Forecasting monthly water resources conditions by using different indices

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***Abstract*— *Sharp changes in the SWSI are an obstacle for accurate estimation of this parameter. In addition, providing all of the information needed to determine the SWSI is not always possible. The SWE because of effective role in the calculation of the SWSI, it is a viable alternative to forecast instead the SWSI. The obtained results showed that the ARIMA model forecasted the SWE values for January to June successfully. Using these forecasted data and by non-linear regression can be estimated the SWSI values for all points of each basin except in cases that the amounts of SWSI and SWE are very low (drought conditions).*

Keywords*— ARIMA, Oregon, Colorado, Atmospheric condition, The US, Water.

I. INTRODUCTION

The SWSI and SWE are two important parameters for agricultural water management and estimating of flood and drought periods for prevent of their damages. Dressler et al. (2006) evaluated gridded snow water equivalent and satellite snow cover products for mountain basins in a hydrologic model. Takala (2011) estimated northern hemisphere snow water equivalent for climate research through assimilation of space-borne radiometer data and ground-based measurements. Kinar and Pomeroy (2007) determined snow water equivalent by acoustic sounding. The measured and the modeled SWE for Saskatchewan snowpacks with high liquid water contents were found to be weakly associated with correlations of 0.30. In addition many studies has been done about SWE using microwave remote sensing (Chang et al. 1982, Molotch et al. 2010, Derksen et al. 2003, Tong et al. 2010, Derksen et al. 2010, Foster et al. 1991, Koenig and Foster 2004, Dong et al. 2007, Durand and Liu 2012, Derksen et al. 2005, Pulliainen and Hallikainen 2001, Derksen et al. 2008, Durand et al, 2008, Pulliainen 2006, Derksen et al. 2012, Langlois et al. 2007, Singh and Gan 2000, Gan et al. 2009, Che et al. 2012, Slater et al. 2009, Pulliainen and Hallikainen 2001, Tait 1998). Cowles et al. (2002) combined snow water equivalent data from multiple sources to estimate spatio-temporal trends and compare measurement systems. López-Moreno et al. (2012) analyzed spatial variability of snow depth and density from measurements made in February and April. Mizukami et al. (2011) presented a regional approach for mapping climatological snow water equivalent over the mountainous regions of the Western United States. For a monthly time step, the reliability of the SWE estimates did not significantly increase when the number of regions was more than five. Snow depth and snow water equivalent estimated from Terra–Aqua MODIS and AMSR-E data based on a priori snow characteristics (Dai et al. 2012, Gao et al. 2010, Derksen 2008, Langlois et al. 2008, Wang and Tedesco 2007). The results showed that the RMSE and the bias from this new algorithm were greatly reduced compared to the National Snow and Ice Data Center, moderately reduced compared to the European Space Agency and slightly reduced compared to the Environmental and Ecological Science Data Center for West China. Another result demonstrated that the accuracy of

Aqua Advanced Microwave Scanning Radiometer for NASA's Earth Observing System SWE products was 68.5% and they tend to overestimate SWE. Bocchiola and Groppelli (2010) studied spatial estimation of snow water equivalent at different dates within the Adamello Park of Italy. Sundström et al. (2012) presented a custom ray-based model of radar wave propagation through wet snowpacks and results of MATLAB simulations conducted to investigate the method's sensitivity to measurement errors and snowpack properties. Spatial distribution of snow depth and snow water equivalent estimated by using artificial neural network and non-linear regression (Tabari et al. 2010, Marofi et al. 2011, Molotch and Margulis 2011, Molotch 2005, Bocchiola and Rosso 2007). . Timilsena and Piechota (2008) focused on regionalization and reconstruction of snow water equivalent in the upper Colorado River basin. The results indicated the average drought duration in the basin was 3–14 years depending upon the variables (April 1 SWE and water year streamflow) and the moving average considered. The different automatic methods compared for estimating snow water equivalent (Egli et al. 2009, Warnick and Penton 1971). Jonas et al. (2009) estimated the snow water equivalent from snow depth measurements in the Swiss Alps. The accuracy of estimating SWE using their model was shown to be equivalent to the variability of repeated SWE measurements at one site. The technique may therefore allow a more efficient but indirect sampling of the SWE without necessarily affecting the data quality. Watson et al. (2006) surveyed optimal sampling schemes for estimating mean snow water equivalents in stratified heterogeneous landscapes. The results indicated that because of large variance at small scales, seasonal snowpacks must be sampled very intensely in order to yield confidence intervals for the mean that are narrow enough to determine vegetation and radiation effects on SWE. Bewley et al. (2010) examines the effect on stand and catchment scale snow processes due to widespread forest disturbance by the Mountain Pine Beetle infestation. The continuous monitoring of snow water equivalent assessed using cosmic ray neutrons (Kodama 1980, Kodama et al. 1979). Tani (1996) presented an approach to annual water balance for small mountainous catchments with wide spatial distributions of rainfall and snow water equivalent. The SWE also measured by gamma-ray spectrometry (Grasty 1982, Bland et al. 1997, Carroll and Carroll 1989, Peltoniemi et al. 1978). The spatial modeling of snow water equivalent presented using covariances estimated from spatial and geomorphic attributes (Carroll and Cressie 1997, Carroll 1995). Huang and Cressie (1996) predicted snow water equivalent using the Kalman filter. Garen (1993) revised SWSI for Western United States. He suggested that indexes for individual hydrologic components be developed to provide supporting information to the SWSI. Shafer and Dezman (1982) developed SWSI to assess the severity of drought conditions in snowpack runoff areas. Hoekema and Sridhar (2011) using surface water supply and soil moisture indices related climatic attributes and water resources allocation in the Snake River basin, Idaho. The results indicates that the decline in midseason and late season diversions is mostly caused by decreasing supply in the study period, while a comparison of diversions to Palmer index and the standardized precipitation index indicates that early season diversions are highly correlated to early season moisture anomalies. Unfortunately, much research has not been done on SWSI and role of surface water supply index has not been considered in other studies about water resources management (Rezaei et al. 2016, Valipour et al. 2015, 2016a-c, 2017a-c; Valipour 2012, 2013a-d, 2014a,b, 2015a-j, 2016, 2017, Yannapoulos et al 2015). Also uncertainty in the SWE has been investigated (Dong et al. 2005, Foster et al. 2005).

