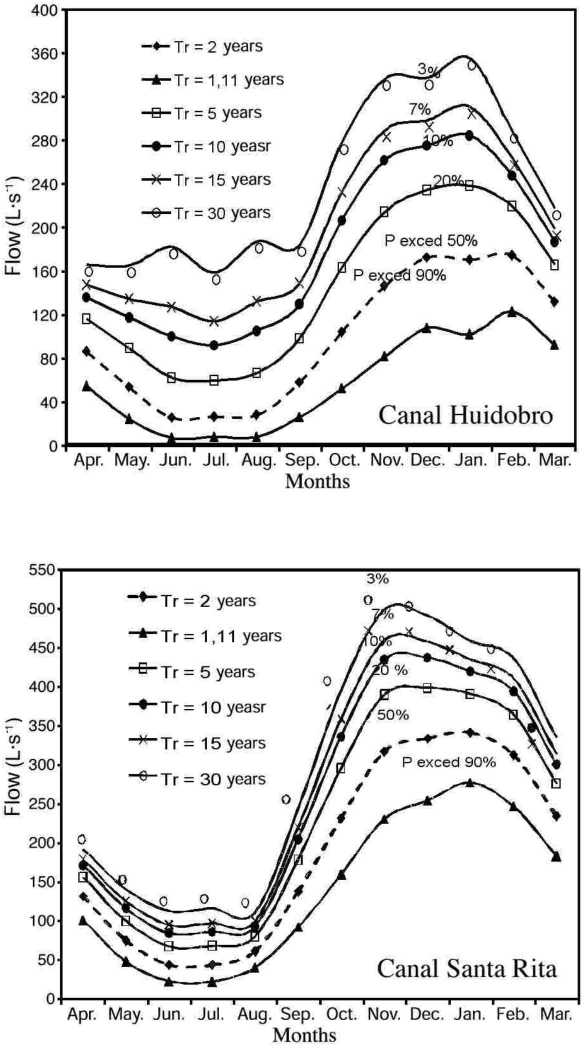


Figure 4. Probabilistic hydrograms for average monthly flow in Huidobro and Santa Rita channels. Tr is the number of years with a statistic probability of occurrence.

Monthly coefficient variation curves for Maipo River between 1912 and 1999 and between 1990 and 1999, are similar in magnitude and symmetry (Figure 5). At the Unidos de Buin canal, the *Cv* curve presents a proportionality in magnitude and symmetry, with respect to the curves of the Maipo River, except between November and February, with inverse results. The Huidobro canal, for May - November presents always *Cv* values significantly larger than that of the Maipo river. This probably implies a strong influence of Clarillo River hydrogram.

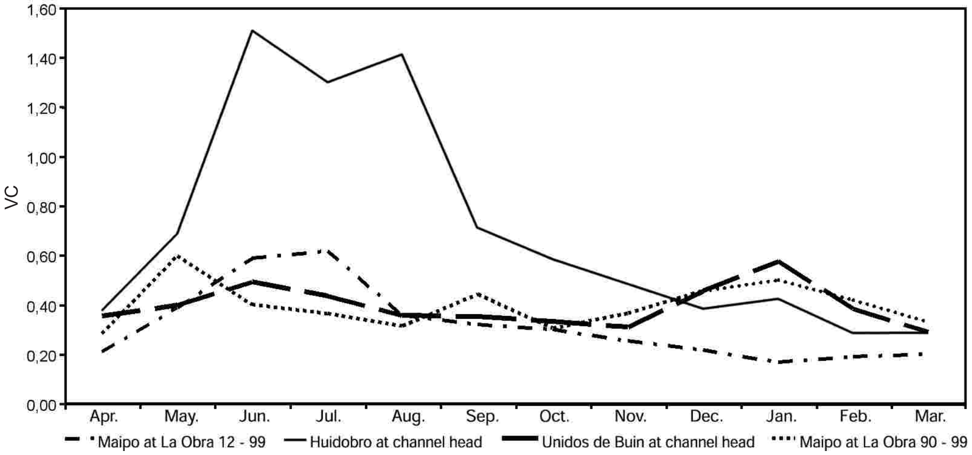


Figure 5. Variation coefficients (VC) for monthly series in the Maipo river and on the main irrigation canals.