Number of studies about SWE is much, although much research has not been done on SWSI. Nevertheless, in majority of studies on SWE, its measurement has been considered or focused on a specific climate. But in some cases, measurement is not economy or sufficiently accurate. In addition, SWE alone cannot criterion to inform the hydrologic condition in the region and decisions about how to manage water resources properly. In this paper, by ARIMA model the SWE was forecasted and using non-linier regression a relationship has been established between SWSI and SWE. Meanwhile based on historical data, about two different climates of United States are discussed.

II. MATERIALS AND METHODS

The surface water supply index (SWSI) is a predictive indicator of total surface water availability within a watershed for the spring and summer water use seasons as follows:

$$SWSI = (aPN_{snow}+bPN_{prec}+cPN_{strm}+dPN_{resv}-50)/12 \quad (1)$$

Where a, b, c, and d are weights for each component and must meet the condition a+b+c+d=1. Each basin has a unique a, b, c, and. PN shows probability of non-exceedance (%) and snow, prec, strm, and resv refer to snowpack, precipitation, streamflow, and reservoir componens, respectively.

SWSI values are scaled from +4.2 (abundant supply) to -4.2 (extremely dry) with a value of zero (0) indicating media water supply as compared to historical analysis. SWSI used especially where palmer drought index does not adequately reflect conditions in snow-dominated regions.

According to the Equation (1) the SWSI is calculated by combining pre-runoff reservoir storage (carryover) with forecasts of spring and summer streamflow, which are based on current snowpack and other hydrologic variables. But there is not always the possibility of measuring all of the hydrologic variables. Since the SWSI focuses on surface water supplies derived from melting snow, which accounts for 65 to 85 percent of the annual flow of the state's major streams (Shafer and Dezman 1982), therefore, in this study the SWE values forecasted using ARIMA model, then investigated the possibility of using non-linear regression to establish a relationship between SWSI and SWE. The reason of use of the ARIMA model is high ability of this model in hydrologic forecasting obtained by author (Valipour 2012).

In this study, in order to comprehensively assess SWSI and SWE in various climates, used historical data of two different climates include Colorado and Oregon. The SWSI data include monthly data of 7 basins of Colorado and 14 basins of Oregon from 1982 to 2011. The SWE data include measured snow water equivalent for January to June in Colorado and Oregon basins from 1997 to 2012.

Colorado is the U.S. state that encompasses most of the Mountains as well as the northeastern portion of the Colorado Plateau and the western edge of the Great Plains. Abundant sunshine and low humidity typify Colorado's highland continental climate. Winters are generally cold and snowy, especially in the higher elevations of the Rocky Mountains. Summers are characterized by warm, dry days and cool nights. The climate of Colorado is more complex than states outside of the Mountain States region. Unlike most other states, southern Colorado is not always warmer than northern Colorado. Most of Colorado is made up of mountains, foothills, high plains, and desert lands. Mountains and surrounding valleys greatly affect local climate.