ETo probability analysis results indicat that the variation of ETo between consecutive years is relatively low. For a month of high potential evapotranspiration, like December, differences over the average rate of ETo of 11.4% are obtained, considering one event as corresponding to one period of return of 20 years. Table 1 shows a summary of the probable total irrigation requirements of the current system, once the requirements of the furrows and drip systems are integrated. Water flow results (Table 1) show continuous flows during the corresponding decadal period.

Fernández (1991), defined for the central zone of Chile the periodic character of the series of water demands, considering it as a constant from year to year, and as a variable for the different basins of the area. Considering the small variations in irrigation demand between events with different occurrence probabilities, in his study the requirements for each one of the decadal periods is considered also as a constant from one year to another. The event that corresponds to a 50% probability of occurrence, is representative of the requirements of the system for the water balance analysis at the different scenarios evaluated in the simulation.

Table 1. Total irrigation water requirements at the Santa Rita irrigation system ($L \cdot s^{-1}$), for different excedence probabilities (Pexc) or return periods (Tr).

	Required Flows							
Date	Pexc=50% Tr = 2years	Pexc=20% Tr = 5years	Pexc=10% Tr = 10years	Pexc=7% Tr = 15years	Pexc=5% Tr = 20years	Pexc=3% Tr = 30years	Pexc=2% Tr = 50years	Pexc=1% Tr = 100years
aug/17 - ago/26	11.1	12.1	12.7	13.0	13.2	13.4	13.7	14.1
aug/27 - sep/05	13.5	14.6	15.3	15.6	15.8	16.1	16.5	16.9
sep/06 – sep/15	76.8	83.0	86.6	88.3	89.5	91.1	93.0	95.3
sep/16 – sep/25	89.8	96.8	100.7	102.7	104.0	105.8	107.9	110.5
sep/26 – oct/05	105.4	113.3	117.7	119.9	121.4	123.3	125.8	128.6
oct/06 – oct/15	125.9	134.8	139.9	142.4	144.1	146.4	149.1	152.4
oct/16 – oct/25	160.0	171.0	177.1	180.2	182.3	185.1	188.4	192.4
oct/26 – nov/04	216.7	231.0	238.9	243.0	245.6	249.3	253.6	258.8
nov/5 – nov/14	287.0	305.2	315.2	320.5	323.9	328.5	334.0	340.6
nov/15 – nov/24	356.2	378.0	389.8	396.0	400.0	405.6	412.1	420.0
nov/25 – dec/04	421.3	446.1	459.3	466.4	470.9	477.2	484.6	493.4
dec/05 – dec/14	461.6	487.5	501.3	508.7	513.5	520.1	527.7	537.0
dec/15 – dec/24	473.4	498.9	512.2	519.4	524.0	530.6	537.9	546.9
dec/25 – jan/03	478.7	503.3	516.1	523.1	527.7	533.9	540.9	549.7
jan/04 – jan/13	468.5	492.4	504.9	511.6	516.1	522.0	528.8	537.3
jan/14 – jan/23	452.5	475.4	487.4	493.8	498.0	503.7	510.1	518.2
jan/24 – feb/02	431.9	453.5	464.7	471.7	474.7	480.1	486.2	493.9
feb/03 – feb/12	406.7	426.9	437.5	443.0	446.7	451.8	457.4	464.5
feb/13 – feb/22	378.0	396.6	406.2	411.3	414.6	419.3	424.5	431.0
feb/23 – mar/04	345.0	361.6	370.4	375.0	378.0	382.2	386.9	392.7
mar/05 – mar/14	307.6	322.2	330.0	333.9	336.6	340.4	344.5	349.6
mar/15 – mar/24	264.5	277.0	283.6	287.0	289.2	292.4	295.9	300.3
mar/25 – apr/03	206.4	216.0	221.1	223.7	225.5	228.0	230.7	234.0
apr/04 – apr/13	139.4	145.9	149.3	151.0	125.2	153.9	155.7	157.9
apr/14 - apr/24	80.7	84.4	86.4	87.3	88.0	89.0	90.1	91.3
Q average	272.6	287.5	295.5	299.6	302.4	306.2	310.5	315.8
Q maximum	487.7	503.3	516.1	523.1	527.7	533.9	540.9	549.7
Q minimum	11.1	12.1	12.7	13.0	13.2	13.4	13.7	14.1

Q = Flows.