Oregon is a state in the Pacific Northwest region of the United States. It is located on the Pacific coast, with Washington to the north, California to the south, Nevada on the southeast and Idaho to the east. Oregon's climate can mostly be classified as mild. Two major geographic features dominate the climate in the state: the Pacific Ocean and the Cascade Range.

Figure 1 shows Colorado and Oregon States with their basins.

III. RESULTS AND DISCUSSION

Despite many advantages of the SWSI, estimation of its quantities due to the lack of permanent access to the parameters and coefficients of Equation 1 or for different parts of a basin (in wide basins), is not possible. Since the SWSI is based on projected reservoir and streamflow values, the SWSI value may change from month to month as the projected reservoir and streamflow forecasts change (Figures 2 and 3). Thus, forecasting of the SWSI by using recorded data due to the drastic changes and the abundant peak points is much more difficult. Because of large role of the SWE in determining the SWSI, in this study at first the SWE values forecasted, and then examined the possibility of a relationship between these two indicators. Table 1 shows forecasted the SWE values using ARIMA model and a compression between average values of SWSI and SWE. After running 900 different structures of ARIMA model for January to June, the best structures for each month were determined for 2012. By comparing measured data for 2012 with forecasted data for this year, it was found that relative error for all basins of Colorado and Oregon was less than 10%. Thus, ARIMA model is an appropriate tool for forecasting of the SWE. Also, a compression between average values of SWSI and SWE in 1997 to 2011 obtained considerable results. The maximum values of SWSI and SWE was 3.2 and 53.3 m, respectively, in Colorado for 2011. The minimum values of SWSI and SWE in this state was -2.7 and 15.5 m, respectively, for 2002. Namely, in 2011, that amount of SWSI was the maximum; amount of SWE was also the maximum. In the same way the minimum values of both SWSI and SWE was occur in 2002. In addition, average of the SWE values from 1997 to 2011 was 34.1 m, while in each year, which the SWE was more than this amount; SWSI was more than zero (wet condition). There was same status in Oregon: The maximum values of SWSI and SWE was 1.6 and 97.0 m, respectively, for 1999. The minimum values of SWSI and SWE was -1.8 and 16.6 m, respectively, for 2001 and average of the SWE values from 1997 to 2011 was 48.6 m, while in each year, which the SWE was more than this amount; SWSI was more than zero (wet condition). Therefore, we can expect to establish a relationship between these two parameters. For this purpose by using regression equations, relationship between SWSI and SWE was examined (Figures 4 and 5). In all years, a quartic or fifth degree polynomial was the best regression equation (except in Colorado for 1997). According to the obtained R^2 values (except in Colorado for 2002) can be estimated the SWSI values based on the SWE values using non-linear regression. The amount of R^2 in Colorado for 2002 was 0.3108. According to the Table 1 in this year amount of SWE was the minimum, thus when average of the SWE was very low (drought condition), this index was not an appropriate parameter for estimating of the SWSI. Because in drought condition, basic assumption based on the effective role of the SWE in calculation of the SWSI is not correct. The other obtained result was better estimation in Oregon than Colorado due to the less changes of the SWSI. Number of years with R^2=1 were 8 and 5 in Oregon and Colorado, respectively. Therefore, obtained results for estimating SWSI are reliable in mild climates. In the worst conditions (lack of access to snowmelt values), can be forecasted this values by ARIMA model and then based on minimum predicted data of SWSI and using non-linear regression, can be estimated amounts of the SWSI for all points of each basin which SWE forecasted for it.

IV. CONCLUSION

Sharp changes in the SWSI are obstacle to forecast it. In addition, providing all of the information needed to determine the SWSI is not always possible. The SWE because of effect role in calculation of the SWSI, it is a viable alternative to forecast instead the SWSI. The obtained results showed that ARIMA model forecasted the SWE values for January to June successfully. Using these forecasted data and by non-linear regression can be estimated the SWSI values for all points of each basin expect in cases that amounts of SWSI and SWE are very low (drought conditions).

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Table.1: Measured and forecasted the SWE values (m) with average values of the SWSI and SWE

Colorado	**January**	**February**	**March**	**April**	**May**	**June**	**SWE Average**	**SWSI Average**
1997	23.0	54.1	55.2	53.6	55.8	15.5	42.9	2.1
1998	11.7	26.3	33.9	42.4	42.4	5.4	27.0	0.2
1999	11.2	26.2	32.8	30.4	35.8	1.5	23.0	0.1
2000	6.8	24.7	38.9	52.9	34.4	1.6	26.6	-0.6
2001	14.0	27.2	37.9	46.8	38.8	2.8	27.9	-0.5
2002	10.1	19.8	25.0	28.6	9.3	0.3	15.5	-2.7
2003	13.0	24.8	38.3	53.0	43.2	4.0	29.4	-1.4
2004	15.3	32.2	43.1	38.0	35.6	3.2	27.9	-0.9
2005	16.9	46.6	57.8	70.0	56.2	9.9	42.9	0.6
2006	17.7	40.3	47.6	61.9	38.0	3.6	34.9	0.5
2007	16.7	37.2	49.8	49.7	39.6	5.5	33.1	0.0
2008	18.9	52.7	72.6	80.4	66.8	15.4	51.1	3.1
2009	20.6	47.8	57.9	62.8	57.2	4.4	41.8	1.0
2010	14.8	35.2	47.3	57.9	44.8	7.3	34.6	0.4
2011	23.4	48.1	61.7	73.8	78.6	34.3	53.3	3.2
2012	12.2	29.5	42.5	33.4	35.9	5.8		
Forecasted	12.9	27.8	42.5	33.5	37.7	5.9		
RE (%)	5.4	5.9	0.1	0.5	4.9	1.1		
BestModel	ARIMA(4,0,0)	ARIMA(0,3,3)	ARIMA(0,3,3)	ARIMA(5,3,1)	ARIMA(5,3,2)	ARIMA(5,0,5)		
Oregon	January	February	March	April	May	June	SWE Average	SWSI Average
1997	53.2	77.4	115.6	105.7	67.6	15.6	72.5	1.5
1998	18.1	67.8	95.9	96.5	55.2	21.1	59.1	0.3
1999	42.3	96.4	136.8	170.4	98.0	38.2	97.0	1.6
2000	20.8	74.6	100.2	100.4	41.1	11.7	58.1	0.1
2001	11.6	22.1	22.0	25.7	17.6	0.5	16.6	-1.8
2002	33.9	70.2	69.9	75.6	39.6	9.4	49.8	0.4

2003	17.4	23.5	30.9	39.7	29.5	6.2	24.5	-1.4
2004	24.1	46.8	66.9	52.3	23.4	4.7	36.4	-0.5
2005	10.4	18.9	27.9	29.1	12.4	4.3	17.2	-1.5
2006	21.8	54.3	60.5	76.7	39.1	9.5	43.6	0.8
2007	19.9	31.2	45.4	39.3	19.5	2.6	26.3	-0.3
2008	23.6	58.1	73.7	91.1	61.8	21.2	54.9	0.2
2009	40.7	59.8	71.0	99.9	59.1	14.7	57.5	0.7
2010	28.2	52.0	54.3	64.1	42.9	21.4	43.8	-0.9
2011	48.5	58.7	75.5	112.9	89.1	48.2	72.2	0.9
2012	39.8	54.5	73.0	98.5	58.4	19.3		
Forecasted	40.2	53.7	68.7	103.5	56.5	21.0		
RE (%)	0.9	1.5	5.9	5.1	3.2	9.0		
BestModel	ARIMA(3,1,3)	ARIMA(5,1,4)	ARIMA(4,1,5)	ARIMA(3,1,3)	ARIMA(5,0,3)	ARIMA(3,0,4)		