According to the information provided in Figure 6, for the average event of water balance in the current situation, attainment of a safety level water availability of 100% is achieved during all the irrigation season. Other results from the simulation model, where the events of lower probability of occurrence, show significant increments in the flow magnitude (over 50% of probability), but indicate that surface water resources are large enough to satisfy actual water requirements.

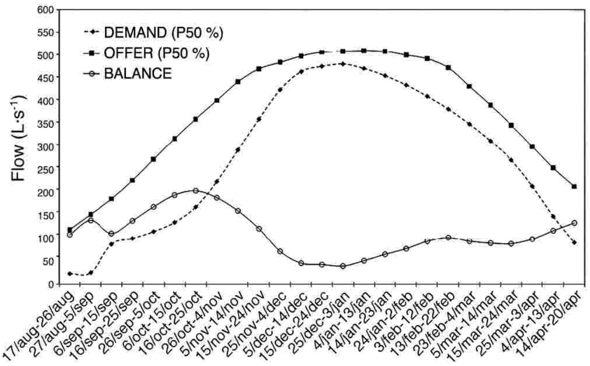
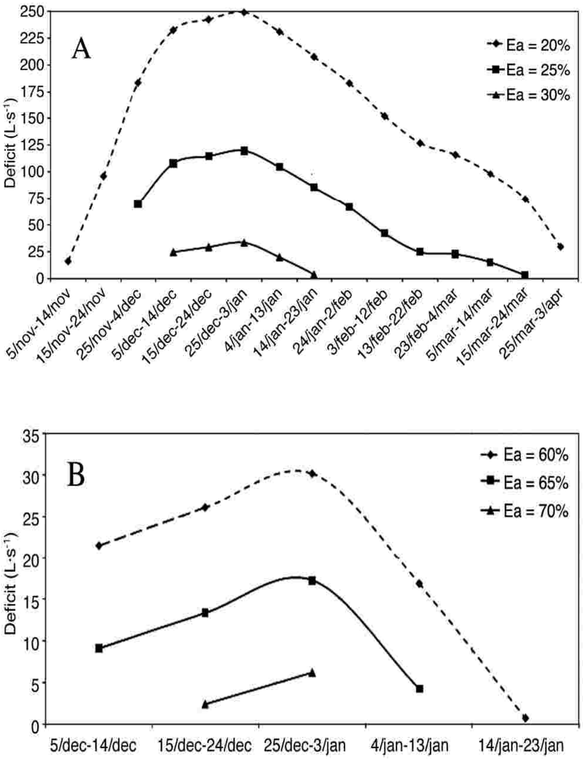


Figure 6. Mean water balance for the present situation at the Santa Rita irrigation system with 50% excedence probability (P 50%).

Water balance results in the deterministic approach, demonstrates that the parameters of greater sensitivity, both in magnitude and time distribution of water deficit, were: water application efficiency (Ea) in furrow irrigation and the Kc evapotranspiration coefficient between grape berry veraison and harvesting. In Figure 7A, results of deficit water balance are obtained for Ea values lower than 33% for furrow irrigation. This is a priority to be improved in drought years (Gurovich, 1999).

Largest water deficits in all simulations (for the deterministic approach) always take place between the last week of December or the first week of January. The deficit sensitivity to the variations of Ea in the drip irrigation system (Figure 7B), is much lower than that estimated for Ea variations in the furrow system.



Figures 7A and B. Water deficits for different Ea values in furrow and drip irrigation.

Simulation results for the probabilistic approach demonstrate that water balances throughout the grapevine production season, for *RRT*50 in dry years Q80, Q90, and Q95, present different levels of deficit, both in magnitude and time distribution. Figure 8 shows the location, distribution, and magnitude of water surpluses and deficits for an 80% probability of occurrence year. The deficit occur takes place between the end of November to the beginning of February, with a maximum deficit of 67 L·s^{-1} during December.

Deficit volume accumulated (drought severity), during that period is 305.788 m^3 approximately, which could be accumulated from the water surpluses occurring in the previous months, if the “Santa Rita” system had a hydraulic storage installation, with a capacity of about 0.35 Hm^3, considering a safety factor of 15%.