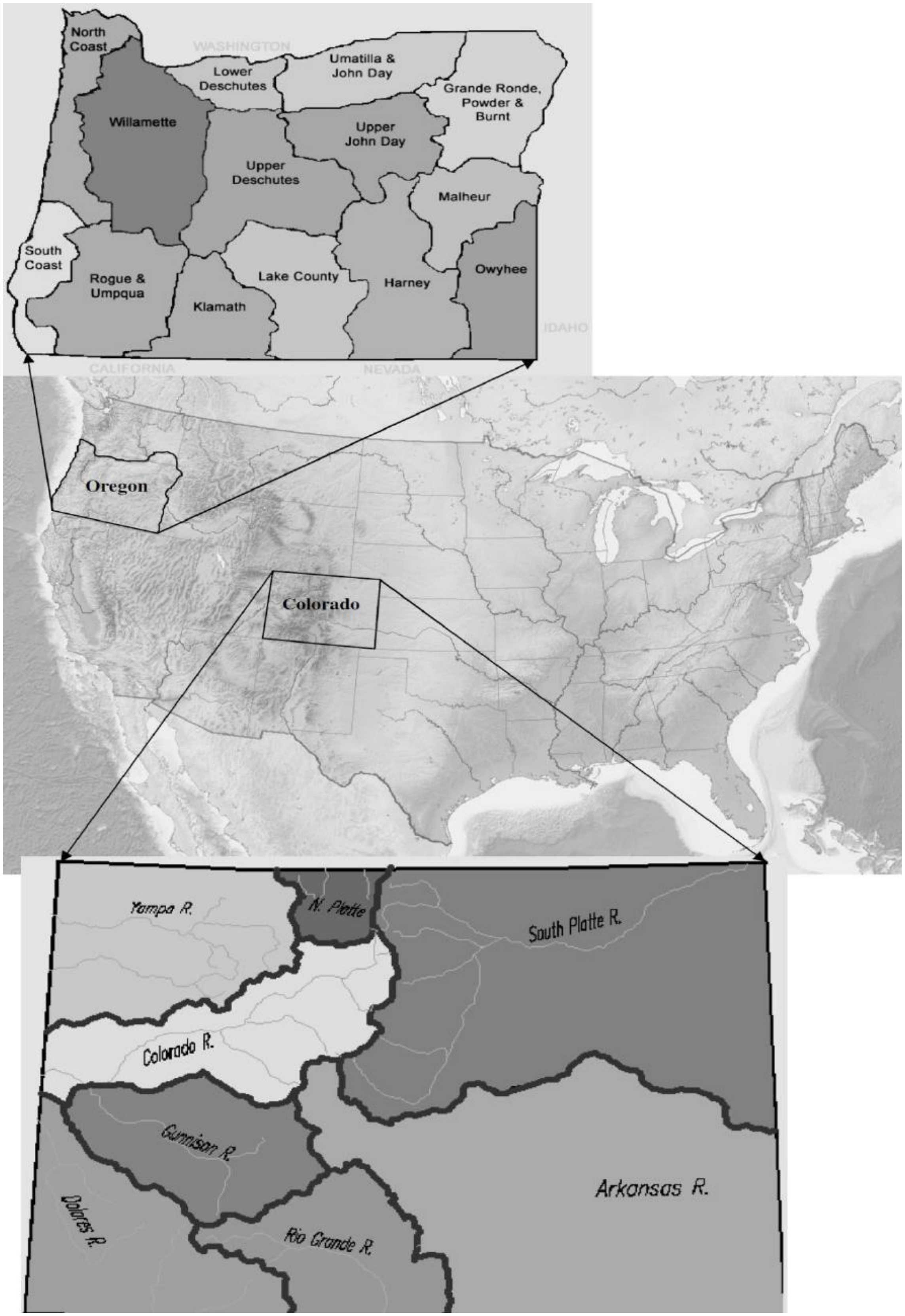

Fig.1: Location of Colorado and Oregon states and their basins in United States

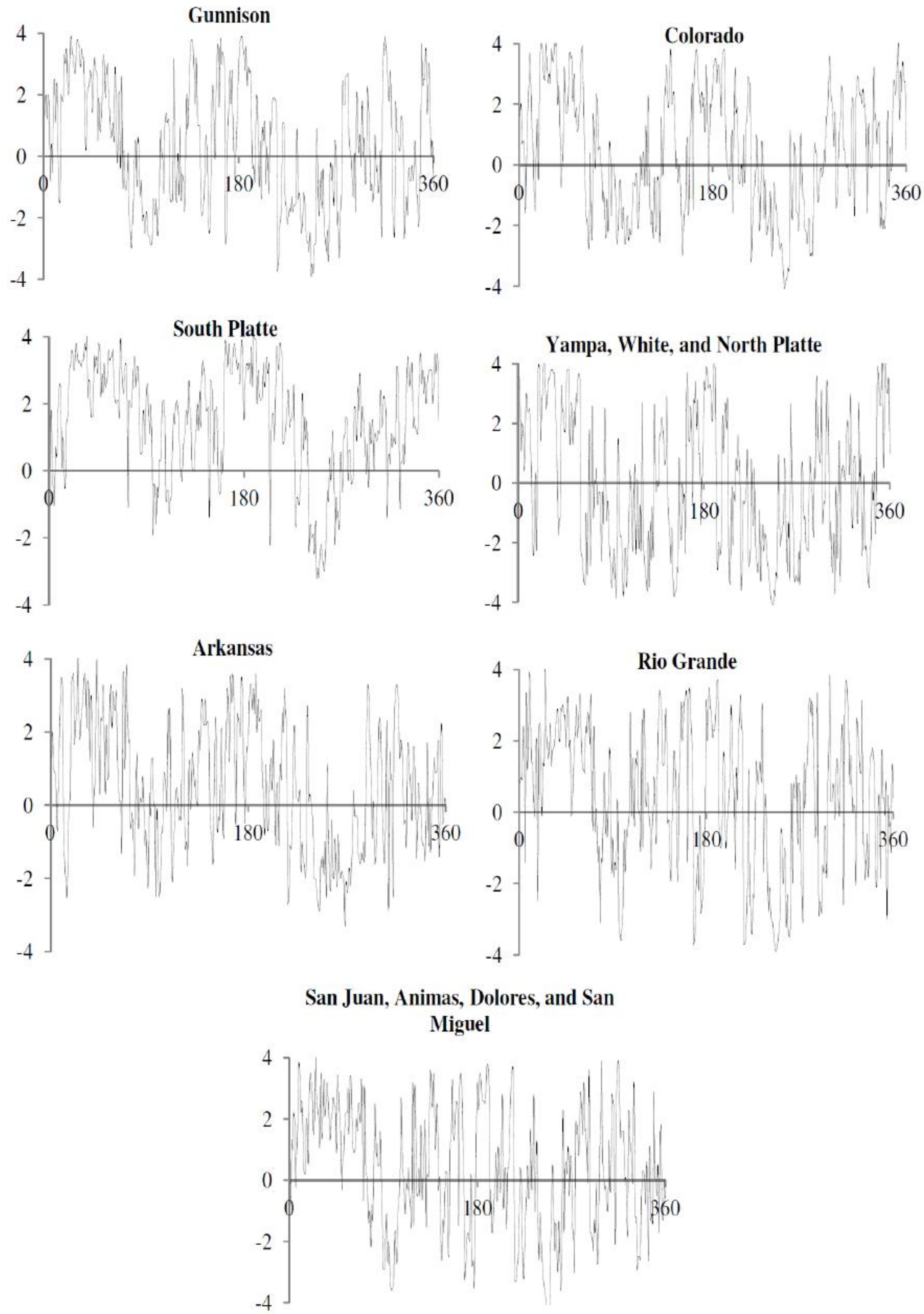

Fig.2: SWSI (vertical axis) versus time in monthly scale (horizontal axis) for Colorado basins

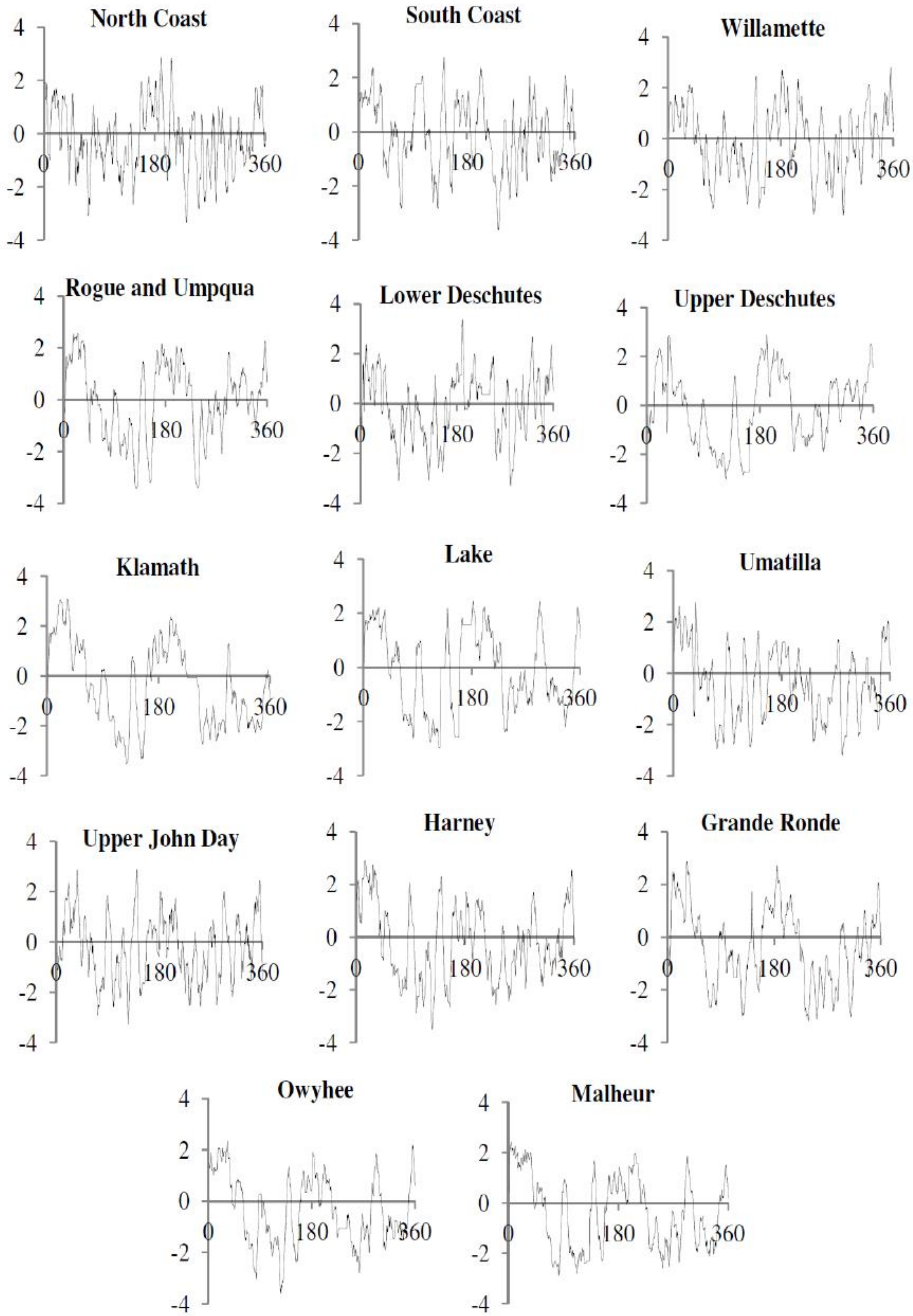

Fig.3: SWSI (vertical axis) versus time in monthly scale (horizontal axis) for Oregon basins