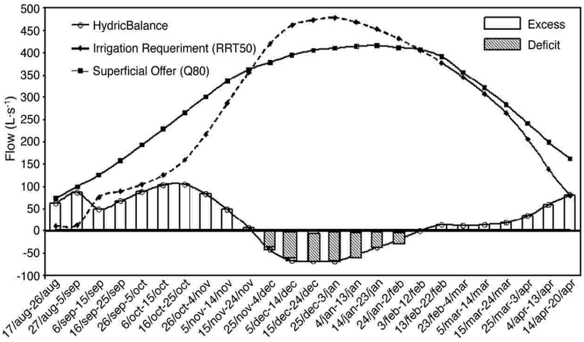


Figure 8. Water balance at the present Santa Rita irrigation system, for a dry year with 80% excedence probability.

A change from furrow to drip irrigation systems, mainly at zone B, where the greater water demands of water currently exist, would drastically reduce the need to invest in water storage installations, thus optimizing the availability of water resources, even for extremely dry years (Figure 9), with an 100% availability. Investments needed to transform furrow irrigated areas to drip systems are significantly lower than investments needed to build a 0.35 Hm^3 reservoir

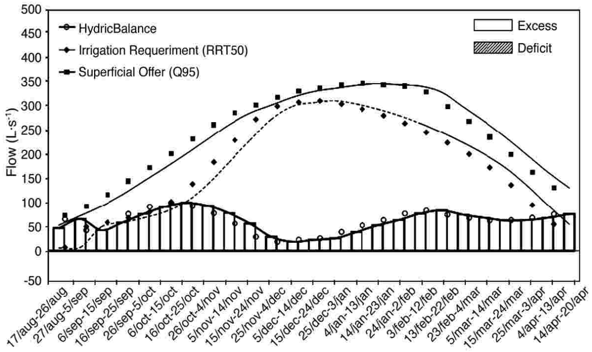


Figure 9. Water balance for a future scenario at the Santa Rita irrigation system, for a very dry year with 95% excedence probability if the 234.21 hectares now under furrow irrigation are modified to drip irrigation.

CONCLUSIONS

Results indicate that probable water flow for the Huidobro interior canal are needed in January and February, in humid and dry years, respectively; in the internal canal Santa Rita, probable water demands take place between November and December during rainy years. Tertiary canal Santa Rita contributes more than two thirds of the total supply during dry years; however, during dry years significant water deficit levels are detected, due to the insufficient flow of this canal to satisfy crop water requirements.

Collecting and storing surface water surpluses guarantees compensating probable water deficits in dry years during December and January and there are enough surface water resources available. For relatively rainy years, there is a 100% irrigation safety guaranteed for the crop season, without the need for additional investments in irrigation infrastructure. The transformation of the current furrow irrigation systems into drip systems, also ensure 100% availability of resources, even for the driest years. Simulation model parameters having the largest sensitivity in the study of probable water deficits were: water furrow application efficiency (Ea), and the evapotranspiration coefficient at grapevine third stage of development (Kc).

RESUMEN

Este trabajo describe una propuesta metodológica para modelar en forma probabilística los componentes y procesos involucrados en la disponibilidad de agua superficial y la demanda hídrica para sistemas de riego en la zona central de Chile. El objetivo fue desarrollar una metodología para estudiar el balance hídrico en campos agrícolas que permita optimizar la asignación del agua disponible. Con este propósito se desarrolló un modelo de distribución probabilística que estimó los flujos hídricos asociados a probabilidades de ocurrencia. Asimismo, se desarrolló un modelo espacial y temporal para simular los requerimientos hídricos de los cultivos, que permitió calcular las probabilidades de excedencia basadas en el modelo Penman–Monteith sugerido por la FAO. El modelo incluyó las características físico-hídricas de los suelos, la evolución temporal de los requerimientos hídricos de la vid (*Vitis vinifera*), la variabilidad temporal y espacial de los recursos hídricos disponibles y de la demanda evaporativa de la atmósfera, así como las capacidades físicas de la infraestructura hidráulica disponible. El modelo de simulación desarrollado en este trabajo se utilizó para evaluar la situación actual y la seguridad de riego en viñedos (Alto Jahuel, Región Metropolitana, Chile), y para evaluar futuros escenarios y alternativas de inversiones en nuevos equipos de riego mecánico y en nuevas plantaciones para promover el uso eficiente de los recursos hídricos y para optimizar la disponibilidad de agua superficial. El modelo obtenido permitió decidir la superficie máxima que la empresa puede plantar con nuevos viñedos, decidir las inversiones alternativas en nuevos equipos de riego, con una consideración probabilística de diferentes escenarios de disponibilidad de recursos de agua.

Palabras clave: balance hídrico, demanda de riego, recursos hídricos.

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