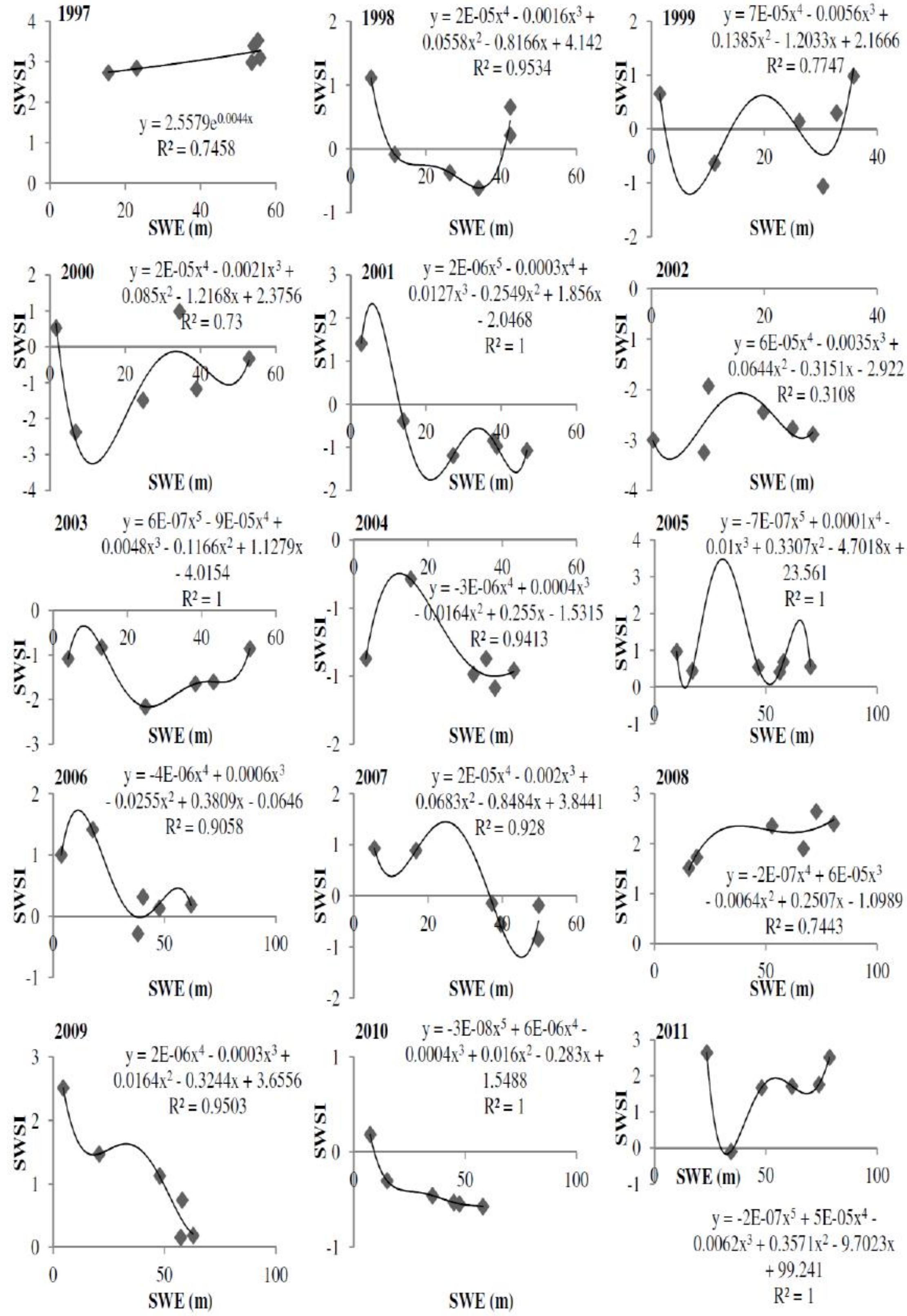

Fig.4: Non-linear regression for establishing the relationship between SWSI and SWE in Colorado

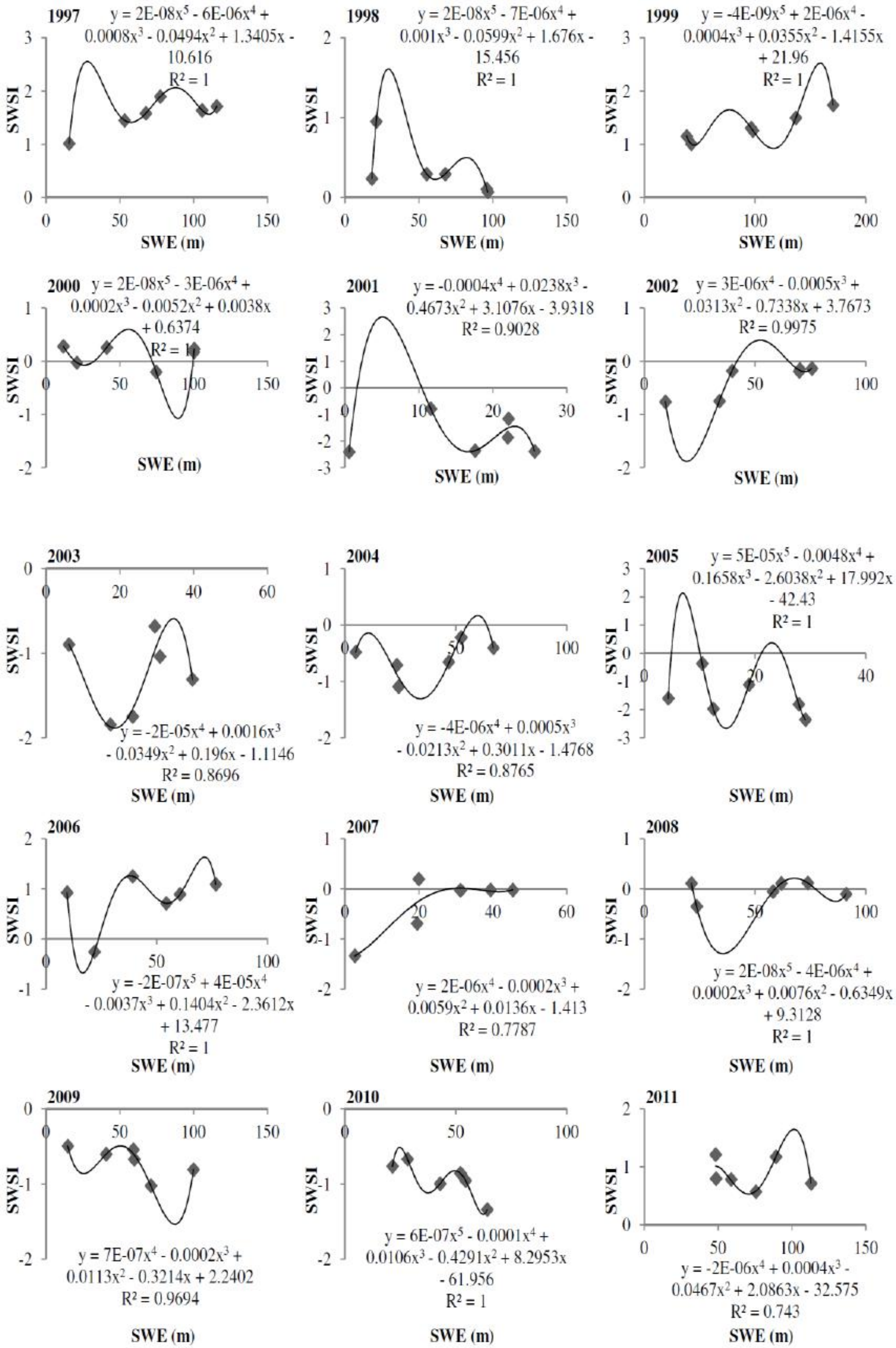

Fig.5: Non-linear regression for establishing the relationship between SWSI and SWE in Oregon